Domestic Photovoltaic Systems: The Governance of Inhabitant Practice in Low Carbon Housing Communities

Submitted by

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DECLARATION

I hereby declare that no part of this thesis has previously been submitted for any degree of qualification at this, or any other University or Institute of learning.

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ABSTRACT

Housing accounts for one-third of all CO_2 emissions in the Western world, yet there is still limited understanding of why housing routinely uses more energy than predicted, resulting in a significant performance gap. Successful energy governance for housing is therefore crucial for cutting CO_2 emissions and preventing catastrophic climate change. Addressing these challenges in the UK is largely shaped by developing *'more efficient'* domestic technologies, which assumes that inhabitants will use their technologies as intended. Conversely, this thesis examines the variation in the governance of Photovoltaic (PV) system provisioning processes and how this conditions inhabitants' practices – a key area overlooked in previous energy efficiency studies concerning PV systems.

This thesis focuses on empirical work drawing on three theories: Actor Network Theory (ANT), Practice theory, and Affordance that are brought in pragmatically as lenses to enable a more comprehensive examination and analysis of different aspects of the overall networks and practices and associated governance involved in a PV system.

The findings show that key provisioning actors understand the PV production process as a 'black box', where the outputs are unquestioningly anticipated from the inputs. This results in an inappropriate governance network and integration between these actors when governing technology affordances and integration into homes. Opening up this provisioning 'black box' suggests two key approaches for developing appropriate energy governance networks and practices: identifying changes required within actors' agency and roles, and identifying changes required in the relationships between the actors in a contractual network. Both changes require new actors to be involved in PV provisioning networks subject to wider networks and arrangements in the UK. The findings also show that good governance requires an examination of home technology practices in more detail, in their specific context, and taking inhabitant's embodied competences and meanings into account, in order to properly anticipate how these designed technologies will operate in reality.

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I especially dedicate this work to my beloved mother, and to my brothers and sisters who have provided me with moral and emotional support in my life and for their unconditional and infinite love. I profoundly dedicate this thesis to the memory of my father who was the key supportive person in my life. He built great confidence within me to achieve this challenging work. My gratitude also goes out to my other family members and friends who have supported me along the way, both in Iraq and the UK.

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LIST OF GLOSSARIES AND TERMS

AC: Alternating Current

ANT: Actor Network Theory

CO2: Carbon Dioxide emissions

CPI: Citizen Participation Initiatives

CSH: Code for Sustainable Homes

DB: Design and Build contract

DC: Direct Current

DECC: Department of Energy and Climate Change

DTI: Department of Trade and Industry

EST: Energy Saving Trust

FIT: Feed-in Tariff

HCA: Homes and Communities Agency

HHP: Hockerton Housing Project

HUG: Home User Guide

IBT: Irrational Behaviourism Theory

IHD: In Home Display

LILAC: The Low Impact Living Affordable Community

LZC: Low and Zero-Carbon

MHOS: Mutual Home Ownership Society

MOZES: The Meadows Ozone Energy Services

M&E: Mechanical & Engineering

NCC: Nottingham City Council

NHBC: National House Building Council

NPC: Non-Participative communities

PC: Participative Communities

PI: Provisioning Inhabitant

PM: Project Manager

PV system: Photovoltaic system

QS: Quantity Surveyor

RPS: Renewable Portfolio Standard

SBC: Standard Building Contract

SC: Service Consultant

SCC: Sheffield City Council

SENSIBLE: The Storage ENabled SustaInable energy for BuiLdings and communitiEs
SHC: Sheffield Housing Company
SRC: Sustainable Resource Centre
TAM: Technology Acceptance Model
TPB: Theory of Planned Behaviour
ZCH: Zero Carbon Home

CHAPTER ONE: INTRODUCTION

1.1 Background issue and significance

In this section, key areas of sustainability, housing and governance are critically reviewed to reveal the significance of current challenges and the associated research gap.

1.1.1 Sustainability and housing performance gap

Climate change presents a major international challenge and an opportunity to improve energy efficiency governance and to achieve a radical reduction in Carbon Dioxide (CO_2) emissions (IPCC, 2014, NHBC, 2015). This is particularly significant in housing sector which is responsible for 74% of global energy use in building sector (IEA, 2015) and one third of the total energy consumption in the European Union (Eurostat, 2013). The UK housing sector also accounts for 29% of total CO_2 emissions during operation (DBEIS, 2017b). For this study, the reduction of CO2 emissions in housing sector can also be considered as a proxy for sustainability (Climate Change Act, 2008).

Despite efforts made by the UK government to produce energy efficient technologies and homes in order to meet its target of reducing CO_2 emissions by 80% against 1990 baseline by 2050 (Climate Change Act, 2008), there is still limited understanding of *why* houses use up to three times the amount of energy than predicted by simulation, resulting in an energy performance gap between anticipated energy savings and the reality of actual use during occupancy (Boyd and Schweber, 2018, Gram-Hanssen, 2010). This performance gap is partly attributed to how and why inhabitants use energy in their homes (Gram-Hanssen et al., 2012, Sunikka-Blank and Galvin, 2012), and to inhabitants' limited understanding of their domestic technologies (Stevenson et al., 2013, Brown and Gorgolewski, 2015), as well as inappropriate policy and standards in terms of delivering projected energy performances (Baborska-Narozny et al., 2016). Other studies ascribe the energy performance gap to the improper assumptions made by home technology professionals with regards to inhabitants' practice of their home technologies (Gram-Hanssen et al., 2017, Wade et al., 2018) and assume that inhabitants will use their technologies as intended.

1.1.2 Governance deficit in housing

Governance is generally defined as "The sum of all ways in which individuals, public agencies, and private organisations govern their common affairs in a continuous process of negotiation and cooperation" (Commission on Global Governance, 1995: 4). This thesis extends the meaning of governance to understand the actions of individuals in terms of their *own* decision-making, and the *collective* action of governance. This is to understand how rationality, knowledge, norms and practices of individuals can steer the decision making process in various governance networks (Bulkeley, 2015). Governance in this thesis, thus, defined as '*the sum of all ways in which individuals, public agencies, and private organisations govern their common affairs both individually when governing their own conduct and in a continuous process of negotiation and cooperation to steer collective actions and decisions'.*

Recent European Union (EU) governance concerning low carbon transition in housing aims to reduce the role of legislation and policies (Schroeder, 2014), and instead to govern environmental problems by encouraging collective action between government organisations, housing industries, building professionals, and community groups (Healey et al., 2002, Bornemann et al., 2018). The key aim here is to produce solutions that respond to inhabitants' capacities and preferences (Chang and Taylor, 2016), and therefore improve inhabitants' use of their energy-efficient homes and technologies (Seyfang et al., 2013). Successful energy governance for low energy housing should, in theory, be effective for cutting CO_2 emissions significantly (DBEIS, 2015). Beyond collective governance lies 'multilevel governance', which emphasises the role and action of multiple actors, across multiple domains to govern a particular object and entities, both individually and collectively (MacLeod and Goodwin, 1999, Bornemann et al., 2018).

Community housing is currently promoted by the UK government and other agents (UK Cohousing, 2017) in order to encourage inhabitants to collectively govern their environment (e.g. energy-efficient technologies) alongside other provisioning actors (Hamiduddin and Gallent, 2013), and to produce solutions from their everyday practice (Seyfang and Haxeltine, 2012, Walker et al., 2007). Understanding inhabitants' governance is also important in terms of improving their knowledge and evolving realistic expectations about their home technologies to help close the implementation gap during occupation, reducing carbon emissions overall, as a result (Chang and Taylor, 2016). Inhabitants' governance of their domestic technologies together with other provisioning team actors, thus, represents the key consideration for this thesis. However, community housing does not guarantee a closing of the energy performance gap either, and understanding can be poor too (Baborska-Narozny et al., 2016). This is due to a multilevel governance focus on identifying new institutional arrangements rather than examining how these arrangements are being produced and how governing takes place (Whitehead, 2003: 6, Bulkeley and Watson, 2007). Developing an analytical approach for understanding 'multilevel governance' represents the main aim of this thesis.

1.2 Research Gap

1.2.1 Research Gap

Given the wide variety of poorly governed technology in the housing sector (Baborska-Narozny et al., 2016, Gram-Hanssen et al., 2017, Boyd and Schweber, 2018, Wade et al., 2017), focusing on just one type of technology, photovoltaic (PV) systems can provide deeper insights into understanding how such systems of provisioning are governed by multiple actors and used by inhabitants, and inform examinations of other home technologies. PV systems offer a real advantage in improving economic, environmental and social consequences in the housing sector, and are targeted to achieve 15% of electricity generation from renewables in the UK (DECC, 2014). These systems also encourage better energy demand management 'load matching' by enabling inhabitants to become more conscious of their electricity generation and consumption (Dobbyn and Thomas, 2005, Bahaj and James, 2007) and thus, encouraging energy consumption reduction (see 2.6.1).

In addition, photovoltaic (PV) installations are the most installed microgeneration technology in the UK as confirmed by the Feed-in-Tariff (FIT's) scheme which represents 79% of the total installed capacity of microgeneration technologies in the UK (see 2.6) (DBEIS, 2018b). PV installations also increased worldwide from one GW in 2000 to more than 404GW by the end of 2017, with expected an annual increase of 100GW by 2022 (Jäger-Waldau, 2018, SolarPower Europe, 2018). The recent report of SolarEnergy Power shows that solar PV installations were the largest power generation technology added in 2017 globally (SolarPower Europe, 2018) (see 2.6).

To date, attempts to understand energy efficiency improvements in housing through PV systems have focused largely on the impact of the system in changing inhabitants' energy practices (Wittenberg and Matthies, 2016); the role of PV polices and incentives in driving energy behaviour changes by inhabitants (Schelly, 2014b); inhabitants' awareness of their own PV system (Bahaj and James, 2007), and load matching challenges and opportunities in new housing (Baborska-Narozny et al., 2016). These studies demonstrate that simply installing a PV system is not enough to achieve a positive low carbon governance and transition in housing.

In terms of the critical PV provisioning process, other studies discuss the governance of PV system from the perspective of an individual actor (the Project Manager) (Abi Ghanem, 2008), and the role of the fragmented contractual arrangements and institutional artifacts in overlooking the energy agenda and omitting the PV systems from the main design as a result, during the construction process (Boyd and Schweber, 2018). However, the detailed analysis and understanding of how multiple human and non-human actors (e.g. polices, professionals, inhabitants, products) are integrated in various governance networks, to govern the PV design and inhabitants' practices, has not yet been investigated and this remains a key research gap in the literature. Thus, the main aim of the thesis is to address this particular gap.

A key research question arising from all the above is:

> *How do multiple PV provisioning actors and networks govern the PV system design, affordance and related inhabitants' practices in low carbon housing communities in the UK?*

1.2.2 Research Approach

Three key theories are brought in pragmatically as lenses to enable analysis of different aspects of the overall networks and practices and associated governance involved in PV provisioning process resulting in the subsequent practice of inhabitants in low carbon community housing: Actor Network Theory (ANT), Practice theory and Affordance theory.

Actor Network Theory (ANT) examines how various actors are enrolled equally in a network to govern a social phenomenon (Callon, 1986). Its symmetrical principle towards human and non-human actors (Callon, 1986) opens up an analytical space for material, polices, and standards and their influences to be understood in PV provisioning and occupancy practices (Bevan and Lu, 2012). ANT redefines the meaning of social from its common understanding as the "science of the social" to 'a sociology of translation' by "…*tracing of associations …* between things that are not themselves social" (Latour, 2005: 5, emphasis original). The agency of actors and their actions in ANT, thus, are “not fixed in form and function, but subject to a series of transformations” as an effect result of their *relations* with other actors in a governance network (Latour, 1999a: 15). Translation looks at the connection between actors, rather than examining actors individually, to understand the way in which the results of negotiations between PV provisioning actors are translated into technological form and decide the ‘*scripts*’ that the PV technology subsequently carries (Akrich, 1992, Kurokawa et al., 2016).

ANT also helps to understand how the agency of PV actors (mediators vs intermediaries) might transform from one situation to another according to their position in the network (Gad and Jensen, 2010), and to examine the role of wider/extended networks (outside the boundary of the building construction contracts), as related to a PV network, in changing PV actors’ agency and power, and the outcomes as a result (Latour, 2005). *Mediators* refers to actors that can transform and shape what they engage with, while *intermediary* actors can only transport the meaning without transformation, and maintain the networks (Latour, 2005). ANT, however, tends to understand actors’ actions and practices in relation to other actors in a network, thus neglecting the role of human intention and intervention, as an individual actor, in making changes through enacting real practices. ANT, hence, cannot explain inhabitants’ practices of using their PV technologies *precisely* due to its lack of focus on analysing the embodied competences of individuals and how these competences can be developed over time when enacting actual practices, and change practices as a result (Nicolini, 2017b). Usefully, practice theory can help to deal with the issues discussed above (Nicolini, 2017a, Watson, 2017).

Practice theory combines social order and individual actions (Schatzki, 1996), and shifts the attention from actors and relations (ANT) to specific *practices.* While a variety of definitions of ‘practice’ exist (Shove et al., 2012, Schatzki et al., 2001, Reckwitz, 2002b), in this thesis inhabitants practices are examined within four key elements: technology and products, know-how and embodied habits, institutional knowledge and explicit rules, and engagement (Gram-Hanssen, 2010). This helps to examine the actual governance of inhabitants’ practices of using their PV systems within their real context (Hill and Huppe, 2014). Each of these elements can influence and change inhabitants’ practices, even if similar actor-networks are presented. Four other core ideas from Practice theory inform the research approach in terms of how PV technologies are used or changed in practices: relational thinking (Shove et al., 2012), knowing in practice (Ingold, 2000), emergence and routinisation, and differentiation among practices (Warde, 2005). All these elements suggest that knowledge is practical and situated in practices, and that different ways of knowing-in-practice can be presented when people enact real practices (Nicolini et al., 2011), allowing diversity in a particular practice every time it is enacted (Warde, 2005).

Neither Practice theory nor ANT studies to date focus particularly *in detail* on what actually is happening inside the PV controls, and how the material agencies of these controls relate to users, which affordance theory can help to do. Gibson's theory of Affordance focuses on the physical properties of objects (action possibilities), which are *independent* of the user's ability to perceive them (Gibson, 1979). The perception of these affordances depends on the users past knowledge and experience, and can be at least as important as actual (physical) affordance (Norman, 1999). Ingold (1992: 46 emphasis added) more specifically states that affordances are "properties of the real environment as directly perceived by an agent in a *context of practical action*". This definition misses out some of Gibson's original meaning, while providing the very helpful notion of 'a context of practical action'. Affordance is thus finally defined in this thesis as: *action possibilities directly understood, or not understood, by agents in a relational context of practical action.* This refines Gibson's original meaning of affordances by defining them with a context of practical action as specified by Ingold.

The theory of affordance therefore helps to explore in detail what the physical properties of PV controls can afford to their users and the potential engagement of inhabitants with these controls when they perceived/not perceived the affordances offered. This theory also helps to understand whether, or not, inhabitants' governance of their PV provisioning process improves their perception of and engagement with the affordance offered in their PV appliances, thus developing their practices as a result. Figure 1.1 shows the multi-lens research approach for examining the governance of *technology in practice.*

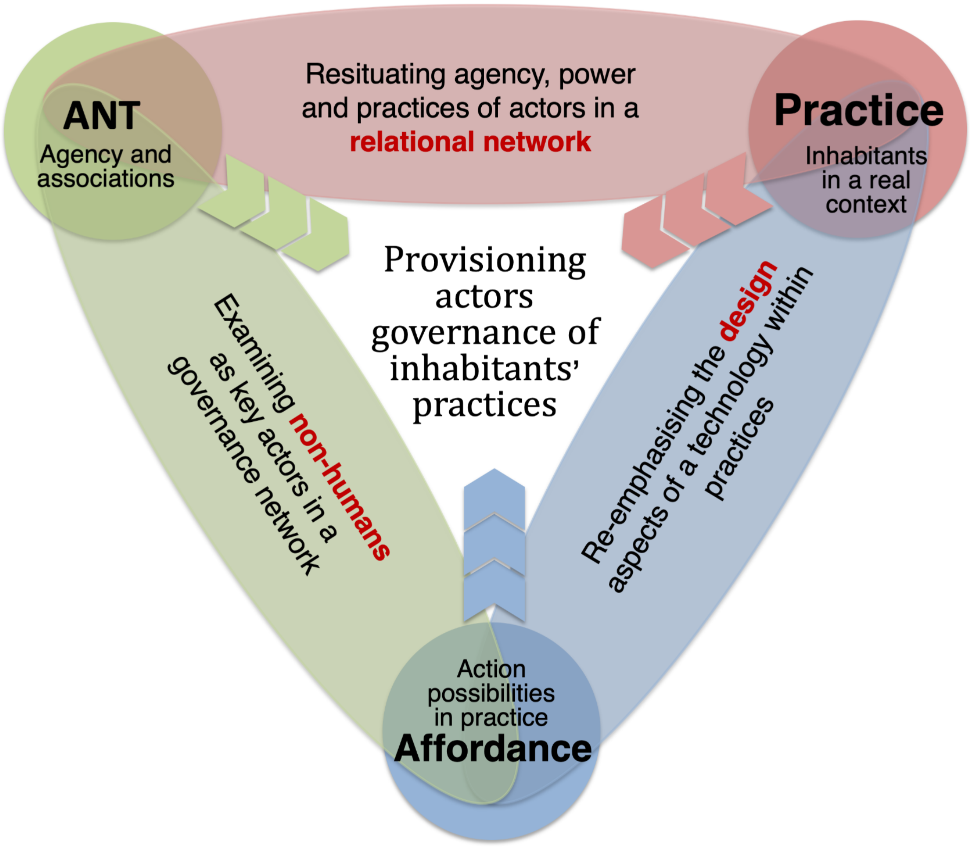

Figure 1.1: Theoretical research approach

1.2.3 Aim and objectives

The aim of this research is therefore:

> *To explore and explain, how multiple PV provisioning actors and networks govern the PV system design, affordance and related inhabitants' practices in low carbon housing communities in the UK, and to develop a better understanding of this interrelationship between homes, people and technology more broadly.*

In order to achieve this aim, the following objectives are set out:

1- Review the literature to understand how the provisioning and inhabitants' practices of domestic technologies are governed drawing on ANT, Practice and Affordance theories.

2- Examine key provisioning actors (both mediators and intermediaries) and their critical relations and integrations in PV networks that influence and govern the technology affordances and integration into homes, and inhabitants' practices during occupancy, taking the wider governance actors and networks, and power transitions into account.

3- Understand how inhabitants' governance and participation in their PV provisioning process influences the governance network and PV system design, and shapes their subsequent practice with the system appliances.

4- Examine how domestic PV systems are being practiced by inhabitants in various material and sociocultural contexts, and how their practices are shaped and sustained by the different provisioning of PV affordances, associated actors, and inhabitants' embodied know-how and engagement.

5- Identify the role of affordance in relation to inhabitants' practices of using PV systems when examining the action possibilities and engagement with the system appliances in their specific home contexts.

6- Use different theoretical lenses related to empirical findings to develop a broader understanding of the governance of technology provisioning in practice in relation to low carbon transition in homes more generally.

The research will be carried out in five stages using the methods as shown in figure 1.2.

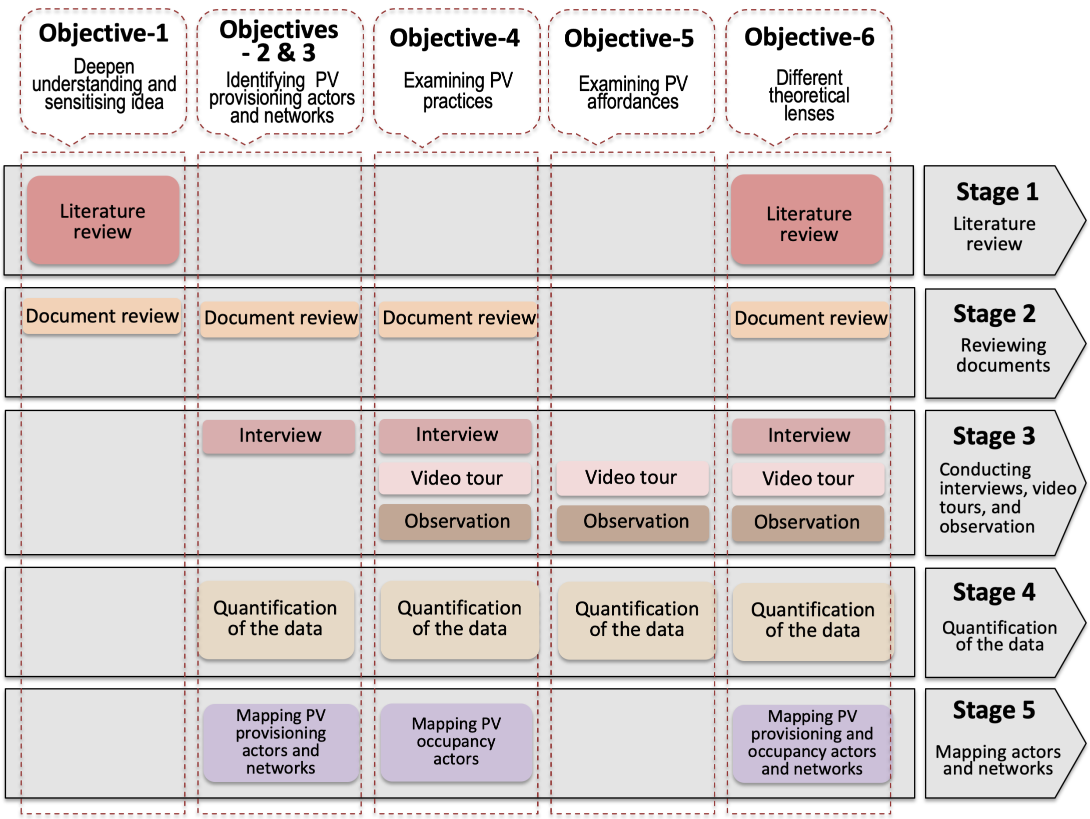

Figure 1.2: Research process and methods

1.2.4 Scope and limitation

Given the complex and explorative nature of this research, which requires a close and detailed examination and analysis of PV provisioning and inhabitants' practices within a specific time frame, only six case studies located in the UK are selected without an international representation, which was beyond the scope of this study.

Small sample studies can be critiqued for the difficulty in generalising from particular events and situations. However, the selection of an appropriate strategy for case study selection (see 4.3.2) can ensure that the selected group is relevant to the research question and the theoretical proposition of the thesis (Flyvbjerg, 2006). The boundary criteria for the UK case studies presented in this thesis ensures adequate representation in terms of location, size and time, and a wide range of geographical and sociocultural characteristics.

1.3 Overview of the thesis

The thesis is structured in ten chapters including this **Chapter,** which introduces the thesis. This chapter highlights the significance of the problems and challenges identified in terms of sustainability, housing and governance related to the provisioning of PV systems. It presents the research gap, research approach, research question, aims and objectives, scope and limitations, and outlines the research methods in relation to the designed research process.

Chapter two introduces the governance of low carbon transition in housing, and compares different approaches in the UK. This chapter further discusses the significance of PV technology in terms of improving inhabitants' awareness of their electricity generation and consumption, and the role of aesthetics in encouraging/discouraging inhabitants' practices of PV system. Finally, the chapter identifies in more detail the research gap in relation to PV provisioning governance and inhabitants' practices of using them. **Chapter three** discusses the selected theories for this thesis (ANT, Practice theory and Affordance theory)- in more detail to inform the research methodology and methods for data collection and analysis. It particularly examines how the different utility of these theories can drive different analytical purposes for answering the research question.

Chapter four sets out the detailed design of the research methodology based on selected qualitative research methods for data collection and analysis within the case study approach, and the theoretical approach of the research to answer the research question. **Chapter five** describes the case studies in this thesis, and brings together the findings derived from the documentary review and interviews with PV professionals related to the case studies. It draws on ANT theory initially in order to understand the basic governance of various PV provisioning actors, including the participating inhabitants. **Chapter six** aggregates data derived from the case studies in terms of the inhabitants' interviews and video tours in relation to their own practices of using PV system during occupancy and in relation to the affordances offered in their PV system.

Chapter seven discusses and maps the different agencies of PV actors in each case study network in more detail, examining how the PV design and inhabitants' engagement are specified and governed, and comparing the key actors and networks between the two sets of housing provision: Participative Communities (PC)[1] and Non-Participative Communities (NPC)[2]. This is to see if one group is more effective than the other in terms of energy governance and performance. **Chapter eight** examines *why* there are differences in PV governance networks in the two main types of building contracts used in the UK and in the case studies presented in this thesis – a key finding in Chapter seven. This chapter also discusses the role of wider/extended networks and arrangements (beyond the contractual networks) in influencing the agency and role of actors using fragmentation analysis in relation to the ANT findings. **Chapter nine** interprets the differences in inhabitants' practices in relation to their own PV systems when performed within a similar governance actors and networks, using Gram- Hanssen's lens of technology and products, know-how and embodied habits, institutional knowledge and explicit roles and engagements as four interrelated elements of practice.

Chapter ten draws conclusions from the preceding chapters by summarising the thesis's key findings underpinning the contribution of the thesis to current knowledge at the theoretical, methodological and empirical levels. It offers recommendations and acknowledges some further limitations of the study and the scope for further research.

Two international journal articles, two international peer reviewed conference papers, and one poster have been published from the work of this thesis. The second journal

[1] Where inhabitants participate in the PV provisioning process with other provisioning team.

[2] Where inhabitants happened to live in houses which have been constructed by a developer with PV systems without their involvement in the construction process.

paper listed combined work from another research project (EU Marie Curie Fellowship: BuPESA) with my own independent thesis work, both drawing on the same single case study PC housing development (Case Study A). The author gratefully acknowledges the helpful comments from the anonymous reviewers of the papers and commentators on the associated conference presentations and poster.

- Journal paper: Frances, Z. and Stevenson, F. (2018). Domestic photovoltaic systems: the governance of inhabitant use. Building Research and Information (BRI), special issue: Energy performance gaps: promises, people, practices. Guest editors: Gram-Hanssen, K., Georg, S., 46(1). 23-41.
- Journal paper: Baborska-Narozny, M., Stevenson, F., Frances, Z. (2016). User learning and emerging practices in relation to innovative technologies: A case study of domestic photovoltaic systems in the UK. Energy Research & Social Science. 13 (24-37).
- Conference paper: Frances, Z. and Stevenson, F. (2017). 'The Role of Intermediaries in Transitioning Photovoltaic Systems into Low Carbon Housing'. In *the 33rd International Conference on Design to Thrive – Passive Low Energy Architecture (PLEA).* 2 July – 5 July Edinburgh: Network for Comfort and Energy Use in Building (NCEUB), 4803-4810. Available at https://plea2017.net
- Conference paper: Frances, Z. and Stevenson, F. (2016). 'Understanding users' interaction with photovoltaic (PV) systems in the UK community housing: practice, actors and affordance', paper presented to the European Network for Housing Research's (ENHR) annual Conference in Belfast on 'Governance, Territory and Housing', 28 june – 1July 2016, https://urbanaffairsassociation.org/2016/05/18/enhr-belfast-2016-28-june-1-july-2016/
- Conference poster: Frances, Z. (2016). Understanding users' interaction with photovoltaic (PV) systems in the UK community housing: practice, actors and affordance. How many ways can you change a light bulb? Exploring methods in energy research. London, Loughborough EPSRC CDT (LoLo conference - June 2016).

CHAPTER TWO: GOVERNANCE AND PARTICIPATION IN DOMESTIC PHOTOVOLTAIC SYSTEM DESIGN AND MANAGEMENT

2.1 Introduction

The widely accepted definition of sustainability as "the economic development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987) has been criticised for its emphasis on management and strategic action by governments at the expense of initiating practical sustainable outcomes which could largely be achieved through communicative actions and wider societal participation (Schroeder, 2014, Rist et al., 2007). This chapter discusses the conceptual framework of sustainable governance in low carbon housing and compares the different theoretical and applied approaches for the governance of sustainability transitions in the UK, highlighting the limitations of each, to inform the theoretical approach of the thesis which will be discussed in depth in the next chapter. In this chapter, a brief context of how the housing situation in the UK compares with the rest of Europe and the world in terms of PV installation and promotion will also be illustrated. This is to: contextualise the UK debate within an understanding and perspective of the global debate on PV systems and low carbon transition in housing; introduce the significance of choosing PV technology among other renewable technologies; and identify a specific gap in PV literature in relation to PV provisioning governance, affordance, and inhabitants' practices of the system.

2.2 Sustainability in housing

Climate change is a critical international challenge and policy discourse, providing an opportunity to transform energy governance and ensure a radical decarbonisation (Bornemann et al., 2018, IPCC, 2018a). Reducing carbon emissions has become the most critical factor in UK sustainable design, as shown in the UK Sustainable Building Code issued in 2006, in order to meet the government target to reduce CO_2 emissions by 80% against 1990 baseline by 2050 (Climate Change Act, 2008). Consequently, there has been a great focus on regulation, policy, finance and design in order to achieve low carbon and energy efficient building envelopes through conservation and efficiency measures (demand side), and the development of low carbon energy generation (supply side) (HM Government, 2009, Cherry et al., 2017).

A particular focus has been given to the housing sector which is responsible for 74% of global building energy use (IEA, 2015) and one third of the total energy consumption in the EU (Eurostat, 2013). According to the most recent UK Committee on Climate Change (CCC) report:

> "We will not meet our targets for emissions reduction without near complete decarbonisation of the housing stock … These emissions need to fall by at least 24% by 2030 from 1990 levels, but are currently off track" (CCC, 2019: 11).

In the UK, the housing sector is responsible for 28% of total energy consumption, compared to 24% in 1970 (DBEIS, 2018a), and is currently responsible for 14% of the total CO_2 emissions during occupation (CCC, 2019). It represents an important field that inevitably contributes to overconsumption in energy use (Arman et al., 2009). Moreover, in order to meet the expanding demand for new homes, 340,000 additional homes need to be built in the UK each year until 2031 to cover the total housing shortage of four million (National Housing Federation, 2018), which means an increasing energy demand in the domestic sector. A successful sustainable energy strategy and transformations for housing, principally driven by government policy and regulation, could be an effective tool for cutting carbon dioxide emissions by significant levels (Schelly, 2016), right across the UK to meet the scale of emission reductions announced by the Government's low carbon plan (CCC, 2019). The CO_2 emissions reduction in housing sector, therefore, will be considered as a proxy for sustainability in this thesis. The next section explores the particular energy transition challenges in low carbon housing.

2.3 Governance approach in sustainable transition

The endeavour to understand, promote and accelerate sustainable transition and management in low carbon housing projects has become a major concern due to a significant failure in addressing the environmental impacts associated with the *provisioning* and *use* of products by consumers (Wang et al., 2014). This is particularly significant in relation to domestic energy-efficient technologies, as they are conceived by the building professionals (transition actors) and policy makers to be the principal mover in a transition process and have a prominent role in their change strategies (Grin et al., 2010). This has resulted in a significant performance gap between predicted energy savings and the reality during occupancy (Boyd and

Schweber, 2018, Gram-Hanssen et al., 2017, Bordass et al., 2004). New homes often uses up to three times the amount of energy that was predicted to be used during occupancy (Gram-Hanssen, 2010, Bordass et al., 2004).

Various studies interpret this performance gap differently due to the differences in their standpoints towards governing energy transition, which are discussed in the next section. A Danish study attributes this gap to the practices of inhabitants when using energy (e.g. by increasing their indoor temperature, extending their heat season, etc.) (Gram-Hanssen et al., 2012, Sunikka-Blank and Galvin, 2012), while other studies mention limited inhabitant understanding of technologies (Stevenson et al., 2013, Brown and Gorgolewski, 2015, Baborska-Narożny and Stevenson, 2018) and the poor capacity of policy and standards to deliver the projected energy performances (Baborska-Narozny et al., 2016, Monahan, 2013). Further studies ascribe the energy performance gap to professionals' practices, showing how professionals inscribe the material configuration and integration of these technologies into home, and frame inhabitant practices as a result (Gram-Hanssen et al., 2017, Abi Ghanem, 2008, Wade et al., 2018). The professionals' practices have been largely driven by the polices and standards related to developing energy performance buildings (Gram-Hanssen, 2014b), and the different perspectives, positions and knowledge of professionals (Van Bueren, 2009). This thesis focuses on how material and practice changes interplay in low carbon transitions rather than discussing them individually.

These concerns among others have encouraged policy makers to introduce alternative approaches to govern environmental problems which are predominantly aimed at reducing the overall capacity of legislation and fostering participation and responsibility of civil society actors including end-users, in terms of taking a more active role in delivering more environmentally sustainable outcomes (Schroeder, 2014).

Three readings and interpretations of governance are discussed by Bulkeley and Watson (2007). The first and broader reading of governance "refer to the modes and practices of the mobilisation and organisation of collective action" (Coafee and Healy, 2003: 1979). By contrast, the second reading of governance emphasises a specific shape of governing and institutional arrangements, which works against the hierarchical forms of authority to see governance as 'governing without government' (Rhedos, 1996, Borzel, 1998, Haahr, 2004). This approach of governance emphasises a move from central authority "state-led direct regulatory interventions" in terms of sustainable development management and strategies to “non-state stakeholders and the use of less-coercive regulatory instruments” (Van der Heijden, 2016: 575, Rist et al., 2007, Borzel, 1998). This approach also places emphasis on the involvement of citizens as a key actor in the development and implementation of public policies, thus, creating a new space for decision making as their “inputs become a much more central part of the policymaking process” (Fischer, 2018: 144). Research shows that communities that engage the practice of governance have a greater capacity for dealing with disasters, both natural and social (Aldrich, 2012) and can provide less powerful groups better chances of influencing both the distribution of resources or delivery of services (Fischer, 2018).

Another aspect of governance described in the literature, as a third reading, is that of ‘multilevel governance’ (MacLeod and Goodwin, 1999), which emphasises the role and function of multiple actors across multiple domains to govern a particular object and entities, including the government bodies and citizens (Dowling et al., 2018, Torfing et al., 2012). The latter approach has great potential in terms of achieving sustainability goals and removing the gap in implementation of sustainable outcomes in part due to its multi-sector approach to problem-solving and encouraging social and collective learning (Mah and Hills, 2012, Happaerts et al., 2010). However, there should be no assumption that this approach will always work as community led initiatives, which enable inhabitants to govern their environment, do not automatically lead to energy efficiency (Baborska-Narozny et al., 2016, Baborska-Narozny and Stevenson, 2014). This is due to its focus on identifying new institutional arrangements (e.g. community housing projects) rather than describing “how and why these arrangements are being produced” (Whitehead, 2003: 6, Bulkeley and Watson, 2007). A key step in this thesis is “to develop an analytical approach which can capture the dynamic and multiple nature of governing, attending to its forms and processes, and the ways in which policy and everyday practice … evolve” (Bulkeley and Watson, 2007: 2734, Butler et al., 2018) in relation to homes.

Several studies claimed that actual practices that have involved governance lack transparency and accountability (Fischer, 2018), thus obscuring the non-linear outcomes and wider forms of influence (Butler et al., 2018). To achieve a successful energy transition, the collective governance concepts described above, thus, need to be incorporated to examine the detailed processes and practices of governance (Schroeder, 2014, Bulkeley, 2015) in order to cover the aspects of practicality and implementation and achieving better carbon transition as a result. The overall governance approach which combines all of the above readings and approaches is defined as “the sum of all ways in which individuals, public agencies, and private organisations govern their common affairs in a continuous process of negotiation and cooperation” (Commission on Global Governance, 1995: 4).

Departing from the collective nature of governance discussed above, individuals’ actions and decisions, conversely, are also considered in this thesis when examining the multilevel governance of PV systems. This is to understand how rationality, knowledge, norms and practices of individuals can steer the decision making process in various governance networks (Bulkeley, 2015). This thesis, thus, extends the meaning of governance to not only focus on how individuals govern their common affairs *collectively,* but also how they govern *individually,* by virtue of how their ‘mediating’ role and decisions sits within the overall governance network, and in relation to their own decision making. This new move in understanding governance has been discussed in several studies concerned PV systems. Abi Ghanem (2008), for example, discussed how the project manager as a key mediator actor in the building construction network *inscribes* the design and use of PV technology according to his knowledge and perception of the system, and how individual inhabitants then *describe* the PV design when individually using the system according to their own interpretation and meaning of the system.

The governance approach, is thus developed in this thesis to include both individual and collective actions and practices, and defined as ‘*the sum of all ways in which individuals, public agencies, and private organisations govern their common affairs both individually when governing their own conduct and in a continuous process of negotiation and cooperation to steer collective actions and decisions’*. Such an approach aims to achieve a radical transformations in sustainable development by enabling people to both individually and collectively *introduce, procure* and *govern* their social, economic and technical context in their technology provisioning network (Grin et al., 2010, Seyfang and Longhurst, 2016). The term ‘radical’ here refers to “the scope of changes, not its speed” (Grin et al., 2010: 11), because the innovation in building sector in the UK is locked into incremental innovation (Lees and Sexton, 2014). Hence, there is the need to look at the governance of domestic energy efficient technologies in greater detail within a wider network of building professionals and other associated actors, to achieve a successful transition plan and to address the unpredictable effects of the failure in energy performance. To better contextualise the governance approach within the UK policies and practices, the next section describes the different approaches of governing low carbon housing in the UK.

2.4 Governing low carbon housing

Three different theoretical and applied approaches have been implemented to interpret and define low carbon housing: technical, behavioural and contextual (Macrorie, 2016, Gram-Hanssen, 2014b, Vob et al., 2006).

2.4.1 Technological approach

According to technological approaches, an effective governance of low carbon housing can be assisted by technological interventions, labelled by Guy and Shove (2000) as the 'techno-rational paradigm'. This paradigm is represented by developing energy efficient building materials, installing low carbon energy generation and energy monitoring technologies, and optimising the physical properties of homes (Macrorie, 2016). The UK Low Carbon Transition Plan (DECC, 2009) introduced two key polices for delivering low-energy hoses based on technological improvements: new building regulations and the Zero Carbon Homes (ZCH) standards. The UK building regulations now emphasise higher standards for building fabric, heating, cooling, ventilation systems and renewable energy generation. This approach has shifted the focus from an energy conservation paradigm to an energy-efficiency and carbon emissions whole house approach (Monahan, 2013). In 2007, the UK government declared that all new-build domestic homes would need to be 'zero carbon' emissions by 2016 as a key mechanism to reduce CO_2 emissions (Fischer and Guy, 2009). An introduction of the Code for Sustainable Homes (CSH) standards in 2007 represented the principal new energy efficiency regulations (DCLG, November, 2010) to improve the environmental performance by limiting carbon dioxide emissions into the atmosphere resulting from the operation of the dwelling and its services (DCLG, 2006). The code was divided into various levels with details and specifications available for each level for achieving a certain performance level as 'a percentage improvement'. CSH Code levels 3 and 4 required the equivalent of a 25% and 44% CO_2 emissions reduction respectively in relation to the Dwelling Emission Rate (DER) specified in the building regulation standards, leading to the 'zero carbon' standards (code levels 5 and 6) (Figure 2.1). However, the CSH 'zero carbon' levels were replaced in March 2015 by new technical standards, which are comparable with the requirements for CSH level 4 (DCLG, 2015). These new standards removed the previous policy in terms of achieving the CSH levels 5 and 6 and the potential to create zero carbon emissions in all new homes by 2016, emphasizing instead issues concerned with the security and affordability of housing (Cherry et al., 2017).

Table 1.2 : Code Levels for Mandatory Minimum Standards in CO_2 Emissions	
Code Level	Minimum percentage reduction in dwelling emission rate over target emission rate
Level 1 (★)	10
Level 2 (★★)	18
Level 3 (★★★)	25
Level 4 (★★★★)	44
Level 5 (★★★★★)	100
Level 6 (★★★★★★)	'Zero Carbon Home'

Figure 2.1: Code levels for mandatory minimum standards in CO2 emissions – Communities and Local Government report- Technical guide 2008

Interestingly, in order to achieve CSH level 4 and above, low carbon renewable energy technologies still need to be installed with a minimum size of 1kWh, which does not challenge how much energy is actually needed for individual homes (Shove, 2017b) and also constrains the possibility of installing these systems in homes. This illustrates the significance of understanding the provisioning and practices of these technologies in housing sector in the UK in order to overcome the implementation gap in the actual use.

The emphasis on physical and technical properties over social and cultural aspects of inhabitants in the technological paradigm pursued by governments, has resulted in lower than anticipated energy savings (Gill et al., 2010, Shove, 1998, Gram-Hanssen et al., 2017), when the technologies "go out to the real world" (Flyvbjerg, 2007). This has resulted in a persistent 'energy performance gap' between design intentions and the reality of energy use (Sunikka-Blank and Galvin, 2012). Such a gap not only undermines the delivery of national carbon reduction plans, but also damages the confidence of the consumer if energy bills are higher than predicted (Zero Carbon Hub, 2009). Accordingly, the low carbon housing governance in the UK began to increasingly place attention on the activities of inhabitants and behaviour change (DECC, 2010b) instead of just examining the technologies in use.

2.4.2 Behavioural approach

The behavioural approach for the governance of low carbon housing focuses on individuals (e.g. inhabitants) as agents for environmental changes as a means to reduce CO_2 emissions within the home (Barr et al., 2011). It discusses the potential of an individual's attitude towards driving energy behaviour changes. In this light, the individuals' actions are seen as being significantly driven by their rational choice-making. In low carbon housing, the behavioural approach focuses on encouraging inhabitants to reduce their energy use during operation of the houses and/or to use the installed energy efficient technologies in their homes properly to minimise the technical implementation gap in actual use (Macrorie et al., 2014). In other words, to ensure that 'correct' behavioural decisions are made (Leaman et al., 2010), drawing on the Theory of Planned Behaviour (TPB) (Ajzen, 1991) to inform policy interventions in terms of how inhabitants behave in low-energy housing.

According to TPB, a behaviour is a joint function of individual's attitude towards performing the behaviour, subjective norms and social pressure, and perceived behavioural control over performance of behaviour (Davis et al., 2006). Drawing on the TPB approach, various studies in low energy housing have tried to identify the different variables that influence inhabitants' practices to reduce energy use (Yearley et al., 2013, Gill et al., 2010, Kriek et al., 2013, Scott et al., 2014, Taufique and Vaithianathan, 2018, Wittenberg et al., 2018). An introduction of the FIT in April 2010 and the Renewable Heat Incentive (RHI) in April 2014 represented key policy interventions in low-energy housing aimed at encouraging renewable energy technologies and driving energy behavioural changes in the UK. TPB, however, has been criticised by Irrational Behaviourism Theory (IBT) for its inability to provide a significant set of non-obvious, empirically sustainable propositions about behaviour (Shapiro, 2005). Frances and Stevenson (2016), highlight that the UK Feed-In Tariff actually discourages some inhabitants in community housing case studies from changing their energy consumption behaviour due to other financial benefits that they could get from exporting their generated energy from the system to the main grid, participially when the tariff was very high in 2010.

Other domestic low energy studies have adopted the Technology Acceptance Model (TAM), developed by Davis (1989) from (TPB), to examine how domestic technologies have been adopted by inhabitants in low carbon housing. Examples include: the uptake of smart meters (Guerreiro et al., 2015), renewable energy technologies (Alam et al., 2014) and advanced electricity metering services (Park et al., 2014). Shove critiques these studies based on the ABC[3] model by stating that this behavioural approach takes insufficient account of the role of social, cultural and infrastructural arrangements in shaping inhabitants' behaviour in their everyday life (Shove, 2010). This has resulted in a failure to achieve desired energy saving practices (Stevenson and Leaman, 2010, Firth et al., 2008).

2.4.3 Contextual approach

Finally, the contextual approach for the governance of low carbon housing puts forward alternative understandings of sustainable transformations and suggests that behaviours are:

> "… fundamentally social, undertaken by social actors acting and interacting within wider social discourses and settings; fundamentally contextual, unfolding according to different dynamics, rules, logics and socio-technical networks in different contexts; and fundamentally political, embodying particular assumptions about individual agency and responsibility and liable to be contested, resisted, disparaged and even to cause offence" (Hargreaves, 2009: 52)

The contextual approach has thus shifted the emphasis from individual cognitive decision making and the techno-rational approach to delivering low carbon housing to investigate what individuals are actually doing in their "sociomaterial" context (Walker et al., 2015: 494, Schatzki, 2002).

The contextualised sociotechnical approach, in opposition to the technological and behavioural perspectives presented earlier, "focuses on the interplay between the technological, the social, the economic and the political" (Rydin, 2013: 25). It moves the argument beyond the attitude, values and rational choices of an individual (as part of the ABC model which Shove critiques), and accepts the role of the technical design in driving behaviours in an intended direction (Jelsma, 2006). The sociotechnical approach, thus, is the preferred approach in this thesis for its focus on the co-evolving human behaviour and objects within wider governance networks when examining and

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[3] "For the most part, social change is thought to depend upon values and attitudes (the A), which are believed to drive the kinds of behaviour (the B) that individuals choose (the C) to adopt. "SHOVE, E. 2010. Beyond the ABC: climate change policy and theories of social change. *Environment and Planning,* 42**,** 12273-1285. (P.1274)

understanding the energy performance gap in new low carbon housing.

Different theories, such as Practice theory and Actor Network Theory (ANT) have been used by recent sociotechnical domestic energy studies to avoid the limitations of regulated low carbon housing policies and to provide a more holistic approach for the governance of low carbon housing (Gram-Hanssen, 2010, Killip, 2013). The ontological and methodological standpoints of these theories will be discussed in depth in the next chapter which outlines the approach towards the thesis methodology in chapter four. Community governance, incorporating individual governance, for sustainability provides a key means to potentially achieve a successful transition plan as “we often achieve more acting together than as individuals” and governance can “create an environment where the innovations and ideas of communities (in response to climate change) can flourish” (HM Government, 2009: 92). It is also a means to broadly understand the social and technical aspects involved in the process of low carbon housing transition, which is discussed next.

2.5 Inhabitants governance and participation

The governance of inhabitants within the process of technology provision alongside other agents, can play a crucial role in terms of whether or not technological innovations in housing produce solutions respond to inhabitant preferences and capacities (Seyfang et al., 2013). Inhabitant participation in decision-making and provisioning strategies, is also important in terms of improving their knowledge and design skills, and developing realistic expectations about their home technologies, which can help improve system design and close the implementation gap during occupation (Chang and Taylor, 2016). The governance approach accrues benefits to both people and the state for promoting environmental goals by joining in participatory processes and provisioning strategies (Seyfang et al., 2013). Environmental governance literature extends the governance concept further by considering consumer technology uptake (both individual and collective) as a critical aspect of governance and conceptualising the dynamics of energy demand (Schroeder, 2014, European Commission, 2008, Shove and Walker, 2010). In order to provide optimal conditions for understanding inhabitant participation and social interaction, community housing projects (where inhabitants have participated in the building construction process of their homes with other agents) are chosen to provide useful case studies for this thesis (Williams, 2005).

Community housing is a key focus in the housing sector and is well understood by policy-makers in the UK because of its ability to broaden housing delivery in an ecological sense and strengthening community relations (Hamiduddin and Gallent, 2013). Moreover, the UK government has claimed that "Community groups can help tackle climate change, develop community energy and transport projects" (HM Government, 2005: 27) and encourage sustainable production and consumption. Such an approach enables wider citizen participation, which represents a critical concept in sustainable governance, to collectively introduce, procure and develop sustainable problems building on local knowledge, social networks, giving solutions from their everyday practice (Mulugetta et al., 2010, Seyfang and Haxeltine, 2012, Walker et al., 2007).

Community participation and governance offers space for creating a new system of grass-root governance and innovation as a "strategic niches" towards sustainability and reducing CO_2 emissions (Seyfang, 2010) as well as multidisciplinary learning processes through its interdependence support network (Chatterton, 2013, Seyfang and Haxeltine, 2012, Stevenson et al., 2016). Such governance supports low carbon community inhabitants to be more resilient by increasing their adaptive capacity to "collectively learn from their experiences and to consciously to incorporate this learning into their everyday lives" (Stevenson et al., 2016: 791).

Community participation also encourages high levels of energy consumption behavioural changes, thus reducing CO_2 emissions overall (Mulugetta et al., 2010, Seyfang and Haxeltine, 2012, Seyfang and Smith, 2007, Seyfang et al., 2013). Indeed, significant energy savings were made by 57% of those living in cohousing projects in the US, which typically used participation strategies (Williams, 2007). Inhabitants also reduced their ownership of tumble dryers and washing machines by 25% when they lived in community housing, because of sharing facilities, such as the common laundry and kitchen (Meltzer, 2005). However, in some cases community participation can backfire leading to poor energy strategies (Baborska-Narozny and Stevenson, 2014). This makes the area also worthwhile to investigate to try and identify further why this is happening. Community housing for this thesis is defined as *a network of activists and organizations brought together with a common interest and particular aims, generating novel solutions and decision-making from their everyday practice and collective strategies* (Grin et al., 2010).

An analysis of inhabitant participation and governance in the technology provisioning and occupancy practices could help to provide practical guidance for policy makers and practitioners in developing an understanding of how inhabitants engage in the technology provisioning process together with the other provisioning team members. It could also help to highlight specific key areas in the provisioning process and their influence on the design of the home in relation to these technologies. Before exploring the relationship between agency, practices and community governance, however, it is important to understand the rationale for focussing on renewable energy and PVs as a particular area of study.

2.6 Photovoltaic (PV) systems

If the UK's target of reducing carbon emissions is to be achieved, significant energy reduction is required in the domestic sector (Committee on Climate Change, 2018). On-site renewable heat and electricity generation combined with low and zero-carbon (LZC) technologies offers a real advantage in promoting domestic low carbon transition efficiently and gradually and are targeted to provide about 70% of the regulated domestic energy use (space heating and hot water, lighting, pumps and fans) by 2050 (McLeod et al., 2012, Koch et al., 2012). Different definitions of Low and Zero Carbon (LZC) technologies are informed by different actors according to their standpoints. The National House-Building Council (NHBC) defines LZC technologies as "generally applied to renewable sources of energy, and also to technologies which are significantly more efficient than traditional solutions or which emit less carbon in providing heating, cooling or power" (NHBC, 2010: 2). The Energy Saving Trust (EST) expands the NHBC definition by introducing the notion of 'operation', defining (LZC) technologies as "zero carbon in operation (powered by 100% renewable energy) and those that are considered to be low carbon in operation (powered at least in part by fossil fuels)" (Energy Saving Trust, 2010: 4, emphasis original). LZC technologies are defined in this thesis as those technologies deriving energy from renewable sources which have net zero carbon emissions in operation (Monahan, 2013). These include: Solar heat, PV, Wind turbines and others technologies, which fit within the definition in the Code for Sustainable Homes (DCLG, 2008).

It has been argued that current housing practices aiming towards achieving low carbon transition 'Code' requirements and building regulations in the UK should emphasise a 'fabric first' policy when designing LZC housing. However when moving towards zero carbon housing, focusing on the 'fabric first' method alone is insufficient (NHBC, 2015). At least one microgeneration per dwelling needs to be installed in addition to the above method in order to meet the 2050 UK government target of 80% emissions reduction (Bergman and Eyre, 2011). This in turn has led the policy makers to introduce new polices and incentives in relation to the installation of micro-generation technologies in housing (ibid). Given the wide range of technologies used in housing sector (e.g. heating systems, mechanical ventilation systems, renewable energy, etc.), focusing on one type of technology - photovoltaic (PV) systems – could provide deeper insights into understanding how such systems of provisioning are governed and used by inhabitants. This type of deep investigatory approach can then in turn be applied to an examination of other home technologies in the same manner.

PV installations had dramatically increased worldwide from 9.2 GW in 2007 to 404.5 GW by the end of 2017, with expected an annual increase of 100GW by 2022 (Jäger-Waldau, 2018, SolarPower Europe, 2018). Significantly, more solar PV capacities were installed than any other power generation technology in 2017, even more than fossil fuels and nuclear combined (SolarPower Europe, 2018) (Figure 2.2).

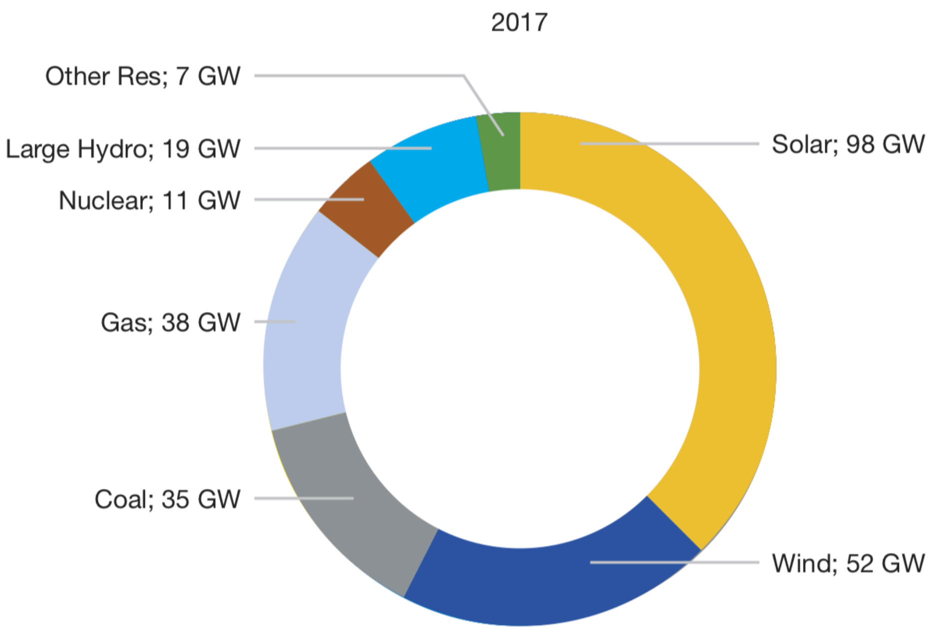

Figure 2.2: Net power generating capacity added in 2017 by main technology (Source: SolarPower Europe, 2018)

Figure 2.3 shows the global top 10 solar PV markets total installed shares by the end of 2017.

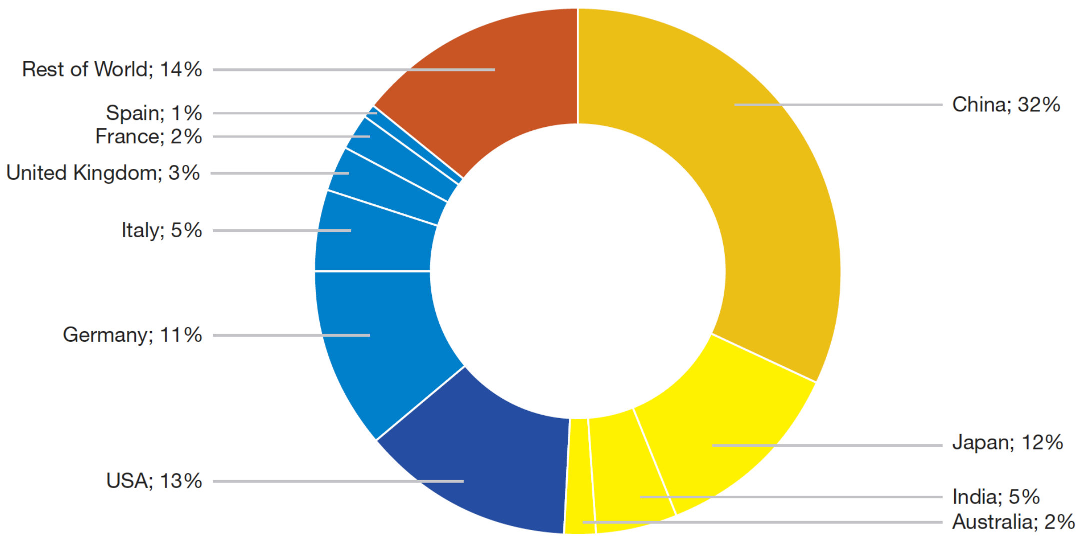

Figure 2.3: The global top 10 solar PV markets total installed shares by the end of 2017 (Source: SolarPower Europe, 2018)

China was recently the world's top PV installer with a total capacity of (130 GW) installed by the end of 2017 compared to (77.5 GW) by the end of 2016. This meant an additional capacity of 52.5 GW in 2017 compared to 34.5 in 2016, resulting in a 32% global share (SolarPower Europe, 2018). This is ascribed to their new regulation for self-consumption followed by a new national level regulation in 2013 which included a significant subsidy for all energy generated of 0.056€ on top of the energy price for consumer (Rodrigues et al., 2016). This approach was also trailed by the USA and Japan. The USA recorded the second largest market in 2017 (51.5 GW) equal to a market share of 12.7% (SolarPower Europe, 2018). The PV installation capacity in the USA has been largely prompted by support mechanisms provided by the federal and state governments[4] to the consumer, such as a production tax credit and an investment tax credit for PV development. Other financial incentives, which targeted energy companies, were also facilitated, such as the Renewable Portfolio Standard (RPS) scheme and a net-metering scheme[5] (SEIA, 2017). Japan moved to the third place after USA, in terms of PV installation capacity by the end of 2017, with total capacity of (49.3 GW) resulting in a 12.2% global share compared to 13.8% in

[4] The state incentive includes a production tax credit (PTC) and an investment tax credit for PV projects. The federal incentive includes a federal tax credit for solar PV, which all households are eligible to receive, worth 30% of the cost of the PV system.

[5] Under the net-metering scheme, the consumer is billed by the utility company for the net consumption of electricity during a billing period.

2016 (SolarPower Europe, 2018). The significant growth of Japan PV installations has been largely attributed to a major shift in their policy from Renewable Portfolio Standards (RPS)[6] scheme to the FIT support scheme introduced in 2015 (Japan's Ministry of Economy Trade and Industry – Agency for Natural Resources and Energy, 2015).

Germany dropped to fourth place after Japan with total capacity of (43.1GW), having been in first place at the end of 2014 (39.864 GW) resulting in a 11% global share. This was due to a gradual reduction in their electricity tariffs (FIT) which was the highest among all other EU countries in 2004. However, it is still producing approximately 40% of the total EU PV energy generation (114 GW) (SolarPower Europe, 2018). The new addition in the top five, is India, which doubled its total PV capacity in 2017 to 19 GW and a 4.7% market share. The two other countries with solar capacities exceeding 10 GW at the end of 2017 were Italy at 19.4 GW (5% global share) and the UK at 12.7 GW (3% global share) (Figure 2.3).

In the UK, PV installations increased rapidly, particularly after April 2010 when the UK government launched new Feed-in Tariffs (FIT) aiming to reach their target of 20GW PV installation in 2020 (DECC, 2009, Muhammad-Sukki et al., 2013). This tariff was responsible for a 99% growth in PV installations by the end of 2016, and an 81% growth in capacity (DBEIS, 2017c). In spite of the large growth in the UK PV market 4.2 GW, 2.5 GW and 2.4 GW in 2014, 2015 and 2016 respectively, the most recent 2020 target might not be achieved due to the significant cut in the FIT rate (from 45.4p/kWh to 4.39p/kWh) that occurred between the years 2010 and 2016. Most of the new PV connections in 2016 were made during the 1st quarter of the year, due to many sites being accredited under the Renewable Obligation system, which was subsequently closed after the 1st April 2016, resulting in a big reduction in the PV connection pace for the following three quarters of the year (EurObservER, 2017). This resulted in less than 1 GW of new PV systems connected to the UK grid in 2017 compared to 4.2 GW and 2.5 GW in 2014 and 2015 respectively (DBEIS, 2018b). However, it is still representing the most cumulative installed capacity in the UK as

[6] Introduced by the Agency for Natural Resources and Energy, aiming at furthering the use of renewable energies by annually imposing an obligation on electricity retailers to use a certain amount of electricity from renewable energy resources.

confirmed by the Feed-in-Tariff (FIT's) at the end of March 2018 which represent 79% of the total installed capacity of microgeneration technologies in the UK (Figure 2.4).

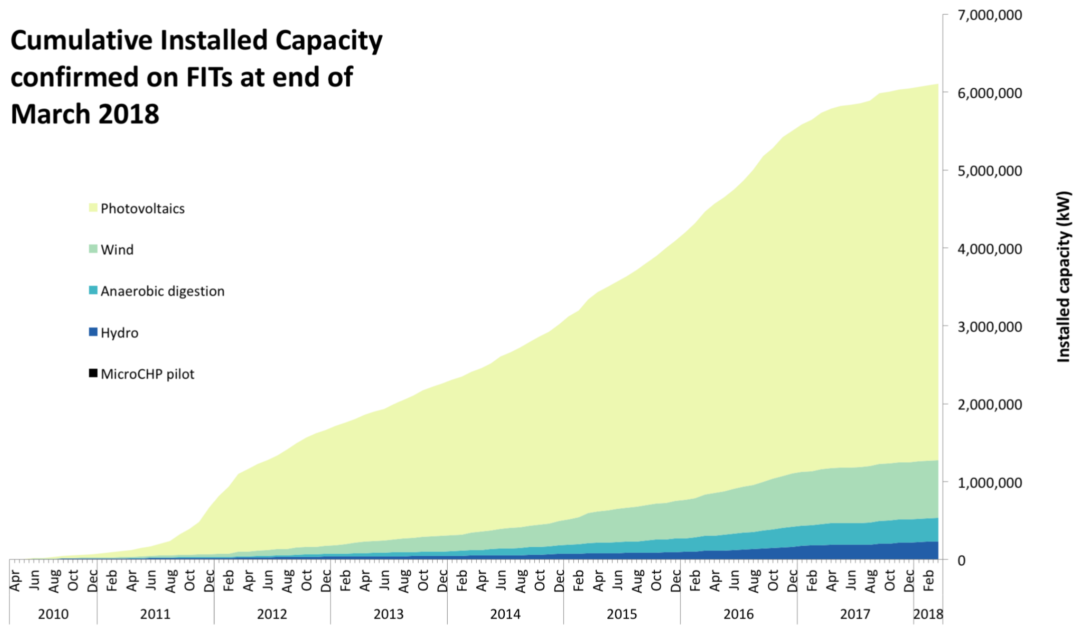

Figure 2.4: PV installations in the UK compared to other microgeneration technologies (Source: DBEIS, 2018)

The UK's FIT consists of two payments made by the energy supplier to the eligible and registered PV installations during the eligibility period of 20 years (25 years for those with an eligibility date before 1 August 2012 (Energy Saving Trust, 2014a): *generation* and *export* tariffs, with the latter one being six time lower than the former. For the generation tariff, the energy supplier pays a fixed rate for each KW that has been generated, while an extra payment for the exported energy to the main grid would be also received and assumed to be at the level of 50% of energy generation. An energy efficiency certificate is required to claim the FIT in the UK (Energy Saving Trust, 2014a).

The FIT plays an important role in inhabitant practices as discussed in chapter seven, which is why it has been described in detail here. Given that PV systems represents the highest percentage of renewable energy installations in the UK (DBEIS, 2018b) and the most preferable renewable technology for inhabitants (NHBC, 2015, DBEIS, 2017a), PV systems will be chosen as the main focus of this study.

A PV system is a power system designed to generate energy by means of a photovoltaic process. The system consists of several components (Mohanty et al., 2013) (Figure 2.5)

- Solar panels which absorb and convert sunlight into a DC current.
- Solar inverter which changes the direct current DC from the solar panels to an AC current of either 50Hz or 60Hz. In some installations, a solar micro-inverter is connected at each solar panel.
- Solar cable which interconnects the solar panels with other PV components.
- PV meter via which the AC output is connected through the electricity meter into the main grid. This provides benefits to the PV owner to get credit for the energy generated by the system (e.g. through a FIT).
- Energy export meter, installed in some cases, which records how much energy the system is exporting to the main grid.
- AC and DC isolating switches to prevent power surges, or to isolate the PV system during maintenance.
- Batteries. A charger controller, which prevents the batteries from any damage that may arise from being overly discharged or overcharged, is also installed if a battery is added to the system.
- PV monitoring loggers might be also provided in some houses to monitor the energy performance of the system.
- Smart energy monitor. This is an extra device that might be also installed in some houses which shows instantly how much energy the system is generating and how much the inhabitant is using energy at any particular moment.

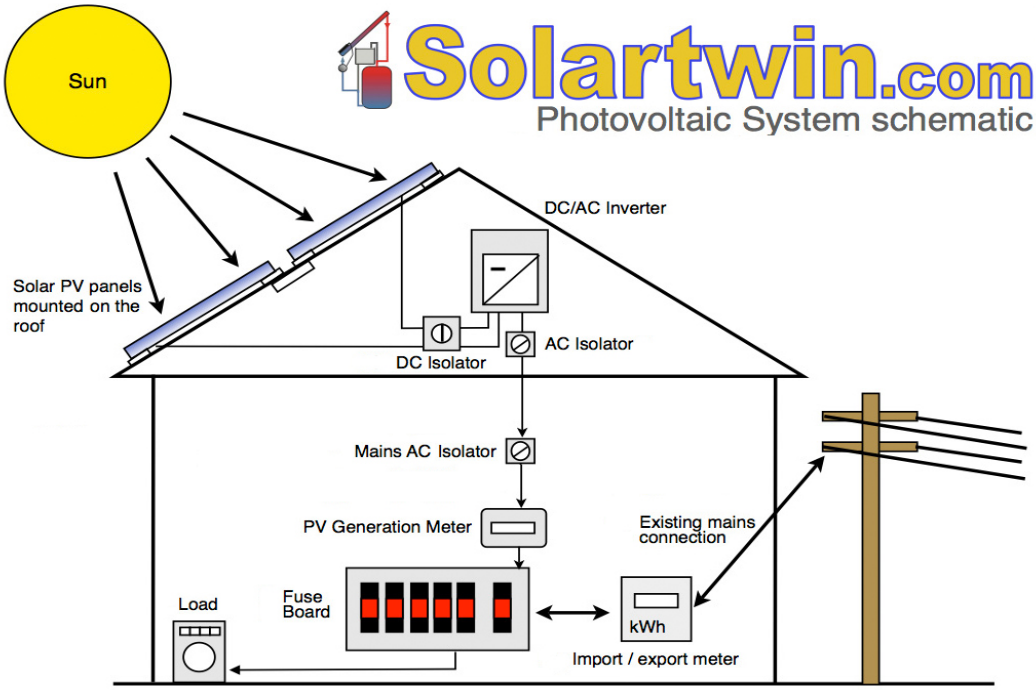

Figure 2.5: Solar PV components arrangements inside the house (solartwin.com)

The role of PV systems in dealing with peak demand[7] challenges in homes will be discussed in the next section (2.6.1). This is to highlights key aspects of appropriate PV provisioning and inhabitants' practices in terms of reducing energy consumption and carbon emissions.

2.6.1: Inhabitants' practices: energy balancing vs load matching

The large reduction in the PV prices (-87%) between the years 2006-2016 led to a significant growth in the PV installation in the world on average by 38% a year (Feldman et al., 2014, EPIA, 2014). This in turn led to increasing amount of electricity feeding into to the main grid, which could assist with mitigating *peak demand* issues in residential sector by offsetting the use of the non-renewable grid energy with the renewable PV energy (Chu et al., 2016, Saffari et al., 2018). Mckenna et al. (2018), for example, illustrate that the average PV consumption of an average UK household with an electricity demand of 4000kWh/year and 2.9 kW PV system could lead to a

[7] Peak demand refers to "the highest demand that has occurred on a utility network over a specified period of time" and has become one of the major global issues due to having a high risk of power system failure SAMUEL GYAMFI, S., KRUMDIECK, S. & URMEE, T. 2013. Residential peak electricity demand response—Highlights of some behavioural issues. *Renewable and Sustainable Energy Reviews,* 25**,** 71-77.

24% reduction in average annual electricity demand from the main grid which is largely non-renewable in the UK.

The high penetration level of grid-connected PV systems can, however, have a potential negative impact during the day on the grid stability in terms of the voltage quality of the UK residential low voltage distribution network (e.g. frequency regulation, the ability to rapidly start and ramp the remaining electric power generation and better match the consumption with the intermittent generation to avoid exceeding voltage limits) if a large proportion of PV energy is exported to the main grid as a result of it not being used efficiently by inhabitants, particularly in high PV generation times (Ali et al., 2012, Bottaccioli et al., 2018). This is because the current distribution network in the UK is not ready to accommodate all the generation capacity that can be installed (Bottaccioli et al., 2018). Limiting the maximum grid feed-in and throttling back PV power in times of high PV generation is essential for improving the grid stability and tackling these peak demand issues (Saffari et al., 2018, Lühn, 2018, Cheng et al., 2016, Freitas et al., 2018). Energy demand management and practices is, therefore, crucial and will be discussed next in this section in relation to the different approaches and practices for managing the energy loads in UK homes.

Various approaches for energy management have been discussed in the literature in terms of user engagement with their building environment, ranging from using technologies and appliances to balance the grid, to changing energy consumption practices to 'load match' energy usage (Roaf, 2013). These approaches alternated between seeing users as *active* recipients, who change their behaviour and practices to adjust with their settings through the way they interact with the environment (a user-enabled approach) (Kim et al., 2016), or as *passive* recipients of the given environment (a *technology-enabled approach)* (e.g. smart homes, smart appliances, batteries, V2G[8], etc.) (Aldrich, 2003, Strangers, 2013). The latter approach developed the concept of *smart homes*, also described by Strangers (2013) as '*smart ontology'*, intended to provide a better quality of life for the residents, based on technological fixes (e.g. monitors, sensors, appliances, interfaces, and devices) that are linked together to enable automation as well as remote control of the domestic environment, without any real intervention needed by inhabitants (Cook, 2012).

[8] V2G is defined as a method whereby electric vehicles (EVs) provide electricity power to the smart grid when not being used ALMANSOUR, I., GERDING, E. & WILLS, G. The feasibility of using V2G to face the peak demand in warm countries. International Conference on Vehicle Technology and Intelligent Transport Systems, 2018 Portugal.

One key aspect of sustainability and decarbonising societies is changing people's behaviour and everyday practices, to reduce their energy consumption and tackle peak demand issues (Shove et al., 2018). Several consumer behaviour studies show that the installation and use of micro-generation technologies, largely based on the PV system, can create a potential "double-dividend" by providing both a green energy supply and a total demand reduction as brought about by inhabitants changing their energy consumption practices when they *actively* engage with their own PV system to match their energy loads (Keirstead, 2007: 4128, Bergman, 2009, Luthander et al., 2015, Stedmona et al., 2013), thus improving the peak demand issues as a result. This is because PV system in itself, or in combination with energy generation and consumption monitoring and feedback technologies (see 2.6.2), creates opportunities for inhabitants to become more *literate* about their energy generation and consumption patterns when they actively engage with it, leading to efforts to further reduce their overall energy consumption and cost and be able to match the PV energy generation to the peak times for grid power generation (when power is more expensive) (Dobbyn and Thomas, 2005, Bahaj and James, 2007, Bergman, 2009, Bergman and Eyre, 2011, Keirstead, 2007, DECC, 2010a, Gölz, 2017, Hargreaves et al., 2010, Gupta et al., 2018). This directly challenges the normal invisibility of energy use where the main inhabitants' energy consumption is the result of routines and habits (Khalid et al., 2018, Shove, 2003). The installation of PV systems, for example, encouraged participating inhabitants to cut down their overall energy consumption by approximately 6% in the UK, and 43% of the inhabitants reported load-matching behaviours when they actively engaged with it during their occupancy (Keirstead, 2007). Dobbyn and Thomas (2005), similarly, showed that inhabitants' active engagement with their microgeneration acts as a vehicle for getting involved in various strategies of energy saving and energy management. On the basis of a focus group interview with PV inhabitants in Nottingham city, Goulden and Spence (2014) found that microgeneration technologies can be an active component of energy consumption practices due to "… prompting the development of new knowledge and skills" when they actively engage with it (ibid: 26). A further study concerned with energy efficiency in two low-carbon housing development in the UK showed how PV inhabitants tried to load match their energy generation and consumption in order to save money by reducing the imported energy from the grid (Baborska-Narozny and Stevenson, 2014). All these studies show that effective energy reduction and energy consumption practices to load match have developed after the installation of micro generation technologies, albeit under differing circumstances.

Although *active load matching* is considered in the literature as one of the key approaches for improving PV self-consumption[9] and energy management overall, (Luthander et al., 2015), the unstable and fluctuating nature of PV energy generation as well as inhabitants' energy consumption practices make the energy management of this micro-generation through active load matching a difficult task and inconvenient for some inhabitants due to reducing the flexibility of their daily life (Yang et al., 2017, Zhang et al., 2017, Friis and Christensen, 2016, Christensen et al., 2017, Khalid et al., 2018).

The passive technology-enabled approach for balancing the grid could, however, provide inhabitants with more freedom and flexibility to use PV energy rather than carrying out active load matching (Khalid et al., 2018). The study of Luthander et al. (2015), for example, found that improving PV self-consumption using a battery storage system was more effective in terms of reducing the imported energy from the grid (13-24%) compared to inhabitants' changing their behaviour and routine of energy use (2-15%). However, the study also claimed that both approaches have improved self-consumption, compared to the original rate of self-consumption. Another good example of the technology-enabled approach are smart home power management systems using smart appliances, which have the capacity to communicate with smart meters, to enable control systems to be managed remotely (özkan, 2016). Another example of improving energy demand management passively was applied in a residential neighbourhood in Oud-Heverlee in Belgium, where all the houses were equipped with technologies (e.g. batteries, smart-control system) to provide a maximum energy management (Horizon 2020, 2016). Further example of using technologies to balance the PV energy and the grid overall was implemented in the Vehcle2Grid project in Amsterdam, which enabled inhabitants to store their locally-produced energy during the day in their electric car battery and unload it again to be used locally in the peak time and at night (when their PV systems don't generate electricity) (Amsterdam Vehcle2Grid, 2016).

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[9] PV self-consumption in this thesis refers to the PV generation that is consumed directly/indirectly by the producer rather than exporting it to the main grid LUTHANDER, R., WIDEN, J., NILSSON, D. & PALM, J. 2015. Photovoltaic self-consumption in buildings: A review. *Applied Energy,* 142**,** 80-94.

Energy storage (e.g. batteries), as a technological approach for balancing the grid, can be installed either individually (for each individual house), or ‘communally’ (one big battery for a group of houses energy communities) (Bottaccioli et al., 2015). Depending on the targets for an increased customer involvement (by using individual batteries) or a better system management (by using a community battery), both approaches show opportunities for reducing the energy import from the grid by potentially around 35% when batteries are used on the individual level and by around 56% when the battery balances within the grid on a community level, as long as the technological specifications are well coordinated and controlled (Marczinkowski and Østergaard, 2018). These batteries can also be combined as part of a smart energy system (ibid) to create synergies with other sectors e.g. by offering locally stored electricity to local Electrical Vehicle (EV) charging stations or even to the heating sector via heat pumps (Marczinkowski and Østergaard, 2018).

Although the technology-enabled system can enable effective use of renewable energy, and can be more effective in terms of reducing the imported energy from the grid, it is not necessarily more effective than active load matching in terms of reducing energy consumption overall. A Dutch study demonstrated that adding further technical devices to the PV systems as means of automatically manage their energy loads (such as an automatic load shifting and a battery storage) supported self-consumption of the PV-generated energy but, importantly, did not reduce their overall energy consumption (Wittenberg and Matthies, 2016). Similarly, the recent study of Hargreaves et al. (2018) concerning the role of Smart Home technologies (SHTs)[10] in reducing energy use, without compromising comfort, showed no evidence of substantial reduction in energy use. Significantly, several inhabitants in this study stated that SHTs led to increase their energy consumption, by creating new forms of energy demand (e.g. pre-warming rooms, normalising or even raising energy-intensive expectations).

The above studies show that *active load-matching* could potentially be more effective than the *automated energy balancing* afforded by technologies in some cases, when

10 SHTs generally refers to “residence[s] equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, access or controlled, and provide services that respond to the needs of [their] inhabitants”. BALTA-OZKAN, N., DAVIDSON, R., BICKET, M. & WHITMARSH, L. 2013. Social barriers to the adoption of smart homes. Energy policy, 63, 363-374.

it comes to changing inhabitants' attitudes and practices, and thus reducing energy consumption overall. Hondo and Baba, 2010, for example, found that inhabitants' overall energy consumption reduction was higher for those who were aware of their PV system and energy generation and consumption patterns than for those who were not. This is because inhabitants actively engaged with understanding how much energy they are using, and carefully adapt their practices to reduce peak demand use of grid energy and use PV energy instead. However, this requires an appropriate feedback system to improve understanding (discussed in the next section), and for new habits and routines of energy consumption to be embedded in their wider socio-material and cultural context.

Although energy efficiency measures at the building level have a great potential in reducing CO_2 emissions in housing (Ratti et al., 2005), energy can also be stored, exchanged and balanced on the higher level (the whole grid system) (Alberto Fichera et al., 2017). Distributed Energy Systems (DESs), as a key strategy for optimising the grid, based on renewable sources have gained a particular attention in countries such as the Finland, Netherlands and Denmark, which place emphasis on balancing the grid from a variety of sources including PV systems using a higher level system perspective to help tackle peak demand issues, thus reducing energy costs and carbon emissions (Kok et al., 2012, Akbari et al., 2014, Lühn, 2018). Moreover, the use of the latter system can achieve double advantages: to achieve energy self-sufficiency by maximising PV self-consumption and to *distribute* the excess of produced energy and reduce the grid feed-in as a result (Alanne and Saari, 2006, Lühn, 2018). However, to date there has been very limited provisioning of technologies and strategies at this higher system level to tackle the PV related peak demand issue in the UK (Kok et al., 2012). This means that empowering inhabitants to actively match their energy loads is still an effective approach for managing energy demand in the UK PV homes compared to a high level system perspective at the moment, until the higher level technologies are installed.

2.6.2: Active load matching via feedback

Active load matching for tackling peak demand issues is often assumed to be largely improved through the provisioning of appropriate energy monitoring and feedback technologies. Feedback technologies can empower inhabitants to monitor their energy consumption and to target energy and carbon savings by bringing habitual behaviour and its context to conscious, thus enabling them to make choices about their energy consumption and facilitating behavioural changes (Nilson and Hayes, 1981, Strengers, 2013, Wilhite and Ling, 1995, Hargreaves et al., 2010, Wittenberg et al., 2018, Buchanan et al., 2014, Gupta et al., 2018). This process is illustrated by Wilhite and Ling (1995) as a 'causal link', where:

> "Increased feedback → Increase in awareness or knowledge → Changes in energy-use behaviour → Decrease in consumption" (p: 150)

An earlier study in energy consumption and feedback has claimed that providing 'direct energy feedback' systems, such as smart-metering, could be tools for sustained demand reduction (Darby, 2006). This was empirically proved by subsequent energy consumption studies which found that an overall energy reduction ranged between 5–20% if inhabitants were provided with appropriate feedback technologies to reduce or shift their energy consumption in response to energy generation and network constraints (Darby, 2006, Karlin et al., 2015, Fischer, 2008, Faruqui et al., 2010). A recent study in China has also demonstrated that homes with In Home Display (IHDs) produced around 9.1% reduction in monthly electricity consumption and about 11.0% cut off in monthly electricity bills compared to homes without IHDs (Zhang et al., 2019).

However, this assumed 'causal link' is criticised by many sociotechnical studies, due to the differences in the technical, socio-economic and cultural contexts of the inhabitants in which the feedback technologies are introduced, influencing therefore, the levels of their engagement with energy feedback technologies and the various ways in which these technologies were introduced (Buchanan et al., 2018, Westskog and Winther, 2015, Abrahamse et al., 2018, Darby, 2018, Gram-Hanssen and Darby, 2018, Darby, 2010). One study, interested in examining smart metering technology in Austria, for example, reported a smaller reduction in electricity consumption of between 1.5 and 4% (Schleich et al., 2013). Other studies found that even if feedback was successful in improving internalised knowledge and awareness of inhabitants' energy consumption, this might not necessarily translate into behavioural changes (Buchanan et al., 2015, Friis and Christensen, 2016), particularly the "seemingly non-negotiable practices which vary substantially between households" (Strangers, 2013: 81). This is due to its explicit focus feedback on energy, which only enable "a limited suite of 'actions' that constitute 'moments' in a practice … rather than fundamentally reconfiguring practice itself" (ibid: 82), where practices are habitually associated with socially conditioned purposes, as Gram-Hanssen (2014) illustrated “When you are cooking, the goal is to serve a dinner and not to save energy”.

Moreover, energy feedback technologies, in some cases, can also increase the energy consumption practices of inhabitants. For example, the study of Strangers (2011) found that the provision of green light indicator in an In Home Display (IHD) (indicating low energy consumption) has driven many inhabitants to increase their use of a specific activity such as using the dishwasher, as one inhabitant stated in the interview (conducted by the latter author): “I was always worried about using the dryer so much, but I figure it doesn’t make it scream red so it’s OK” (p: 2140). This is one of the rebound effects[11] of using feedback technologies. Another form of negative impact of feedback technologies is the establishment of ‘normal’ benchmark of consumption, which discourage inhabitants to reduce their energy consumption below this benchmark (Hargreaves et al., 2013).

Feedback can be provided at three main levels: individual, comparative and community. Individual feedback is specific to a home or an individual energy consumption, whereas community feedback is often aggregated. Comparative feedback allows individual feedback to be shared in a community such as using social media to share energy data with friends or neighbours to stimulate individual energy consumption reductions (Petkov et al., 2011). All these levels are significant and worth examining in this thesis due to focusing on low carbon community housing case studies. More significantly, feedback technologies not only enable users to evaluate their past behaviour (reflection-on-action), but more significantly, enable the analysis of behaviour as it occurs (reflection-in-action) (Schön, 1988), which can be very effective in relation to energy consumption through the provisioning of direct continuous feedback (Ehrhardt-Martinez et al., 2010) via effective policy agendas.

There is not yet an agreement about whether feedback technologies will effectively support energy demand reduction in households (Pullinger et al., 2014). A key UK policy measure and intervention for improving energy saving and effective low carbon transition was the introduction of Smart Meter Implementation Programme (SMIP) in

11 Rebound effect refers to energy practices where energy “savings are frequently found, in practice, to be less than those predicted in calculations” GALVIN, R. 2014. Making the ‘rebound effect’ more useful for performance evaluation of thermal retrofits of existing homes: Defining the ‘energy savings deficit’ and the ‘energy performance gap’. Energy and Buildings, 69, 515-524.

September 2013. This programme aims to installs a free IHD – a visible face of smart meters each home – in each home by 2020, as a mean to provide a real-time energy feedback for the consumer in aim to actively manage their energy demand and to reduce their overall energy consumption (DECC, 2016). This programme, however, has been criticized for its failure to achieve the projected energy consumption reductions in homes (5-15%), which is now anticipated to be only about 1-3% (Sovacool et al., 2017). By contrast, in the Danish case, energy feedback technologies have not been included, as policy makers report "it is not believed that such feedback will have any great effect on flexibility" (Schick and Gad, 2015: 55), due to the lack of evidence that it can promote energy savings (Buchanan et al., 2015). Instead they are implementing other measures (e.g. Distributed Energy Systems) for improving energy demand management as discussed in the previous section.

These contradictions in energy management strategies have led to suggesting other ways for improving energy saving practices which go beyond the conventional approaches to energy feedback which have a quite narrow understanding of households' everyday practices (Hargreaves, 2018). A key approach places emphasis on developing effective interventions and polices for shaping whole energy consumption practices in homes, and its *meaning* for inhabitants, rather than merely introducing new feedback technologies to change individuals' energy consumption practices (Wittenberg et al., 2018, Rosalyn et al., 2018). This approach also suggests examining how "evaluations of and learning about energy feedback interventions are themselves fed-back into policy and decision-making" (Hargreaves, 2018: 336). However, this require effective networks of multiple actors to achieve successful two-way translation.

Based on the discussion above, the focus in this thesis is on how the introduction of feedback technologies and its meanings, via the various actors (e.g. policy makers, designers, installers), can led to new dynamics and practices for inhabitants to manage their energy loads. In other words, how these technologies have been 'domesticated' (Hirsch and silverstone, 2003). Effective energy transition, therefore, is not only subject to inhabitants' engagement with feedback technologies and the benefits of their engagement, but also to how these technologies are perceived, designed and installed by various actors including the policy makers (Wilson et al., 2017). This means developing new roles for both inhabitants and other actors in order to realise the potential role and value of energy feedback in future energy transition.

In terms of the materiality and design of feedback technologies, various aspects that influence feedback effectiveness and inhabitants' engagement to reduce their energy consumption are discussed by (Fischer, 2008). These include: content (e.g. sign, comparison and level of detail), timing, modality, frequency, duration, and aesthetic. Modality refers to the type of feedback (e.g. visual, auditory and tactile) which needs to be decided in terms of the amount of detail that needs to be communicated to inhabitants. Visual feedback can also be more effective than other forms of feedback in this regard (Hoggan et al., 2010). Visual design and the aesthetic of a feedback technology can significantly define an individual acceptance and engagement towards a design (Tractinsky et al., 2000). Inhabitants can feel more positive towards an aesthetically pleasing intervention and can be highly inclined to persevere in using it (Hermsen et al., 2016). However, this is not always happening for various reasons discussed next.

2.6.3 Aesthetics

Aesthetics is generally conceived by the naturalistic approach as "a normative process that enables agents to enhance their interactions with physical and socio-cultural environments" (Xenakis and Arnellos, 2014: 1), but definitions vary. The term *aesthetic* was first introduced by Alexander Baumgarten as "taste or sense of beauty of art – the good and bad test which means perception by means of the senses" (Budd, 1998). Dewey (1980: 16), move from 'beauty' to a "drama in which action, feeling and meaning are one" in a practice context in which it is perceived. According to Dewey, *aesthetic* cannot be found in the objects *per se*. Instead, it can be understood through the engagement with these objects in which deep feelings of fulfilment that arise from the engagement are developed to the point where these objects are regarded as aesthetic. Xenakis and Arnellos (2014: 2) further argue that "there is no such thing as an aesthetic object per se, but it is a particular interaction that might have an aesthetic dimension or not". They associated the emergence of feelings with the bodily and behavioural changes during the engagement that promotes the potential interest in everyday objects.

Other studies attached aesthetics to the *sensory* perception of the recipients. Fitch, for example states that "The aesthetic enjoyment of an actual building (as opposed to a mere photograph of it) is not exclusively a matter of vision, but of *total sensory perception*. Thus, to be truly satisfactory (that is, to be truly beautiful), a building must meet the demands of all the senses, not just those of vision alone" (Fitch, 1961: 11, italics original). Similarly, Hekkert (2006: 159) describes aesthetics as a "pleasure attained from sensory perception" which derives from patterns of features that are beneficial to the adapted function of the sensory systems, such as hearing, seeing, smelling, testing, touching, and thinking.

Other researchers have associated positive 'usability' with positive aesthetics (Stevenson et al., 2013, Tractinsky et al., 2000). An early study conducted in Japan, found a surprisingly a high relationship between users' understanding of an interface's aesthetics and their perception of the apparent ease of use (kurosu and Kashimura, 1995). The empirical study of Tractinsky et al. (2000), for instance, found that post-perception of a system usability was affected by the interface's aesthetics rather than by the actual usability of the system – a significant point that need to be examined in relation to PV appliances' design and aesthetic.

Further studies examine aesthetics of objects in relation to the *emotional* responses of the users (Chapman, 2005, Walker, 2006), discussing the role of cultural norms (e.g. cleanliness, fashion, religion), cultural meanings and values, and traditions in empowering the emotional tie between a user and the object, and improving the object's aesthetic over time, which can also help to sustain a positive practice. Walker claims that "product aesthetics are often reduced to the superficial styling of an outer casing that gives the impression of newness and progress" (ibid: 142) resulting in a "lack of understanding and devaluing of material culture" (p. 53). Similarly, Chapman (2005: 76) discusses different ways to create an *emotionally* rich interaction between objects and their users through designing "cherishable"[12] interfaces, which again can help to sustain engagement and practices.

More specifically, other studies discuss the specific aesthetic aspects of the PV appliances in relation to their physical environment. Tsoutsos et al. (2005), for example, found that the aesthetic impact of solar panels was negative in historic buildings and buildings with cultural values, while it was positive in the new modern buildings if the solar elements are used as architectural elements in attractive and visible ways rather than attaching them involuntary to the buildings, which led to many clients being reluctant to install PV systems in their new or retrofitting homes. Building

[12] Cherishibility is a "powerful signifier of an object capacity to be cherished, loved, and cared for by whatever means … including unpredictable, symbolic, sentimental, adaptive, enduring, personal and dependent". CHAPMAN, J. 2005. *Emotionally Durable Design: Objects. Experiences & Empathy,* UK, Earthscan.

Integrated Photovoltaic (BIPV) systems – the integration of photovoltaics into the roof and facade of building envelope – was thus developed to satisfy both aesthetics, a major concern of many clients, and technical architecture constraints e.g. to be used in facades, and skylights where traditional solar modules cannot be installed (Jelle et al., 2012, Hestnes, 1999, Ballif et al., 2018). However, BIPV systems can largely increase the cost of the building due to the high cost of the panels and labour charges, as well as lower the efficiency as BIPV modules normally are made of thin film which have lower efficiency. Another disadvantage of BIPV concerns the difficulty and expense to maintain and change the panels if damage occurs (Shukla et al., 2016). BIPVs as photovoltaic solar cell glazing products can also be provided in different colours, transparencies and semi transparencies which can make many different aesthetically pleasing results possible, thus, providing a great variety of options for windows, facades and roofs (Shukla et al., 2016). However, an architects perception of BIPV is often influenced by aesthetically unappealing PV installations due to a lack of knowledge and failing to view PV as a true construction material, and also due to codes and standards which do not take adequate account of BIPV systems (Ballif et al., 2018) – a significant gap in architectural profession and education.

Another study claims that the engagement preferences of inhabitants for joyful and aesthetically pleasant interfaces might be thwarted by the architecture of the homes (Winther and Bell, 2018). This empirical study found that the IHD device, which requires an electricity socket to power the display, was placed in the living room due to the insufficient provision of power sockets on the kitchen benches (with the kitchen being the most frequently used room by the inhabitants, and therefore more appropriate).

The choice of PV systems and appliances, and their location in homes by professionals, therefore, needs to be critically questioned and discussed in relation to inhabitants' subsequent practices. Aesthetics will be examined and discussed in detail in section 9.6 in relation to both professionals and inhabitants' engagements and practices of PV technologies and other monitoring devices that provides direct feedback technologies.

2.7 PV provisioning and practices: the implementation gap

Having established the literature on PV and renewable energy approaches towards low carbon housing, this section investigates the contribution of previous studies in terms of the thesis objectives related to PV provisioning, design and inhabitants' practices, and their subsequent impact on energy use and CO_2 emissions in low carbon housing. This is to understand how the PV system is governed by the different provisioning actors and introduced to the inhabitants, how inhabitants influence the design through their participation in the PV provisioning process, and whether this improves their occupancy practices and/or reduces the implementation gap.

In an early survey of 12 low-energy solar houses around the world to describe how consumer behaviour influences energy consumption, Mathieson (1991) concluded that the discrepancies between the designed energy savings by experts and the higher levels of actual consumption was largely due to the inhabitants. He founded that technical calculations alone cannot predict the energy use of a PV inhabitant and highlighted a critical need to explain very thoroughly to users how their building behaves, when they first move in.

The inhabitants' practices of their domestic PV systems are another key focus in previous studies. For example, one study investigated the influence of PV installation in Off-grid housing on changing the energy practices of inhabitants (Moore, 1991). They found that inhabitants' energy consumption reduced dramatically when they installed PV systems, because they had to adapt their energy consumption to the production of a 'limited electricity supply' from their PV systems. By contrast, an empirical study of 91 On-grid PV systems found no change at all in the energy consumption practices of 55% of inhabitants', while 34% developed small energy savings, and only 8% highlighted large energy savings after the installation of their PV system installation (Keirstead, 2007). However, this study also concluded that solar photovoltaic (PV) technology provides a low carbon energy supply and a change in the energy consumption practice of UK households when they engaged with their PV systems (ibid). Another key argument in Keirstead's study concerns the positive influences of energy monitoring technologies and polices (e.g. FIT) on driving energy consumption practice changes. This shows the significant role of government incentives (FIT) and the specific affordances delivered by the different PV provisioning actors, in improving energy efficiency and managing energy loads by inhabitants - a point that will be carefully investigated later on in this thesis. This discrepancy in inhabitants' energy consumption practices before and after PV installation was also found in other countries (e.g. Austria, Germany). In an Austrian government programme to install 200kW grid-connected PV systems, the inhabitants with high energy use tended to slightly reduce their overall energy consumption after PV installation, while those with a low original energy use tended to slightly increase their consumption (Haas et al., 1999). This shows that a financial incentive alone is not enough to promote energy saving; PV provisioning actors also need to provide inhabitants with feedback systems to enable them to actively understand and manage their personal energy use overall, to potentially save energy and money.

The energy consumption and generation of nine PV-equipped social housing in the South of England were monitored to understand the impact of installing PV technology on energy consumption practices by inhabitants (Bahaj and James, 2007). They found that among houses with similar layout and features, the energy consumption levels varied in some cases up to three times across the inhabitants. This is attributed to the differences in inhabitants' practices of using energy. They also found that load matching practice among inhabitants was limited despite financial incentives and the visibility of the PV affordances. They concluded that educating inhabitants how to use their PV systems efficiently was the key driver to reduce the energy consumption, particularly, among high-energy usage inhabitants. However, the effects of initial training only lasted for a short time, highlighting the need for new agencies to ensure long-term and continuous user education programmes. The role of different PV policies in incentivising inhabitants to engage with the wider energy system after installing their PV system revealed that the FIT was the principal policy actor that encouraged more energy-efficient practices, due to financial savings whereas other policy actors (e.g. size limitation of the PV system according to prior energy consumption) increased energy consumption before and after PV installation (Schelly, 2014b, Bahaj and James, 2007).

In a different empirical UK study on photovoltaic systems (29 in depth inhabitant interviews) the energy consumption reduction and load shifting (i.e. switching demand to times of generation) was evident amongst inhabitants that had actively chose to install PV systems and participated in PV provisioning governance with other actors (e.g. installers), as opposed to having it installed through a local authority project without their interventions and participation (e.g. as in social housing for rental) (Dobbyn and Thomas, 2005). The same study found that the second group of inhabitants was only likely to adopt energy-saving practices if they were properly introduced to the system in terms of affordances provided in the appliances and given an explanation about how to engage with these affordances (information packs or manuals). However, the study did not discuss the detailed aspects of inhabitants' governance of their system design and integration into homes, and the role of their governance in terms of developing their understanding of the system affordances and consequently improving their PV and energy practice. This is due to the study focusing on the operational side of the domestic PV system rather than investigating the actual governance of inhabitants in the PV provisioning network.

A study interested in examining how collective and self-energy management, through the mean of changing energy consumption behaviour, can lead to well-adapted energy consumption patterns for a multi-users PV system in a village in Cuba with the dynamic of energy generation (Jenny et al., 2006). The study has found that the village inhabitants have developed new rules and agreements to collectively adapt their total energy consumption with what have been generated from their community PV systems. These self-imposed rules were organised by the mean of well-informed community, monitoring system and generating appropriate figures for energy generation and consumption patterns for each house as a collective feedback. The shared use of appliances and energy use rules, beside the use of energy saving appliances as another community rule, have led to a good adaptation to the dynamics of energy generation which mainly comes from changing their energy consumption behaviour, reducing the total energy consumption as a result. The finding also showed that by engaging with a powerful monitoring process and the production of the appropriate figures for energy generation and use patterns, rules for adequate energy consumption were developed more accurately (Jenny et al., 2006). In regards to improving self-consumption, the study of (Luthander et al., 2015) has discussed. The latter study discussed two key approaches for improving inhabitants' self-consumption: technical solution such as battery storage systems for balancing the grid and behavioural approach by inhabitants' actively matching their energy loads.

In general, all the above studies have mainly focused on inhabitants' practices of using energy in their homes in order to interpret the discrepancies in inhabitants' overall energy consumption. These studies introduced and suggested possible methods to improve the system affordances and the potential agencies to increase inhabitants' engagement. However, they appear to contradict the claim that just having PV system installed will inevitably lead to a reduction an energy consumption. This indicates that simply living in a house equipped with PV system may not be enough to drive energy behavioural changes - another significant point that will be investigated in this thesis in relation to the provisioning side of the system. Moreover, understanding the detailed inhabitants' practice in relation to their PV appliances in terms of affordance offered and the arrangements of the system inside the house has not been sufficiently investigated because the focus in all the studies above has been on the effect of the PV system and feedback itself, rather than the effect of design and construction of the feedback and PV system itself.

From the PV design viewpoint, the study of Hondo and Baba (2010) attempts to understand whether or not the affordance offered by the PV appliances influences inhabitants' capacity to actively match their energy loads. The study argued that providing PV inhabitants with action possibilities (Gibson's affordance) to visualise the energy efficiency of their home (by visibly connecting energy production and consumption) would significantly help them to manage their energy loads. Inhabitants' awareness also came from their collective PV and energy performance governance through communication with other PV owners in a PV networks or in the neighbourhood. The latter *community* feedback approach is understood as a significant means for inspiring competition to reduce individual consumption (Petkov, et al., 2011). By contrast, another PV study shifts the investigation from largely focusing on the design of PV appliances (affordances) to exploring the usability of PV display screens and their affordances (Darby, 2006). This study recognised the importance of designing user-friendly displays by the industry in order to help PV inhabitants to understand their energy generation and consumption patterns. However, little work has been done to examine the factors that make an energy display screen usable or user-friendly. A recent housing case study in the UK found that only 7% of inhabitants were actually aware of their PV inverter affordances, while the highest understanding related to the PV meter was still only for 30% of inhabitants in one housing development (Baborska-Narozny et al., 2016). These low scores are attributed to lack of inhabitant understanding of the purpose of their controls and other problems related to the usability of their appliances. A key limitation of this case study, however, is that it was based on only one housing case study which is hard to generalise from.

Research on understanding inhabitants' governance in terms of making a decision to install PV system has also attempted to understand the diffusion of PV technologies from a sociotechnical perspective, in order to cover the limitation of techno-economic approach, through the analysis of social factors (Abi Ghanem, 2008). The study by Abi Ghanem showed how a project manager of the PV installation process 'writes' the technology according to his knowledge and expectation regarding the inhabitants and how the inhabitants in turn 'read' the technology. What is missing in this analysis is any understanding of the human governance and agency role of other actors (both human and non-human) in the PV provisioning network, and the role of the PV governance network in changing these agencies and outcomes. Moreover, the role of an inhabitant's governance, when they become an actor in the provisioning of the PV system in influencing the final design has not been investigated, which is a key objective in this thesis. Another study used interviews with key actors to compare two approaches of PV provisioning in Austrian Citizen Participation Initiatives (CPIs) (market-based approach (profit-oriented) and grassroots initiatives-based approach (civil society)), in relation to the three key processes needed for development from innovation niche to mass market: actor network formation, learning and expectations management (Hatzl et al., 2016). The study shows that the market-based approach exhibits a wider and more stable actor network including business development policies and more professional learning processes. By contrast, the grassroots approach consists of a smaller actor-network of local actors and informal learning and the development of shared expectations. Even though the grassroots approach was more successful than the market-based approach, in terms of translating their local innovation niches into the mainstream regime, the study highlights that both approaches still performed the translation of niche idea relatively ineffectively. This is due to lack of intermediary actors to institutionalise knowledge and resources. In general, the study focuses more on the translation of niche outcomes rather than examining the links between the various actors in a network when governing the PV design and integration into homes.

Other studies identify two sets of different dependencies that influence inhabitants' decision to adopt PV systems: subjective and objective. The subjective dependencies include: environmental awareness (Haas et al., 1999, Korcaj et al., 2015, Leenheer et al., 2011), technological interest (Haas et al., 1999, Schelly, 2014b, Schelly, 2014a), values, perceptions, and learning (Faiers, 2009), and being a self-sufficiency energy household (to be to a certain degree independent from grid electricity) (Korcaj et al., 2015). The objective dependencies include: the existence of a social network (Jager, 2006, Faiers, 2009) and peer effects (Palm, 2016). While financial aspects were highlighted as a key objective dependency in some studies (Haas et al., 1999, Korcaj et al., 2015), others did not mention it as a factor (Jager, 2006). By contrast, further studies highlighted different dependencies that prevent the adoption of solar power technologies by inhabitants, such as aesthetics, cost, inhabitants' low levels of knowledge in terms PV installation and operation practices (Faiers, 2009, Caird et al., 2008). However, all these studies failed to discuss the influence of these many dependencies on inhabitants' actual practice of the system, and which dependency has greater influence than others. Investigating this forgotten aspect might well reveal new dimensions regarding PV practice, and forms another part of this thesis.

From another perspective, the recent study of Boyd and Schweber (2018) discusses the provisioning of PV systems within the whole building construction process in three non-domestic buildings in the UK. Using a social construction of technology (SCOT) analysis, the study aims to understand why energy performance is not achieved as designed. The finding shows that the dominants contractual arrangements and highly fragmented ways of working, and the unrelated institutional artefacts (planning requirement and schedules), which privilege certain criteria over others, contribute to the poor location and integration of expertise and the consequences of decisions made under this regime. This often resulted in unintended consequences for the energy performance by overlooking the energy agenda inherent in the design and construction process. For example, in order to meet the planning requirements, a redesigned building form in one case reduced the design roof area for PV systems, making it difficult to meet the original energy performance target. However, crucially, the study did not discuss the role and level of integration between the building professionals, to help keep energy performance on the agenda.

Another recent study discusses the role of the environmental motivation of PV inhabitants in influencing their energy saving practices when engaging with their PV system using the modified Norm Activation Model (mNAM) and online questionnaire method with 425 PV households before and after 2012, when Grid parity was introduced in Germany (Wittenberg et al., 2018). The NAM model assumes that personal norm (PN) is the principal construct of human behaviour (Schwartz, 1977) (e.g. energy saving behaviour). The study shows that external factors (e.g., incentives for self-consumption) had a big impact on the internal motivation (impact of PN) of PV inhabitants. For example, the PN was more significant in encouraging energy saving practices for inhabitants that had installed PV system after 2012, while monitoring was a more powerful role for inhabitants that had installed PV system before 2012. This is due to the former inhabitants becoming interested in the financial benefits that they could achieve from introducing Grid parity, which financially was less attractive before 2012. This suggests that external factors can significantly change inhabitants' energy saving practices. The study further discussed the impact of technology motivation (the specific context of technology use) on normative aspects of environmental motivation. The study claims that the affinity of a technology has a greater impact on energy saving practices and overall energy consumption if its focus is on managing energy consumption, rather than focusing only on the PV system and its appliances. The role of other external factors (e.g. FIT, PV installation grants) in influencing energy saving practices, and the role of various PV provisioning actors (e.g. professionals, polices, etc.) in inscribing the affinity of a PV technology and its environmental meaning for inhabitants, were not discussed in this study, and consequently will be explored in this thesis.

In summary, research to date has focused on recognising the impact of the PV system on changing inhabitants' practices in relation to using energy and overall energy outcomes. However, there is insufficient knowledge about how inhabitants engage with their PV appliances through their actual practice, and how the affordances offered in the PV appliances are understood by their inhabitants and determine their practice. In terms of the provisioning side of PV system, there are also very few studies that discuss the role of the various PV provisioning actors, including inhabitants in terms of community governance, to inform the system design, affordances and integration into homes, and their subsequent influence on shaping the types of inhabitants' interaction with the system.

2.8 Sub conclusion

Failure to address the environmental problems associated with the *provision* and *practice* of energy efficient technologies by inhabitants has resulted in a significant performance gap between the designed energy saving and reality in new housing. To address this gap, individual and collective governance between multilevel actors, and the consideration of governance itself, is identified as a key concept in sustainable development beside social, economic and environmental concepts when governing environmental problems. Such a governance approach potentially enables inhabitants to govern their PV social, economic and technical context, and could produce solutions that respond to their needs and capacities. Inhabitants' governance of their technology provisioning process could also help to develop their know-how and build a realistic expectation about their domestic technologies, thus, potentially improving inhabitants' practices in relation to their domestic technologies and address the implementation gap in reality.

PV systems were selected as a focus for study in this thesis for two reasons stemming from this Chapter: firstly, they generate significant renewable energy and appear to sometime drive energy consumption practice changes when inhabitants install these systems and interact with them. Secondly, this technology represents the highest percentage of renewable energy installations both in the UK and globally, and the most preferable for inhabitants. This chapter also showed that active load matching (active engagement of inhabitants with their PV and energy monitoring appliances to match their energy loads) can sometimes be more effective than the automated energy balancing offered by technologies if an overall energy consumption reduction is to be achieved to tackle the peak demand issues in the UK homes, depending on a variety of factors and contexts. This is due to empowering inhabitants to be more literate of their energy generation and consumption patterns when they engaged with their PV and energy monitoring technologies. However, this requires an appropriate, meaning, context, design, integration and aesthetic of feedback and monitoring technologies to stimulate effective engagement by inhabitants. Previous PV and energy efficiency studies, related to technical, behavioural and contextual approaches, have focussed largely on the occupancy stage of PV systems concerning inhabitants and not the provisioning stage, which is a significant research gap identified in the PV literature. The introduction in this thesis of a governance approach provides an opportunity to understand the provisioning side of PV systems (the *production* of occupancy effects), particularly the role of various PV provisioning actors impacting on inhabitants' practices when provision actors govern the system design, affordance, and integration into homes, which is also underexplored in the literature. The next chapter will introduce and discuss the theoretical basis of the research methodology.

CHAPTER THREE: A THEORETICAL APPROACH TO UNDERSTANDING PV SYSTEMS IN HOUSING

3.1 Introduction

In this chapter, a theoretical rationale for this thesis will be provided by positioning it within the broader literature associated with two theories, Actor Network Theory (ANT) and Practice theory and the need to augment these two theories with a more detailed approach for examining technologies using Affordance theory to answer the research question in relation to governance. Key principles of each theory will be discussed, their theoretical and implications, and limitations in terms of informing the research methodology.

3.2 Sociotechnical approach

Hitchcock (1993) argued that energy consumption practices are a complex social and technical phenomenon and must be viewed from a broad sociotechnical context. This is particularly significant for energy efficiency studies, which aim to understand the relationships between people and technology in the development process (Killip, 2013), to follow the actors involved in the technological construction process who influence the co-construction between the technology and user in reality (Killip, 2013, Latour, 2005). Such an approach requires an interdisciplinary research agenda in which different theories, methods and perspectives are used as lenses to provide a more holistic outcome (Bruce et al., 2004). This entails developing a qualitative research agenda in the analysis of a technology design and implementation to "bridge the gap between the technical and social dimensions of building energy use" (Guy, 2004: 691). This is done by engaging with various qualitative research methods including: interview, ethnographic, mapping and document analysis (Bowden, 1995).

Given that the main aim of this thesis is to understand the roles played by various actors (both human and non-human) and inhabitants practices that relate to the provisioning and occupancy practices related to PV systems in a society, a qualitative approach is chosen as a powerful research strategy for data collection and analysis (Guy, 2004). Moreover, qualitative research in this thesis will use the case study approach, with selected housing projects centred on the PV technology installed in the homes and the various actors associated with the installation and occupancy practices. This research strategy provides the researcher with a powerful framework to collect data using different methods which will be described in chapter four. This chapter introduces the theoretical approaches adopted in this study as three lenses to focus the research perspective and design: Actor Network Theory (ANT), Practice theory and Affordance theories.

3.2.1 Actor Network Theory (ANT)

3.2.1.1 Introduction

Law (1992) and Latour (2005) state that ANT is about understanding how actors (both human and non-human) are enrolled in networks to achieve particular goals (e.g. the provisioning and occupancy practices of PV systems), and that both objects and people can influence actions and decisions. ANT is not about the actors per se to be studied, but about examining the network of connections being built and the actions taking place in a specific situation, and then describing the agency as a whole network (Latour, 2005). This theory therefore, "refuses to accept technology and society as ontologically distinct categories and insists on considering sociotechnology as a dynamic co-production that only makes sense in a relational perspective" (Fallan, 2008: 82).

3.2.1.2 Core principles of ANT

The core principles of ANT originated from a study by Callon (1986) and (Latour, 1986) are: generalised symmetry, agnosticism and free association.

3.2.1.2.1 Generalised Symmetry

The principle idea of generalised symmetry is the removal of the human from the centre of agency that is favoured in sociological studies (Strangers and Maller, 2018), and is described by Latour (1986) as *flat ontology.* ANT gives technology 'objects' the same value as 'people' when investigating a social phenomenon as Law (1992: 383) explains "to say that there is no fundamental difference between people and objects is an analytical stance, not an ethical position". Accordingly, ANT explores the co-evolution of technology and society rooted in the sociology of technology and examines actors (both human and non-human) in their field instead of people within a context (Latour, 2005). An actor, therefore, can be either agency as "something that acts or to which activity is granted by another …" or it "… can literally be anything, provided it is granted to be the source of action…" (Latour, 1999b: 180 and 214). The key methodological implication of generalised symmetry is that the "same type of analysis should be made for all components in a system whether these components are human or not" (Law, 1987: 132). This entails two core ideas: firstly, non-human actors can shape the world as much as human actors can (Maller, 2018b). This provides a space for the non-human materials, technologies and polices, and their influence in the network to be understood in the provisioning and use of PV systems (Gram-Hanssen, 2018, Fallan, 2008). Secondly, the effects of network means that "actors take their agency and qualities as a result of their relations with other actors in a network and have no inherent agency on their own" (Wong, 2016: 107). In this light, social factors, such as culture and values cannot solely be investigated as references to explain sociotechnical phenomena, because they are themselves formed by network of social and material entities (Wong, 2016). The study of Bevan and Lu (2012) investigated the explicit role of policy, regulations, and standards as non-human actors in informing the adoption of LZC technologies in new housing in the UK. Shove et al. (2018), likewise, examine the role of infrastructures (e.g. road networks and electricity grids) in shaping energy consumption practice across space and time.

3.2.1.2.2 Agnosticism

The principle of 'Agnosticism' suggests that the observer of the actor network needs to be "…impartial towards the scientific and technological arguments used by the protagonists" and this impartiality needs to be extended towards the actors' understanding of the social environment that surrounding them (Callon, 1986: 200). According to this principle, the observer needs to "…*start* with what and how questions instead of making assumptions about who is acting on what" (Wong, 2016: 109). In terms of this thesis, the role of the researcher is to focus on understanding how the PV technology as well as the social and cultural aspects have all been understood by the actors. This is in order to open up the analysis framework to a wider range of network of human and non-human associations that constitute the research problem.

3.2.1.2.3 Free association

According to the principle of free association, all the prior assumptions in the relationships between human and non-human actors should be abandoned (Callon, 1986). This position allows the observer to freely follow the actors and their association in the network (Latour, 1987). Having zero assumptions allows the researcher to "…identify the manner in which these [actors] define and associate the different elements by which they build and explain their world, whether it be social or natural" (Callon, 1986: 201).

What is important in this thesis, in relation to these three principles, is the rejection of any prior distinctions between the social and the technical. Judgment is thus reserved without any assumptions at the start in terms of whether the PV influences are coming from human or non-human actors when analysing the actors and their associations in the network (Latour, 2005). This helps the researcher to trace the actors as they move, and to identify the influence they have in the networks of associations. To do so, the researcher needs to consider that he/she does not know the truth, but rather that "actors know what they do and we have to learn from them not only what they do, but how and why they do" (Latour, 1999a: 19). Moreover, the three principles helped this author to design the research strategy and to identify the necessary methods and data collection tools described in chapter four.

Latour used the three key principles of ANT described above to introduce and develop the process of 'translations' within sociotechnical phenomena Latour (1986). The term 'translation' refers to the processes through which actors are related to one another and are transformed in their movement between practices "sociology of translation" (ibid). From this perspective, actors and their actions are different from situation to situation according to their relations with other things and not because of their essential qualities (Gad and Jensen, 2010). This means that the action of an actor is interchangeable and subject to a series of 'transformations', which is a result of the 'translation' of concepts between the various actors who are enrolled in a specific network to achieve a specific goal (Latour, 1986). The concept of translation in ANT is adopted in this thesis as a powerful notion of thinking about interdisciplinary energy research in practice and to argue that entities "change their identity, redraw their boundaries and modify their practice to align more with that of the network" (Wong, 2016: 107). In this sense, "agency is not the intention that people possess, but refers to their capacity in doing these things in the first place" (Giddens, 1986: 9). In a similar way, Ryghaug (2003) has claimed that the concept of energy efficiency in architecture gets "lost in translation" when the various participating actors in a group try to build their networks. This is because, the architects' aesthetic values and actions have shaped their own space between the networks, resulting in the aesthetic values overruling energy efficiency when difficult choices have been made by the actors. This could have important implications for the PV provisioning studied in this thesis.

The notion of translation, therefore, is the initial potential contribution of ANT in this thesis in terms of understanding the relationship between the different participating actors in the specific PV provisioning network, and in the wider networks. It also helps in understanding their agency in influencing the PV selection, installation and demonstration both in terms of the possibility to act, and the role of network in supporting and constraining these possibilities. In other words, participating actors have different agendas and interests which are performed in different situations and negotiations. Their power and tactics decide the '*scripts*' that the technology carries (Fallan, 2008: 81). These 'scripts' in turn define a framework of action comprising the actors and the space within which they are meant to act out inhabitants practices (Akrich, 1992: 208). ANT is thus a very useful approach to investigate the roots, or 'origins' of various problems resulting from inhabitants' engagement with their PV systems by "…following the negotiations between the actors to study the way in which the results of such negotiations are translated into technological form." (Akrich, 1992: 208) and in suggesting solutions. In other words, ANT is useful for *investigating* "…*the traces left behind by moving* actors" (ibid: 208). It also provides a way of thinking about processes of change (e.g. PV provisioning governance and network) through the enabling of successful governance among multiple actors (Killip, 2013).

In terms of the sociology of translation and PV systems, different studies have argued that inhabitants do not interact with their technologies independently; instead, they have been highly influenced by different building professionals, who play a strong role in informing domestic energy consumption (Parag and Janda, 2014, Schweber and Leiringer, 2012). This include architects (Fischer and Guy, 2009), energy efficiency advisors (Owen and Mitchell, 2014), and low carbon technology installers (Rohracher, 2002). One empirical study identified how the PV design and affordance was the result of the project managers' knowledge and expectations in relation to the users when negotiating with other participated actors in the network (Abi Ghanem, 2008). The language of translation also emphasises the role of different actors in enabling the "…uptake of new technologies and changed social practices within the production/consumption nexus." (Moss et al., 2009: 21-22). For example, Keirstead (2007) adopted the notion of translation as a way to understand how the different PV actors (human and non-human), such as the electricity suppliers and the FIT policy, shaped the adoption and diffusion of new sustainable technologies (e.g. PV systems). The notion was also used to understand what role the early PV users (inhabitants as consumers) played in this network in terms of system diffusion, transforming the environmental meaning of PVs to other users, and participating in the technological development process through their strategic niches.

Other studies have investigated the role of professionals in informing the practice of domestic heating installation. When examining the how the selling and installing heat pumps technologies in Scandinavian countries constructed inhabitants' engagement with these technologies, Gram-Hanssen et al. (2017) showed that the meaning and competence of energy-efficiency technologies generally, and heat pumps technologies specifically, were poorly defined and translated to inhabitants by professionals. This resulted in the designed performance target not being achieved. The key policy recommendation in relation to this concern was that professionals' experience and knowledge of a technology needs to be systematically exchanged with inhabitants. To achieve that, knowledge exchange needs to be a part of the regulatory framework, providing routine guidance on how to select, install and explain controls rather than this being individually practiced by installers who are often reliant on learning from peers and obtaining information from manufacturers (Wade et al., 2016).

Another study claimed that both technological strategies and information campaigns fail to acknowledge that end-users' engagement with their domestic heating controls is a result of social actors' practices and transformations, particularly the installer's selection, installation and explanation of the controls to the inhabitants (Wade, 2016). The installers' decision in term of choosing a particular device is highly shaped by their familiarity with a product, the cost and the budget of the end user, the economic and aesthetic priorities of the inhabitants (Munton et al., 2014), and "… their own heuristics of risk and acceptability." (Owen and Mitchell, 2014: 176). For example, (Wade et al., 2016) claim that the installers' have a desire to demonstrate themselves as experts to customers, with an 'expert identity' which makes them reluctant to accept new technologies (e.g. heat pumps, biomass systems) generally or new products specifically, due to their familiarity with a specific technology and product. Her recommendations, in terms of improving the UK's heat strategy, include providing a form of training and learning which allow the installers to build and improve their expert identity and to 'reorient' themselves within wider heat strategies which would help them to choose the most effective products in terms of energy consumption.

Not only does the installers' knowledge determine the type and design of the domestic heating systems, but also they shape inhabitants' practices of domestic heating technologies. In spite of the affordance offered in some devices (e.g. programmers), inhabitants did not interact with them due to the installer asking the inhabitant to leave the system on constant and simply operate it via the thermostat (Wade, 2016). In this example, the installer's assumption in term of inhabitants' interaction with their systems shaped the inhabitants' practice of the system resulting in them solely engaging with their thermostat. This issue of provisioning assumptions will be further investigated in this thesis in relation to PV systems.

While some studies are concerned with the design aspects of central heating controls (e.g. small size of fonts and buttons) (Combe et al., 2012), and inhabitants insufficient understanding of symbols, terminology and abbreviations (Karjalainen, 2007), others have shifted the investigation from the system design to "product resembling software or consumer electronics" (Peffer et al., 2011: 2533). All these were highlighted as problems by inhabitants, particularly old people, which limited their engagement with the controls, providing significant evidence that justifies the need to investigate how and why specific PV appliances and software have been chosen during the design stage of the system. Moreover, empirical evidence indicates that the provision of professional actors to demonstrate home technologies is a very important practice to improve inhabitants knowledge and actions especially during the early stages of learning and use (Stevenson and Rijal, 2010). In order to understand the different roles and capacities of actors in a PV governance network (both provisioning and occupancy stages), the next section discusses Latour (2005) distinction between 'mediator' and 'intermediary' actors.

3.2.1.3 Intermediaries vs Mediators

An intermediary actor is a passive component of an actor network that "transports meaning or force without transformation" and could be anything passing between actors which make no difference to the networks they are part of and just maintains the network (Latour, 2005: 39). Intermediaries are sometimes referred to by Latour as a 'black box' because their outputs are presumed from knowledge of their inputs. In contrast, mediators are active entities within an actor-network because they "transform, translate, distort and modify the meaning of elements they are supposed to carry" (Latour, 2005: 39), as such, "… they render the movement of the social visible to the reader." (Latour, 2005: 128). The outputs of a mediator, thus, cannot be predicted from knowledge of its inputs and might be different in different circumstances due to their *capacity to transform whatever they engage with*.

Other sociotechnical studies also preclude intermediaries from having any independent agency, with their actions only defined by their "*in- betweenness*" rather than as actors in the system, (Moss, 2009: 1481, van Lente et al., 2003, Hodson et al., 2013). Their *priorities* and *performances* are shaped by other social actors (individuals, organisations, institutions, etc.) in order to facilitate relationships between them for a specific goal. Any theorising of the intermediary should therefore account for both the actors which they mediate, and the type of relationships in which both are involved (van der Meulen et al., 2005). The category of intermediaries can also vary depending on the situation, context and their position in relation to other actors. Local government, for example, could be regarded in one context as a governing mediator and in another as an intermediary (Parag and Janda, 2014). This has crucial implications for the findings in the Chapter seven in this thesis.

In ANT intermediaries and mediators as human or non-human actors can greatly affect governance. Some studies, for example, have investigated and described the hidden work of various organisations (individuals or group of people within organisations) showing that their actions are highly significant for the shifting energy governance (Bush et al., 2017, Kivimaa, 2014, Hodson et al., 2013, Kivimaa and Martiskainen, 2018). Other studies have explored the role of various intermediaries in niche nurturing processes (Hargreaves et al., 2013, Kivimaa, 2014). Further studies have focused on examining how non-human intermediaries acted in a network, such as a programme of work (Iles and Yolles, 2002), planning documents and energy models (Rydin, 2013) and Information Technologies (IT) which transmit information from sources to users (Cecez-Kecmanovic and Marjanovic, 2015). Both human and non-human intermediaries can make connections, facilitate relationships between key actors, skills development, provide guidelines and aggregate and enable an exchange of knowledge (Kivimaa, 2014) as part of governance.

Intermediaries become highly significant in achieving low carbon transition in the housing sector when there is limited policy support for zero carbon housing innovation (Martiskainen and Kivimaa, 2017). This is due to the potential of intermediary actors in performing various 'roles' and activities that support environmental transition and innovation (Wittmayer et al., 2017) as their roles and practices are also influenced (enabled or curtailed) by policy changes (Kivimaa and Martiskainen, 2018). Various studies have discussed intermediaries in different layers in relation to Strategic Niche Management (SNM). Seyfang et al. (2014) and Hargreaves et al. (2013) have identified intermediaries that function on the 'Cosmopolitan' niche level (e.g.

intermediary organisations that join up learning from multiple local projects – zero carbon building projects) and reframe it into global transferable standards. Martiskainen and Kivimaa (2017) by contrast, have focused on understanding intermediaries from the perspective of specific niche projects (e.g. the role of environmental intermediaries and champions in advancing energy efficiency during the different stages of a project at a local level). The latter authors in a subsequent study examined intermediaries working at different scales of niches (project, local and cosmopolitan niche intermediaries) in the One Brighton housing case study in England (Kivimaa and Martiskainen, 2017). Similarly, a study concerning UK district heating projects found that both national and local intermediaries could act as different support for niches (Bush et al., 2017). Another study has claimed that the failure to introduce intermediary organisations that enable the production of institutional knowledge weakens the construction of PV niches in Austria (Hatzl et al., 2016). Other organisation intermediary roles have been identified including brokering between parties (networking), finding funding resources and improving learning process by disseminating information from projects (Kivimaa, 2014).

In terms of building construction actors, Fischer and Guy (2009: 2579) argued that architects can perform as a powerful intermediary "between the regulatory requirements and regulators on the one hand, and the design process and its actors on the other hand" to improve the building regulations in the UK towards zero carbon building transition. The local authorities in Denmark, as mediators, have also greatly influenced the polices by enabling a powerful network for the facilitation and dissemination of low energy housing concepts (Holm et al., 2011). A passive house platform in Belgium, as an institutional intermediary, played a significant role in steering and facilitating the innovation journey towards highly energy-efficient buildings (Mlecnik, 2013).

Building professionals, with their mediating functions between the top (government) and the bottom (users) agents, are recognised by policymakers to be intermediaries, or as 'filler' between the two levels, rather than actors who have their own agency[13] and capacity[14] to make changes in energy systems (Fischer and Guy, 2009, Parag

[13] The willingness and ability of actors to make their own free choices LUTZENHISER, L., JANDA, K., KUNKLE, R. & PAYNE, C. 2002. Understanding the response of commercial and institutional organizations to the California energy crisis. The California Energy Commission.

[14] The ability of actors to execute or perform these choices.

and Janda, 2014). However, ethnographic research has shown that those actors who have an interest in promoting low carbon buildings also tend to build their own practices to solve problems (Parag and Janda, 2014, Guy and Shove, 2000, Hill and Lorenz, 2011). They then become active actors in the network as mediators, capable of creating or preventing change in top and down levels, and “are placed in the field on their own right, pre-existing agency, function and agendas” (Parag and Janda, 2014: 105). There is no agreed definition or a common conceptual understanding of what mediators and intermediaries actually are (Fischer and Guy, 2009, Moss, 2009). The thesis, therefore, uses the core definition of Latour as described at the start of this subsection, while *adding* to the definition some extra point for clarification.

According to Latour’s definition, mediators in this thesis ‘*can be both human and non-human actors who are placed in the network on their own right and agenda. Human mediators include all the human actors that have made the key decisions in relation to the system design and integration into homes, and human actors who have actively transformed what they engage with. Non- human mediators include all non-human actors which have actively transformed what they engage with. Intermediaries include both human and non-human actors who transport the governance and meaning of other actors in the network without transformation, and as their roles and agenda are shaped by the other actors in the network’*.

PV actors can perform as mediators by having their own agenda and capacity in a network, or as intermediaries by just maintaining the network and passing on the governance of other bodies. This distinction between intermediaries vs mediators underpins the methodological framework used in this thesis to identify, distinguish and map the way in which intermediaries work and the impact they might have on the governance of PV provisioning actors when acting as mediators in a PV network.

ANT can be additionally adopted as a powerful theoretical lens to explore the role of various mediators and intermediaries in influencing, or impacting, the practices of inhabitants when engaging with their systems and energy efficiency during occupancy, and identifying which key roles and impacts have been sustained from provisioning stage to occupation stage, and why. Moreover, the governance approach being used to answer the research question in this thesis, underlines the importance of actor networks in analysing the specific role of inhabitants when participating in the PV provisioning process with other actors. This is in terms of whether they perform as a mediator by actively participating in the decision-making process and governing their PV systems with other actors, or act as an intermediary, by passively facilitating connection between actors, and have no agency in the network. This helps to analyse and compare the two different roles (mediator vs intermediary) in terms of identifying ways to improve the system design and inhabitants' practices. The active participation of inhabitants allows them a 'space of negotiation' through which the inhabitant practices of PVs are negotiated rather than being 'prescribed' (Murdoch, 1998). The study of Dobbyn and Thomas (2005) in social housing showed the influence of installing PV technology on total energy reduction was greater for active users of PV technology than passive users.

To summarise the ANT discussion so far, the basis for introducing the sociology of translation can provide a novel and unique interpretation of what forms inhabitants' engagement with their PV systems; who is responsible in low carbon housing communities in relation to PV provisioning network; and which mediators and intermediaries are missing in the PV provisioning and occupancy networks to improve the system provision and implementation. However, this powerful starting point for approaching the shaping of inhabitants' engagement and practices remains rather *one* sided, attending to only examining actors' agencies and actions in relation to other actors in the network, rather than seeing them as "independent actors with morality and intentions in a 'play of forces' in which no change through human intervention seems possible" (Gad and Jensen, 2010: 61).

In ANT, there are no predefined characteristics and agency for an actor. This might undermine the role of human intervention to make a change through practices (Watson, 2017). Bourdieu's concept of habitus is an example of how practices can be reproduced and changed through the variation in practitioners' norms and tendencies, which can heavily influence their actions, rather than their actions being formed only through relations (Bourdieu, 1984). Practice theory can *add* this dimension (perceiving the embodied norms and competences of individuals) to the ANT methodological approach (Nicolini, 2017b). This is particularly significant when examining inhabitants' practices in relation to their own PV appliances, in terms of the individual capacity and engagement to improve their practices and routines over time as they continuously learn from enacting a practice.

Additionally, many key ANT studies focus on surprisingly conventional humans (or human organisations) as *powerful* orchestrators of networks of relations. However, this is in tension with the notion of 'generalised symmetry' (empirically taking into account every actor's heterogeneous contribution in a chain of action) as a theoretical proposition and the relationality of ANT in terms of perceiving agency and power as a function of a network rather than actors (Whittle and Spicer, 2008). To deal with this contradiction in ANT, the analysis in this thesis will examine the translation model of power within an actor-network rather than focusing on the diffusion model of power when examining complex issues (Fox, 2000).

Fox neatly summarises Latour (1986) distinction between the translation vs diffusion of power:

> "The former assumes that a successful command issues from a central source through the chain of command, and is implemented. A macro-actor such as a president or manager, representing the will of the state, the people, the organization, speaks and action simply follows. In contrast, the translation model looks at the links in the chain and notes that at each point there is local agency" (ibid: 861)

The following section thus introduces Practice theory which is adopted as the second theoretical lens in this thesis to examine how inhabitants' engagement with their PV appliances when individually govern their PV and energy consumption practices can be varied due to the variation in their intentions, competence and meaning of the system.

3.2.2 Practice theory

3.2.2.1 Introduction

According to the Oxford English Dictionary (OED), the principle definition of practice is '*what people do'*. However, when the concept is used to understand a social phenomenon, it is potentially more complex than this (Hill and Huppe, 2014) and as Schatzki (2001: 11) points out: "there is no unified practice approach". Different studies have formed different definitions for practice which reflect their ontological viewpoint about the nature of the world. Schatzki defines a practice as an "Arrangements of people and the organism, artefacts, and things through which they coexist" (Schatzki et al., 2001: 51). From this perspective, practices are the 'site' of social activity and a combination between social order and individual's action (Schatzki, 2005). Reckwitz, in his definition, focuses on mutual understanding, meaning, norms, practical consciousness and purposes as an entity of practices. He defines practices as "…a routinized way in which bodies are moved, objects are handled, subjects are treated, things are described and the world is understood…a practice is social, as it is a 'type' of behaving and understanding that appears at different locales and at different points of time and is carried out by different body/minds" (Reckwitz, 2002b: 250). Similarly to Reckwitz, Rasche and Chia (2009: 721) define practices "…as a nexus of routinized performances of the body". Both Reckwitz and Schatzki acknowledged the collective aspects of practices. However, the former emphasises individuals as a carrier of practices, while the later focuses on people's doings and sayings held together by certain elements.

Hill and Huppe (2014: 32) define practice as the "actual application or use of an idea, belief or method, as opposed to the theory or principles of it". Shove and colleagues have synthesised the views of Schatzki & Reckwitz (and others) to develop a general definition of practice as "…embodied, materially mediated arrays of human activity centrally organised around shared practical understanding." (Shove et al., 2012). An embodied array means that the form of human activity is interweaved with the character of the human body (ibid). The latter authors aim to re-group the elements holding practices together and add in the role of the material elements of practices in changing social activities. All these definitions emphasise the key aspects of practices, such as materiality, embodiment, knowing and routine (Cox, 2012) rather than distilling the concept of the term 'practice' itself (Gherardi, 2009).

3.2.2.2 Elements of practice

There is no complete agreement on the naming of the elements that link 'sayings and doings' in order to constitute a practice among those working with a practice approach (Gram-Hanssen, 2014a, Jansen, 2014). In his description of a practice as "…a collection of activities that are linked through an array of understandings, rules and 'teleoaffectivities.'" (Schatzki, 2002: xxi emphasis original), Schatzki originally proposed three elements holding practices together: firstly, 'practical understandings', which refers to "knowing what to do, and knowing how to identify and react to something" by practitioners (Schatzki, 2006, Schatzki, 2001). This concerns routinized bodily and mental activities carried out by practitioners and is also related to Bourdieu's 'habitus'[15] (Gram-Hanssen, 2010). Schatzki further argued that a

[15] Habitus is the capital (social, economic and symbolic/cultural) of the individuals (agencies), which consist in a certain context (field) to create practice. BOURDIEU, P. 1984. *Distinction: A Social Critique of the Judgement of Taste, translated by R. Nice,* Oxford, Polity Press.

practical understanding of people decides their ‘agency’ - the ability to freely do one action rather than another (Schatzki, 1997). Secondly, Schatzki represents explicit rules of how to do things as ‘rules and knowledge’, - what is allowed and what is not. However, tacit knowledge or implicit rules are excluded in his definition. He argued that people follow rules, but not at the micro-levels of practice (Schatzki, 1997). Rather, they rely on their habitual and practical consciousness when deciding the right practice to engage with and in what way. For Shove and Pantzar (2005) practice represents both tacit and verbal/theoretical knowledge. They combine both practical understandings and rules (both tacit and verbal/theoretical knowledge) into one element: ‘Competences’. Thirdly, Schatzki defines the *teleo-affective structure,* which represents the meaning or goal orientation of practice in which beliefs, purposes and emotions are the key elements. Warde (2005), Shove and Pantzar (2005) have differently renamed this teleo-affective structure as ‘Engagement’ and ‘Meaning’ respectively.

A fourth element ‘Technologies’ or ‘Products’ has also been added to Schatzki’s original definition of practice, inspired by the work of (Reckwitz, 2002a) on how to include the materials and what role materiality and products can play when performing a practice (Shove and Pantzar, 2005, Gram-Hanssen, 2011, Warde, 2005, Shove, Watson, Hand and Ingram, 2007). All these authors emphasise products/technology as a significant element of practices, particularly in energy efficient studies. Masden (2018), for example, found a clear difference in inhabitants’ perception of comfort and their everyday heating practices as a result of the change in the material configuration of heating houses, from a radiator to an underfloor heating system. Another study concerned inhabitants’ practices of heat-related habits shows that changing the material arrangements of houses (heating technologies and building characteristics) has a significant impact on inhabitants practices of adjusting thermostats and clothing, as well as comfort expectations (Hansen et al., 2018). However, in his early version of Practice theory, Schatzki explicitly does not consider the material objects, (e.g. technologies) to be an important element in constructing practices (Reckwitz, 2002a, Halkier et al., 2011). In his later work, he does, however, offer a comprehensive account of the ways objects are implicated in practices (Schatzki, 2010) when he discusses the notion of a material-human ‘arrangements’ which form inhabitants’ practices. Specifically, he argues now that materiality has a unique role in shaping and interacting with practice, and thus he separates it out. He considers materiality as a consequence of social practices and part of the context for these practices

(Gram-Hanssen et al., 2017).

To sum up, two key discrepancies, in terms of identifying the number and nature of the elements that hold a practice together, have been highlighted in relation to the key elements of practices. The first discrepancy is where Shove suggests ‘technology or products’ as a single key element of a practice (Shove et al., 2012) inspired by the work of Reckwitz (2002a), rather than separating these two elements out, by seeing them as having a unique role in constituting practices (Schatzki, 2010). Another significant discrepancy concerns the description of the ‘knowledge and rule’ element, with Shove including both ‘tacit knowledge’ and ‘explicit rules’ under one element ‘competence’ (Shove and Pantzar, 2005). By contrast Gram-Hanssen separates Shove’s ‘competence’ into two distinct components: know-how and habits, and institutional knowledge and explicit rules (Gram-Hanssen, 2010), following Schatzki in her approach.

Importantly, Gram-Hanssen approach also deals with know-how and habits as tacit learning, and institutionalised knowledge and explicit rules as expert-derived knowledge. This approach to understanding practice is preferred in this thesis for reasons will be discussed extensively in chapter nine. Following Gram-Hanssen (2010), the four linking elements of practice considered in this thesis are therefore:

1- Technologies and products. This refers to the physical characteristics of the PV appliances and their integration into the homes, and the stuff of which objects are made.

2- Know-how and embodied habits. This includes the skills and know-how that the practitioners have or acquire in in terms of how to carry our any practice. This is closely related to (Reckwitz, 2002b) belief of the role of individuals as a *carrier* of practices.

3- Institutional knowledge and explicit rules. This refers to the policies and regulations of the governments, written advice and any other technical knowledge and documents that influences the system design and use.

4- Engagements. This refers to the symbolic meaning, social expectations, ends and inspiration, purposes, and beliefs. All of which shapes whether one opts to perform a practice or not.

3.2.2.3 Core principles of practice

Following on from the core definition of practice above, four core principles are now discussed in theories of practice: relational thinking, knowing-in-practice, emergence and routinization, and differentiation among practices. These principles are important to understand PV practices because they help to illustrate how PV systems are governed during the provisioning and occupancy practices.

3.2.2.3.1 Relational thinking

This stipulates the co-construction of the four elements technologies and products, Know-how and embodied habits, Institutional knowledge and explicit rules, and engagements (Gram-Hanssen, 2010), where no element can be understood in isolation of the other elements (Schatzki, 2002, Nicolini et al., 2011). The relational thinking of Practice theory also acknowledges, for some theorists, the relations between human and materials in producing any practices (Huizing and Cavanagh, 2011). For example, Orlikowski (2007: 1438) suggests the idea of sociomaterial practices to understand "…the constitutive entanglement of the social and the material in everyday organisational life". In this sense, humans and non-humans can be seen as a co-constitution when investigating the practice of using PV technologies. Moreover, Schatzki's notion of 'site' as 'mesh of practices' discusses the relational thinking of Practice theory in a larger context – the relation between practices in the context (Schatzki, 2002: 151) – practices that presuppose each other, particularly the relation between inhabitants of PV practices and overall energy consumption practices during occupancy.

3.2.2.3.2 Knowing-in-practice

The positivistic and rationalistic views of knowledge has been criticised by practice theorists who understand knowledge not as an object but as an activity which clearly admits the role of people to get things done, and through their competence, to solve practical problems that emerge when performing a practice (Orlikowski, 2002). As such, knowing in Practice theory is not situated "… in the brain of the human body or the organisation" instead, it embraces thought, body, sensory, passion and aesthetic knowledge when performing a practice (Ingold, 2000, Strati, 2007, Gherardi et al., 2007: 318). Thus, PV practices as a place of knowing can be perceived as "a collective and distributed 'doing'…as an activity situated in time and space" (Gherardi, 2009: 353). Thus for the thesis objectives, "the site of knowing is never a single practice but a set or nexus of interconnected practices (Nicolini et al., 2011: 614). This approach helps to investigate how the practice of PV appliances is influenced by other practices, such as the more general energy practices of inhabitants.

3.2.2.3.3 Emergence and routinisation

Different Practice theorists have different views in relation to the degree of the ability of practices to change in every use (Nicolini et al., 2003). Schatzki highlights the productive and temporally evolving aspects of practices, which is constitutive of practice itself as: “a temporally evolving, open-ended set of doings and sayings” (Schatzki, 2002: 87). As such, each practice has adaptability in relation to external impact, which dismantles the dichotomy between persistence (institutionalisation) and change (situated performance) (Warde, 2005). This can help to explore the sustainability of the positive routine engagement of inhabitants with their PV system and to examine the key changes in PV practices. However, this thesis will not look at historic traditions in terms of their influence on sustaining or changing PV system practices, as this is beyond the scope of the aim and objectives, and would form another thesis. The thesis will only discuss whether positive PV practices are sustained and changed in relation to current changes in inhabitants’ know-how, meaning, and understanding of PV technical knowledge and affordances. The influence of changes in PV rules on the sustainability of inhabitants’ positive practices and low carbon targets will also be examined.

3.2.2.3.4 Differentiation among practices

Warde (2005: 138) argues that “…practices are internally differentiated providing room for diversity within a particular practice every time it is enacted”. This means that different ways of knowing-in-practice can be presented when enacting PV practices (Nicolini et al., 2011). However, (Gherardi, 2009: 357) claims that a “… minimum agreement is necessary for the practice to continue to be practiced”. This contradiction is crucial to differentiate one PV practice from another by using the notions of knowing and to test for preference (Warde, 2005), intentionality and emotionally (Reckwitz, 2002b) and the practical competence (Schatzki, 2002).

Different aspects are highlighted in Practice theory literature in relation to using technology in practice in general and PV systems in particular. Many contemporary sociologists identify the potential of Practice theory to critique the latest public policy in terms of energy consumption and sustainability in housing sector (Shove and

Pantzar, 2005, Shove and Walker, 2010, Shove and Walker, 2014, Spaargaren, 2011, Kuijer and Watson, 2017, Shove, 2017b, Rinkinen et al., 2017). These studies help to reveal the role of material and social context in changing energy consumption practices in contrast to earlier more individualistic understandings of these topics.

Similarly, in sustainable transformation studies, Sengers et al. (2016); Seyfang (2010); Femenias and Hal (2009); and Mulgan (2007) have all examined the social, environmental, and physical aspects in relation to achieving successful sustainable housing transformations and to examine the key actors that enable theses transformations. They state that inhabitants' opinion (governance) and performance (practice) are important in the process of improving sustainability in housing sector such as energy consumption, materials consumption and renewable energy. They focus on how these transformation processes are initiated, motivated and implemented in bottom-up provisioning strategies and respond to the local situation in order to speed up the positive practices in large perspective. This approach will be used in this thesis to explore how positive PV practices are translated between actors and the key actors and relations that enable successful transformations.

In terms of agency, Boudreau and Robey (2005); Orlikowski (2000) have pointed out that inhabitants change and develop their technologies in response to their local experiences and needs in everyday practice; significant organisational changes may result over time as a consequence of inhabitants' governance. For example, Orlikowski (2002) has demonstrated that transformations of organisational practice were enacted through use rather than caused by technology. Thus, the designer's vision of new organisational forms may be deconstructed by improvised actions in which the system users appropriate technical features for purposes other than those originally proposed (Schultze and Orlikowski, 2004). Importantly, "Every engagement with technology is temporally and contextually provisional" (Orlikowski, 2000: 412). For example, the study of Hyysalo et al. (2013) highlights how the inhabitants can significantly modify and improve renewable energy technologies in their homes, by empirically charting inhabitants inventions in wood pellet burning and heat pump systems in Finland between the years 2005–2012. They found 192 modifications that improved the efficiency, suitability, usability and maintenance of the systems, as evaluated by domain experts, which could speed up the development and proliferation of distributed renewable energy technologies. All of this shows that people are potentially relatively free to enact PV technologies in different ways according to what they can and are willing to do in actual practice. This understanding will help to examine whether, or not, PV systems enable inhabitants to change and improve the physical characteristics of the system appliances according to their preferences and various situations.

Other studies have addressed the effect of inhabitants' behaviour in their everyday practice of a particular technology or a system in the housing sector and its effect on energy consumption by identifying the various dependences that affect their behaviour (Shove et al., 2007, Denise A. et al., 2000, Frances and Stevenson, 2017). The empirical study of (Santin et al., 2009) demonstrates that inhabitants characteristics and behaviour significantly influence energy consumption by (4.2%) for identical buildings and conditions. This is useful to understand to what extent the different drivers of inhabitants' practices might influence their PV practice and energy efficiency as a result.

Several energy efficiency studies have adopted Practice theory (individually or in combination with other theories) as a powerful lens to investigate the energy performance gap in new housing and to identify the performance discrepancies inherent in domestic technology provisioning processes. For example, Gram-Hanssen et al. (2017) discusses this discrepancy in relation to the assumptions made by heat pump installers in regards to inhabitant using their heat pump technologies, while Baborska-Narozny et al. (2016) analyse this gap in relation to the capacity of PV policy and standards to deliver the projected energy performances.

Stevenson et al. (2016) employ Practice theory to identify the role of 'redundancy' (as an aspect of resilience related to a system having more than one way of satisfying any particular function within the system) in preventing failures in comfort, ventilation and energy performance in homes, and to understand the capacity of the inhabitants to understand and use such redundancy to increase the resilience and performance of their homes. Using Practice theory analytical methods (among others) of investigation in a single exemplar community project in England, the study identifies PV systems as a key physical redundancy embedded in the community in terms of energy supply sources, operating in tandem with other energy supply systems. However, the lack of learning opportunities for inhabitants to understand their home technologies in general, and the insufficient provision of energy generation and consumption feedbacks for PV systems in particular reduced the potential of this redundancy to improve the performance of their homes in terms of overall energy efficiency.

The social and behavioural issues of photovoltaics have also recently become a key focus in sociotechnical studies. Schelly (2016) employs Practice theory methods to investigate the role of PV systems in the residential sector in promoting alternative environmental practices, revealing how households understand and discuss the potential of their technology choice. By conducting interviews with 96 homeowners who had installed domestic PV systems in the USA, the study identifies that polices intended to encourage PV systems also positively encouraged changes in energy consumption practices, a topic that will be discussed in relation to the UK PV and energy polices later on in this thesis.

To provide contextual understanding, the practice of using technology must be understood by looking at inhabitants' everyday activities to reveal "what people '*actually'* do rather than on what they say they do or on what they ought to be doing" (Schultze and Boland, 2000: 194). As such using PV technology should be seen as a highly contextualised phenomenon and examined at a micro-level. Previous Practice theory studies have tended to look at technologies in relation to other practices at a larger scale, and to other elements of the practice such as know-how, explicit knowledge and the consequent engagement at a small scale (Orlikowski, 2000, Schultze and Orlikowski, 2004). For example, Orlikowski (2000) found that users did not use their particular technology if it operated against institutional practices. In this sense, the research approach adopted in this thesis could help to interpret the differences in practices when enacting PV systems in different contexts by different actors, and could help to understand the actual governance of inhabitants when using their PV components, rather than just relying on what they say they do (Schultze and Boland, 2000).

Various studies suggests that inhabitants in practice are relatively free to enact technologies in different ways according to what they can and are willing to do in actual use (Warde, 2005, Vaast, 2007). This helps to understand how and why PV inhabitants use their system appliances in their real physical context, and to explore the differences in their use and why these differences occur.

In summary, all the studies in the above sections have shown the potential of Practice theory as a powerful lens to enrich the understanding of domestic PV system by providing a novel interpretation of *how* PV systems are being practiced by inhabitants today in various material and sociocultural contexts, and how their practices are shaped and sustained by the different provisioning of PV affordances and contexts, associated actors, and inhabitants' embodied know-how and engagement.

One of the key features of Practice theory across the different scholars is that they "foreground the centrality of interest in all human matters and therefore put emphasis on the importance of power, conflict, and politics as constitutive elements of the social reality we experience" (Nicolini, 2012: 6). So, it is clear that Practice theory can be understood as being about power. However, "Practice theory has within it a largely unspoken account of power" (Watson, 2017: 181). This is discussed next.

Practice theory ontology states that "Power must be understood as an effect of performances of practices, not as something external to them" (Watson, 2017: 171). In terms of understanding power through immediate relational interaction, by the mean of speech, bodily conduct and human interaction, practice theorists can reveal how power exists as an effect of collective activity by examining the capacity of practitioners to act with effect through diverse relationships (ibid). However, "it is harder [for Practice theory] to grasp how power is executed in the directing of another's action, in authority over others, or in the core of what it takes to understand and tackle the effects of power in the world" (Watson, 2017: 173). Watson (2017: 172) aptly describes this issue when he states that practice components "...focus on how actions are shaped rather than how power is wielded to shape it".

Shove's model of practices as shaped by "relations between materials, competences and meanings" (Shove et al., 2012: 24) also reveals little of "the means through which power operates" (Watson, 2017: 172). Even when Schatzki introduces the implicit *rule* element as a mean of exercising power in practice, he only aims to understand how practitioners integrate the 'rule' element with other practice elements in a practicable action. Thus, although both Shove and Schatzki indicate the significance of conceptualising the connections between practices (Schatzki, 2011, Shove et al., 2012) in terms of how specific actors and practices can shape the capacity of other actors and practices elsewhere, they do not really discuss the detailed relationships between actors and their practices in terms of shaping powers. Therefore, it is important to enrich Practice theoretical resources and analysis by engaging with another theory that is more obvious in its treatment of power and can complement Practice theory in terms of answering the research question. ANT's concept of sociology of translation provides a further lens and resource to examine how power(s) are transformed and translated to and between practitioners to deliberately shape actions and outcomes when governing a social phenomenon (Marshall and Rollinson, 2004, Fox, 2000, Watson, 2017).

This thesis thus draws on ANT's concept of sociology of translation, and Latour's specific concept of intermediary vs mediator (see 3.2.1.3) for different analytical purposes in relation to understanding power, practice and governance. This includes the analysis and discussion of how power can meaningfully engage with and translate during the governance of PV provisioning, and to show how certain practices act upon others to inscribe the PV system design and integration into homes. The use of ANT theory not only enables the distinction between PV actors who have the capacity to exercise power (mediators), and actors who only pass on the power of other actors (intermediaries), but also the examination of the wider networks and powers effecting practices. Drawing on these different concepts also helps to analyse and map the shifting of power between the various human actors, and the affects that result from these shifts. This is done in order to critically understand points of failure and how a more appropriate governance networks could achieve greater energy saving from the provisioning and occupancy practices of PV technologies.

Schatzki has previously engaged with Latour's ANT to better understand how large social phenomena and actions (e.g. government, universities, etc.) can emerge or improve from practices (Schatzki, 2011). Shove (2017a: 7) moves beyond Latour's concepts to examine how broader practices are constituted teleogically stating "It is not only that 'we have never been modern', as Latour suggests, but that the forms of material –human entanglement, which characterize all periods of history, have some kind of direction". A recent study of Gram-Hanssen (2018) rethinks the theory of practice to include "devices and systems not only as the material arrangements within which humans perform practices (following Schatzki), but as carriers and performers of practices", following the symmetrical anthropology of ANT by conceiving non-humans as carries and performers of practices rather than only having a place in practices or as a result of practices (ibid: 235). The distributed agencies of non-humans are also reconsidered by other Practice theory proponents, to show how non-humans become 'dynamic' and act performatively in social practices, thus engaging, directly or indirectly, ANT's ontology of symmetrical analysis into ontology of theories of practice (Kuijer, 2018, Strangers, 2018, Maller, 2018a). Interestingly, although there numerous books and articles bringing Practice theory and ANT together (e.g. Schatzki, 2011; Shove, 2017a; Watson, 2017; Nicolini, 2017b; Schäfer, 2017; Pichelstorfer, 2017; Gram-Hanssen, 2018), only a handful of them have applied and discussed the outcomes empirically (Nicolini, 2017b) – something which this thesis aims to do.

To sum up, using the lenses of ANT and Practice theory could provide different interpretive approach and lenses for understanding the different aspects of the provisioning of PV systems and the subsequent inhabitants' practices. By bringing insights from these two theories, human agency and materialities can be examined in a relational networks and practices, taking objects *as well as* embodied competences and tacit knowledge of practitioners into account.

Engaging with ANT and Practice theory analytical approaches can also enable the understanding of PV provisioning governance in greater detail in terms of mapping the dynamics of powers and agencies closely when examining the practices, emphasising the transitional shifts in the links between actors and practices that change the quality of the entire network. In other words, understanding *governance in practices,* as described by Watson (2017: 168) where "Inscriptions are outcomes of particular, normalised practices".

However, neither Practice theory nor ANT focus particularly *in detail* on what the physical properties of an object are, in the way that Gibson (1979) does, and how these detailed properties relates to the person in a real situation. For example, Hill et al. (2011) have pointed out that the lack of using a boiler timer efficiently in a home by the household did not stem from a misunderstanding of how to use the timer but from the pre-existing central heating *time-switch*, as an object whose designed and installed properties only allowed the limited engagement choices of OFF, ON TWICE, ON ONCE, or ON, rather than a full range of bespoke timing options relevant to the inhabitants. Insights from Affordance theory (Gibson, 1979) could be an additional lens here enabling empirical and analytical attention to focus on objects and details of design, as distinct from their entrainment (that have been joined up with practice) to practice.

3.2.3 Affordance theory

3.2.3.1 Introduction

The discussions about ANT and Practice theory approaches in sections 3.2.1 and 3.2.2, recognise human and material agencies as both distinct and fundamentally interdependent phenomena, which are the basis of both routines and technologies. To this extent, people and technologies are both able to change when they imbricated

(Leonardi, 2011). The critical question is, if an individual has the choice to change either a technology or a routine, which one does he/she decide to change and why? This question can be answered by considering how people and technology are imbricated (ibid). The theory of affordances provides a pragmatic and distinct additional lens enabling analytical attention to be focused empirically on objects and details of design as distinct from their entrainment to practice.

3.2.3.2 Gibson's affordances

Gibson (1979: 127) theory of *affordance*, has defined the affordance of any environment as: "what it offers the animal, what it provides or furnishes*,* either for good or ill, and they have to be measured relative to the animal". According to this definition, the material *propertie*s of a technology are the same for all people who encounter them, but the *affordances* of that technology are not. Thus the material property of a technology affords different users different possibilities for action (Leonardi, 2011). In this light, Gibson (1986: 134) explains the relationship between materiality and affordances:

> "The psychologists assume that objects are composed of their qualities... color, texture, composition, size shape and features of shape, mass, elasticity, and mobility... But I now suggest that what we perceive when we look at objects are their affordances, not their qualities. We can discriminate the dimensions of difference if required to do so in an experiment, but what the object affords us is *what we normally pay attention to*" (authors italics).

McGrenere and Ho (2000) illustrate three fundamental properties of an affordance in Gibson's theory: *firstly*, an affordance exists in the environment (environment-relationship), where the physical properties of the objects constitute what they afford (the action possibility) and the actor's capability to perform the affordances offered. *Secondly*, the existence of an affordance is independent of the actors' knowledge, experience, culture or ability to perceive them. *Thirdly*, an affordance does not change when the goals of the actor change (an affordance is invariant).

3.2.3.3 Norman's affordances

Extending Gibson's view, Norman (1999) and his proponents: Stoffregen (2000) and Chemero (2003), have perceived affordance as a relation between agent and environment, and stated that this can be internalised in the object or organism.

Therefore, Norman defines affordance as: "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used. A chair affords (is for) support and, therefore, affords sitting. A chair can also be carried" (Norman, 1988: 9).

Affordances, according to Norman, are "designed-in" properties of artifacts. He argues that each design consists of "[real and perceived affordances], but the perceived affordances are what determine usability" (Norman, 1998: 123). He added that the perceived affordances result from the users' understanding of the artifacts, based on their past knowledge, experience and that the role of good design is to make affordances easily perceptible in products and environments. According to this view, inhabitants are central to identifying a technology's affordances. However, their role in creating affordances in objects is very limited. The role of PV designers, therefore, is to make affordances easy to perceive and understand: good designers need to "purposefully build affordances into a technology to suggest how its features should be used" (Leonardi, 2011: 14).

The fundamental clarification of Gibson's affordance theory by Norman in terms of technology design (e.g. PV systems) is that, for Gibson an affordance is the action possibility inherent in the system design, whereas Norman goes onto to say that affordance is both the action possibility and the way in which that this inherent possibility is conveyed to the user of the technology. Therefore, designing the usability of an object (Norman goal) is one step on from designing the utility of an object (Gibson view) (McGrenere and Ho, 2000). This develops an important distinction of usability as 'the perceptual information that specifies these affordances' versus usefulness as simply 'the possibility of action in the design' (Landauer, 1995). The perception of affordances provided, therefore, becomes a critical factor in investigating inhabitant's practice of domestic technologies when considering the discourse on usability. For example, to understand the usability of the 'In Home Display' (IHD) technology in the UK housing sector, the Department of Energy and Climate Change (DECC) conducted interviews with a large number of inhabitants to examine the inhabitants' feedback in relation to such technology. The study revealed that the high level of inhabitants engagement with the IHD, including those who generally had little interest in technology, was due to the usability of the technology (DECC, 2015). Similarly, Leaman et al. (2010); Stevenson and Leaman (2010); Stevenson and Rijal (2010); Harun et al. (2011) have all used affordance theory in building performance evaluation as an approach to study the usability of different home technologies in the UK in a real situation. Although these authors recognise inhabitants as one of the best instruments for measuring housing performance given that their feedback can quickly explain why a technology does or does not work (Cole et al., 2010), their approach was primarily driven by *usability* as the main measure of the building and its systems (Baborska-Narożny and Stevenson, 2018), in contrast to Practice theory approaches which emphasise inhabitants' practices as situated in their real context (Tweed, 2013).

3.2.3.4 Relational character of affordances

Building on Gibson and Norman's work, in order to understand the relational character of affordances, Hutchby (2001: 16) argues that affordances are not "…exclusively properties of people or of artifacts", instead they are created in relationships between people and the 'designed-in' properties of artifacts. According to this view, the affordance of a technology can change across different contexts (e.g. material arrangements, sociocultural context), even though its materiality does not. This claim was also emphasised in the anthropological work of Ingold when he defined affordances as: "properties of the real environment as directly perceived by an agent in a *context* of practical action" (Ingold, 1992: 46). Ingold effectively brings Practice and Affordance theories together, even though he misses out the broader Gibson definition of affordance which includes properties not directly perceived by an agent, as well. In this light, PV technologies affordances should not be seen in isolation, instead they should be investigated within their context and in actual engagement which ethnographic methods can help to illuminate as discussed in Chapter 4.

According to this relational view, affordances exist in the space between humans and technology and are influenced by the context in which the affordance exists. As such affordances are finally defined for the purpose of this thesis as: *action possibilities directly understood, or not understood, by agents in a relational context of practical action.* From this definition, this thesis argues that peoples' engagement are shaped, to a high degree, by their perception/lack of perception (Gibson, Norman) in the context of practical action (Ingold). However, their perceptions/lack of perception are also formed by peoples' agency and goal and other practice elements such as rules, know-how, and engagement (Practice theory).

Turning to sociocultural influences, Heft (2003: 158) explains how the sociocultural aspects of a context effects affordances in practices. He demonstrates that a "…pen on the desk may be graspable for me, given its diameter in relation to my grip, but because it is resting on the desk of the president of the college, it is not a pen I ought to pick up". In this sense, the affordance of PV technologies and inhabitants' practices need to be investigated together in a relational perspective and in different physical and social contexts, as will happen in this thesis. In other words, broadening the investigation from solely understanding the physical affordance of PV technologies to understanding the affordance for PV practices as being inclusive of agency and in action, thus adding new dimensions for data collection and analysis to the methodological toolkit of this research (Fayard and Weeks, 2014: 236).

Several Practice theorists have built on Ingold's (2000) understanding of affordance, which connect the affordance of the environment with doing actions in a specific context, to discuss technology (affordance), as an element of practice, with other practice elements in relational manner. However, they still neglect the detailed role of the physical property of a technology when discussing practices, due to focusing on practices rather than affordances. Even when Gram-Hanssen et al. (2017) discuss technology in more detail, they focus on the influence of the technology integration into homes on inhabitants practices, rather than focusing on the physical property of a technology (Gibson's affordance) impacting on practices. This thesis, therefore, re-emphasises the role of affordance (what the properties of the actual equipment offers its user) within Practice theory which has been rather neglected by practice studies. The new definition of affordance theory in this thesis is a means of bridging affordance theory in relation to practice and agency to explain *in detail* the role of affordance in relation to inhabitants' practices of using PV systems when examining the action possibilities and engagement with the system appliances in their contexts (5th objective).

Interestingly, Baborska-Narozny et al. (2016) attempted to study PV technology affordances and inhabitant practices in a unique social context (low carbon community housing project) in the UK. The study revealed that the potential benefits from the live energy generation display screen provided in the PV inverters was significantly undermined by inhabitants' insufficient understanding of the affordances offered and the poor location and position of the device inside the home. This resulted in a low level of inhabitant engagement with their inverters. A similar case study with an interest in understanding the role of different provisioning actors in constructing the affordance of PV technologies in community housing projects attributed the low level of inhabitants' understanding of the affordances offered in their homes to the poor home induction process and insufficient provision of HUG, as well as the failure of inhabitants to govern the location of their PV appliances inside the homes during the PV provisioning process (Frances and Stevenson, 2016). Investigating PV affordances in relation to inhabitants' actions and agency, thus, is crucial to understand how professionals and other provisioning team govern inhabitants' practices through the affordances offered in their appliances, and the consequences in terms of energy efficiency in an individual home.

Drawing on the three particular lenses of ANT, Practice theory and Affordance theories is, therefore, necessary to get a more complete insight of understanding how PV systems' affordances, and inhabitants' perceptions and practices are governed by a network of actors in low carbon community housing, and what role inhabitants could play in terms of improving energy efficiency when governing their system design. Figure 3.1 shows the overall theoretical research framework drawing on the three theoretical lenses as developed in this chapter.

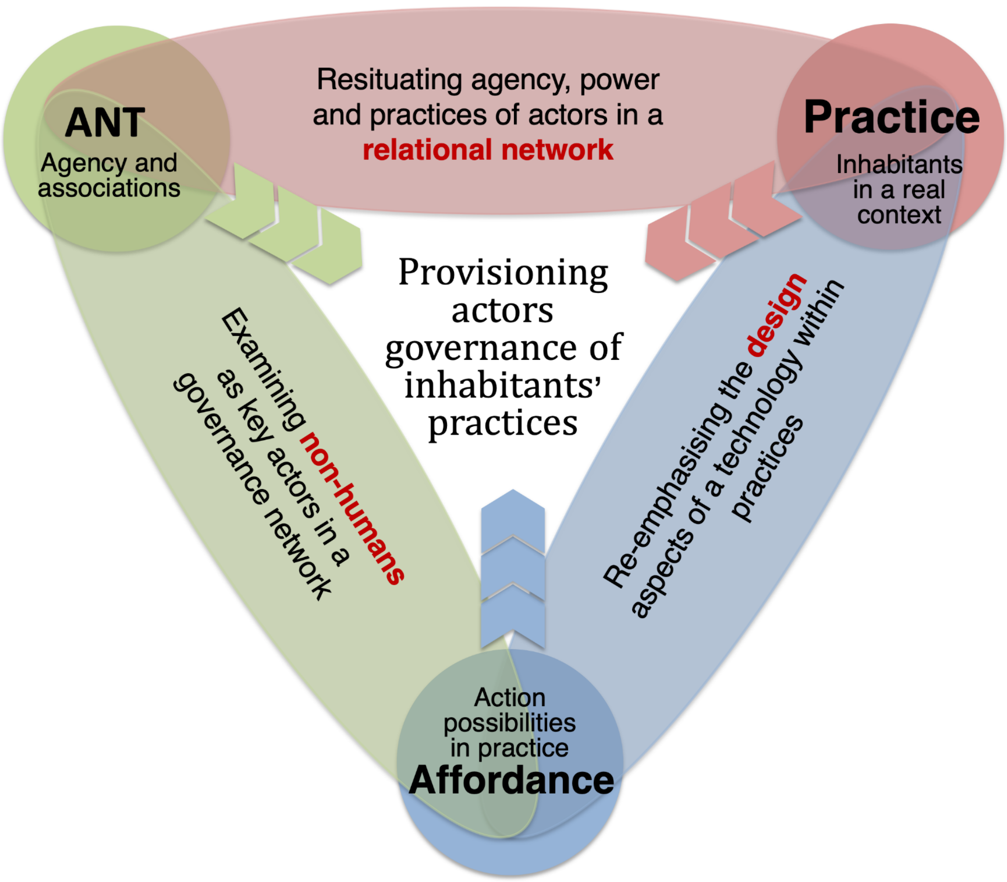

Figure 3.1: Theoretical research approach

However, a further question now arises - how can these three theories possibly be used in association with each other when they use different methods, and even different paradigms? The research design resulting from a distinct methodology to answer this question will be explained in the next chapter.

3.3 Sub conclusion

Chapter two in this thesis introduced the governance approach as a powerful approach to investigate and understand the provisioning process of PV systems. This chapter then introduced a sociotechnical approach as a further methodological basis for understanding the impact of the governance of PV systems in relation to the energy performance gap.

Three key theories – Actor Network Theory (ANT), Practice theory and Affordance theory – were then innovatively introduced as three distinct lenses in this thesis through which to understand the role and action of various PV provisioning actors in governing inhabitants' practices related to their PV systems in low carbon housing communities.

ANT's notion of sociology of translation enables the examination of how a network of connections is built between PV provisioning actors (both human and non-human) to govern the provisioning of the system design, affordance and integration into homes, and the subsequent practices of inhabitants when engaging with their PV systems during occupancy. The agency and actions of actors are interchangeable (mediator vs intermediary) as a result of their associations with other actors in a governance network (Latour, 1986). Thus, it is important to focus on the links between actors rather than just focusing on actors individually. Importantly, it has been explained in this chapter, that non-human actors also 'make a difference' to the governance network and outcomes by impacting on the governance and decision of human actors.

This powerful approach for understanding the shaping of inhabitants' engagement and practices of their PV appliances, however, discounts the role of embodied competences, intentions and meanings of individuals in shaping PV practices (Nicolini, 2017b). Practice theory helps here by combining social order and individual actions (Schatzki, 1996), and shifting attention from actors and relations (ANT) to a detailed examination of practices within their real context (Hill and Huppe, 2014), in order to explore routinisation and variation in inhabitants' practices when they are engaging with their PV controls. There is still a gap, however, in Practice theory in terms of how power(s) are transformed between actors to deliberately shape actions and outcomes (Watson, 2017). Drawing on both Practice theory and ANT methodology as distinct lens therefore effectively overcomes the challenges of both theories. However, this chapter has further shown that neither Practice theory nor ANT focuses *in particular detail* on how PV systems actually work, and how the physical property of PV systems impact inhabitants in a real situation, thus determining their practice. Gibson's theory of Affordance is introduced as a lens to deal with this aspect through revealing *action possibilities directly understood, or not understood by agents in a relational context of practical action*.

In the next chapter, the methodology, research design and methods used to generate and analyse both PV provisioning and practice data will be introduced on the basis of this theoretical approach.

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

This research adopts Groat and Wang (2002) perspective of a system of inquiry as a philosophical standpoint of research that is focused on a designed methodology and identified methods. Chapter one introduced the research study while chapter two set out the background. The overall theoretical approach of the research was described in chapter three, drawing on three different theories: ANT, Practice and Affordance, to provide a better understanding of how domestic PV systems are designed and practiced. In this chapter, the methodological approach and the specifically chosen methods to collect and analyse data will be presented and discussed.

This chapter is divided into five key sections: firstly, the overall methodological framework is presented, then the Case Study approach, which discusses its significance in terms of answering the research question, the strategies used to select the case studies, and the case study boundaries. Thirdly, the specific methods for collecting data and the limitation of each method is discussed, in the context of the research design combining two different approaches to generate and manage data (inductive and deductive), and fourthly, the practical research set up is described and fifthly, the data analysis approach is set out.

4.2 Methodological framework

Lincolin and Guba (2000) point out that using qualitative methods within a case study approach could be the most useful paradigm to provide a more complete and contextual understanding of a social phenomenon within its context. This is most relevant when the researcher wants to know *how* and *why* certain phenomena are taking place (Yin, 2013). The overall methodological framework and the methods used for data collection and analysis in this thesis are therefore, based on the analysis of technology provisioning and occupancy practices within a Case Study approach.

Latour (1999a: 20) notes that ANT is neither a theory of the social norm, nor a way of explaining society. Instead, it is “a very crude method to learn from the actors without imposing on them a priori definition of their world building capacities”. Yaneva (2012) has used ANT as a lens to analyse and understand the controversy around a particular building or technology in architecture using three stages of analysis:

1- *To follow*: being able to trace the dynamic of the relationships between actors in time.

2- *To document*: to collect a variety of materials such as images, interviews, documents.

3- *To map*: to present the chronological development of a controversy in a very visual way and in details.

To rigorously follow and trace the PV provisioning actors and their association in a network, PV provisioning data should be collected from various materials such as document reviews and interviews with PV provisioning actors in selected case studies. This is to examine a real world setting and to ensure an in depth understanding of the complexity of PV provisioning network (Yin, 2013). The concept of *mapping* provides an effective approach and method to analyse and visualise the chronological power relationships of different participating actors (both intermediaries and mediators) in the PV provisioning process. This approach will uniquely capture the dynamics and chronology of the relationship between actors, how they form alliances, the agency and capacity of different actors, and will provide a visualisation of how the actors' agency can change in different networks and how a personal view might turn over the whole configuration of this relationship, in other words, "visualising interactive chronologies" (Yaneva, 2012: 73, Petrescu et al., 2016, Petrescu, 2012).

Silva (2007) has used phenomenological approaches and observation methods to investigate the role of different actors in influencing inhabitants' engagement with their technologies by focusing on objective reality in order to conceptualise the power in terms of its components. This method can also be usefully deployed to examine the role of various actors (both mediators and intermediaries) in influencing inhabitants' engagement with their PV system during occupancy. Figure 4.1 illustrates the various research methods deployed to examine actors' agency and associations in different PV networks when governing PV systems during the provisioning process.

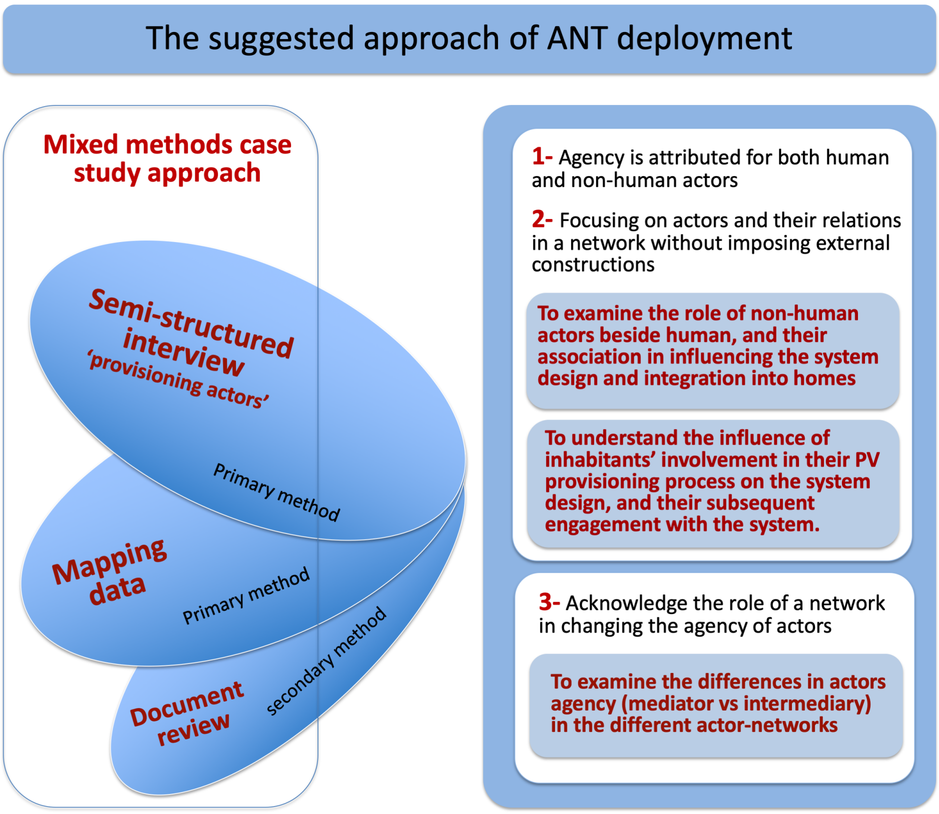

Figure 4.1: The suggested methods to examine PV actors' agency and networks

Schelly (2016) demonstrates the strength of qualitative research for understanding the environmental consequential pattern of human engagement. More specifically, Nicolini et al. (2003: 28) state: "a practice-based approach directs the researcher's attention to what people do and say, to the world of life made of the details and events that constitute the texture of everyday living". Therefore, ethnography (e.g. observation) provides a "key methodology with which to observe social and situated practices" (Corradi et al., 2008). Similarly, Ingold (2000) argues that reality cannot be simply established from verbal communications of objectified knowledge, such as through interviewing. Instead, reality can only be found in the process of investigation in the work place, because the skills transmission of 'tacit knowledge' is happening in practice and the ways of knowing that skills embody are located in practice (Strati, 2003). Thus, using ethnographic observations combined with interviews could help to examine what and how other people know in relation to PV practices (Pink, 2007).

Pink (2009) has developed a new methodology of ethnographic investigation, which includes 'the video tour', using an ethnographic walkthrough method commonly deployed in an energy and building context (Stevenson and Rijal, 2010). This creates a dialogue between theories of practice 'knowing from activity' and ethnographic practice 'observation' using a variety of techniques. This helps ethnographers to better understand other people's experiences, and to generate closer and empathetic understandings of these experiences in their real contexts. Figure 4.2 shows the additional research methods deployed to examine closely how PV systems are being practiced by inhabitants in their real contexts.

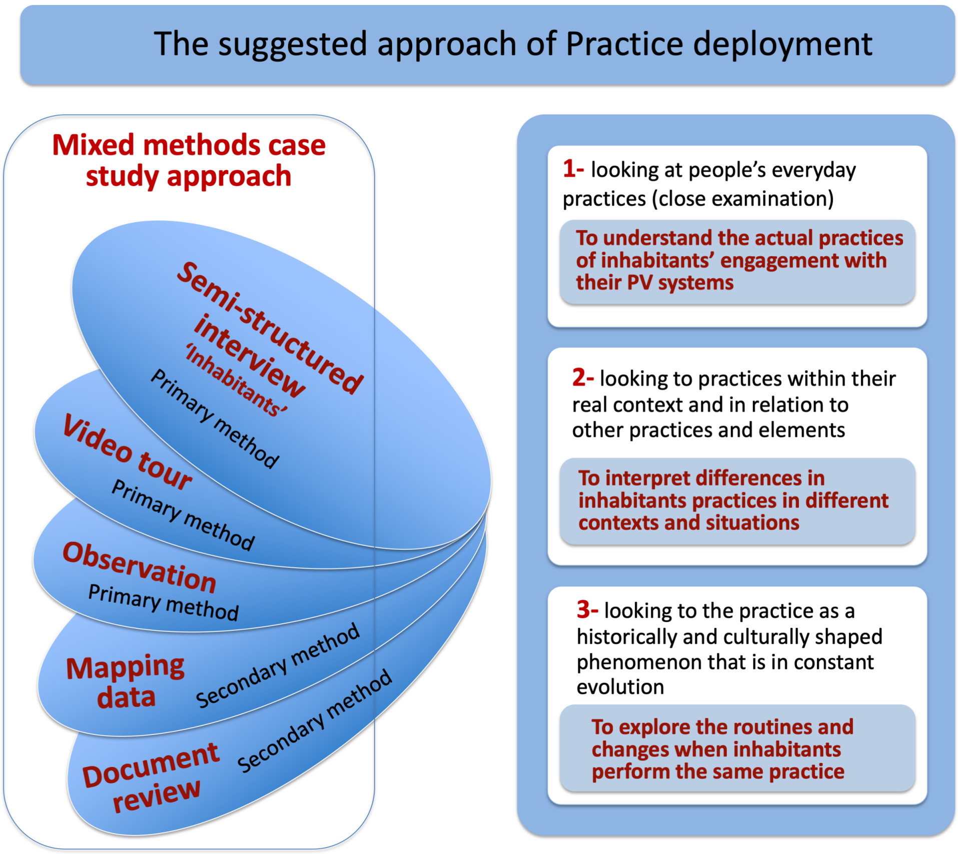

Figure 4.2: The suggested methods to contextually examine inhabitants' actual practices

To examine what the physical properties of the PV appliances afford their inhabitants in a context of practical actions, PV technologies affordances should be investigated within their context and in actual practice which ethnographic methods (e.g. observation, video tour) enables using questions, such as "what did the technology enable you to do"; "what did you use the technology for" (Volkoff and Strong, 2013). Figure 4.3 shows the research methods deployed to examine how PV affordances relates to inhabitants in actual practice and in relation to their engagement with these affordances.

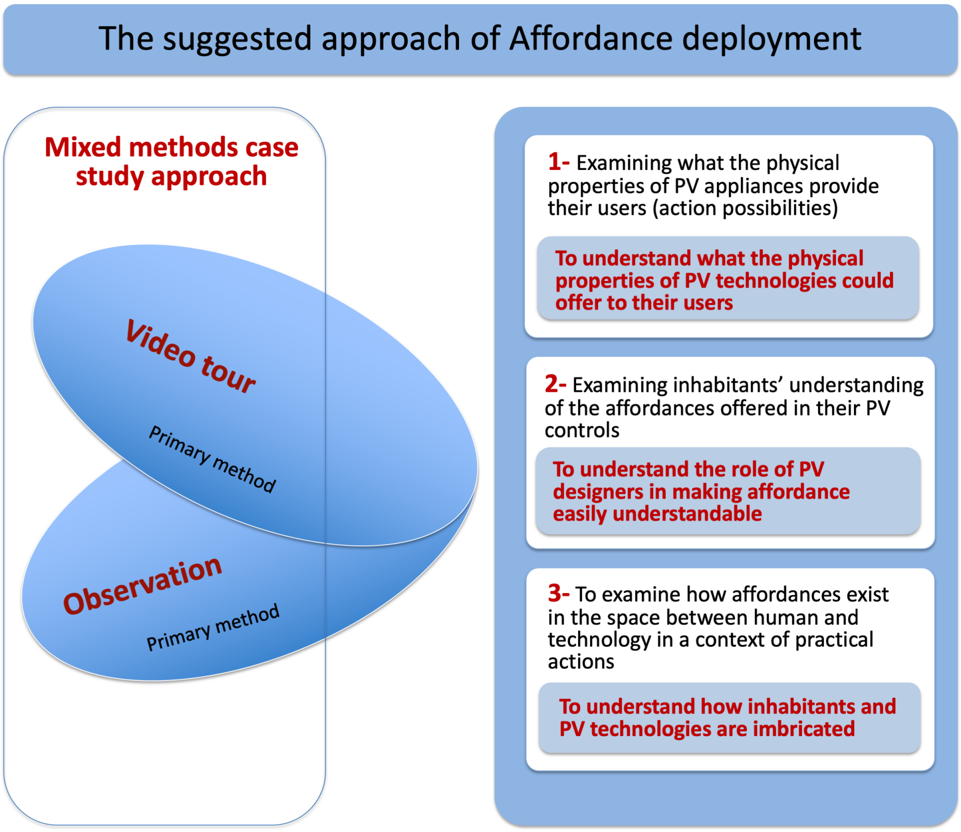

Figure 4.3: The suggested methods to examine the detailed role of affordances in relation to inhabitants' practices

4.3 Case study

4.3.1 Case study method

Case study is a powerful method to answer questions of what, whom and how the co-construction of users and their environment occur (Lindsay, 2003). More specifically, given that *context* has been identified here as the key concern in the governance of different building construction actors in constructing the PV design and affordance during the provisioning process, and in investigating inhabitants' practices of these systems during occupation, a case study is an ideal vehicle to explore such concerns (Yin, 2003: 5-11). According to Yin (2003: 13-14) a case study is "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". In this way, a case study is an appropriate approach using a mixed-method design (Robson and McCartan, 2016). This is due to capacity of a case study to examine *reality* in a greater detail and to analyse a greater number of variables (Galliers, 1992), within number of contexts (Stake, 2000), thus, providing a complete and contextual understand of a social situation.

Case study method and particularly interpretative case studies have traditionally been criticised for providing knowledge which is limited to specific cases, thus providing little basis for generalisation (Schweber, 2015). However, Flyvbjerg (2006: 228) argues that "…formal generalization is overvalued as a source of scientific development, whereas "the force of example" is underestimated". Regarding generalisation, Yin (2003: 3) also counters this criticism by distinguishing between *analytical* generalisation and *statistical* generalisation. Contrary to *quantitative* research, where samples are to be selected randomly from a large population, case study research enables the comparison of the empirical result to the previously proposed theory (Bryman, 1988), thus, providing theories applicable in the world at large (Yin, 2003). Generalisation for interpretivists is particularly about *theory development*, where the term 'theory' refers, "not to the development of general laws, but rather to the identification of mechanisms and processes, whose effect varies across different contexts" (Schweber, 2015: 844). Other researchers suggest more conservative approach to deal with generalisability in case studies. Giddens (1986), for example, suggests conducting several case studies in order to ensure an identified social phenomenon can be more generalisable. According to his recommendations, two different sets of case studies, four community housing case studies and two non-community housing case studies, were selected in this thesis, in order to compare the findings from two different forms of PV governance networks and to examine some aspects from each type of housing provision that can help the other, in terms of how each of them is governed.

4.3.2 Case study selection strategy

Choosing an appropriate strategy for the case study selection can increase its generalisability (Flyvbjerg, 2006: 229). Given that this research is theory driven with an interest in examining PV provisioning actors and inhabitants' practice of their PV systems, the generalisable quality of the case study should be tested against the theoretical proposition rather than the population which Flyvbjerg (2006: 219) names as representative "*exemplars*" and is termed by (Bryman, 1988: 90) as "*theoretical sampling".* Such a strategy for case study selection should ensure that the selected group for case study is relevant to the research question and the theoretical proposition of the thesis (Bell and Warter, 2005, Mason, 1996). The significance of *representative exemplars* in terms of increasing the generalisability of the research, is also evident in Hakim's account of case study research, where their "strength and weaknesses ... depend on the degree of fit between the questions to be addressed and the particular case, or cases, selected for the study" (Hakim, 2000: 62). This thesis examines housing case studies where their inhabitants, through their Provisioning Inhabitant (PI), have participated in the governance of their PV provisioning process, and case studies where they have not, in order to examine and compare the dynamics that construct the design of the technology in the two significantly different types of housing – community and non-community–referred to earlier.

Given that understanding the influence of user participation in the PV provisioning on the system design and the subsequent practices by inhabitants represents a key objective in this study, the chosen case studies should reflect 'extreme cases' for case study selection (Flyvbjerg, 2006: 229) in terms of inhabitants' participation in the system design. This is to allow a comparison to be made between the participating inhabitants in PV provisioning process and the non-participating inhabitants, to "clarify the deeper causes behind a problem" (ibid: 229) (e.g. the PV implementation gap of using a domestic technology in different social contexts). As such, two particular sets of contrasting housing case studies were selected as exemplary cases for identifying, evaluating and comparing the PV provisioning and occupancy practices: 'Participative Communities' (PC) housing case studies, where inhabitants have participated in their PV provisioning process with the other provisioning actors and 'Non- Participative Communities' (NPC) housing case studies', where inhabitants happened to live in houses with PV systems which have been constructed by a developer and other provisioning actors without inhabitant involvement in the construction process.

Moreover, the thesis deliberately examines PV governance process in houses/flats that are part of larger housing development/redevelopment projects, where various professionals (e.g. architect, contractor, project manager, etc.) have participated together in the building construction process, rather than examining PV governance purely in individual houses where PV installation has been a fairly standalone initiative. This is to understand the different agencies and roles of all actors involved in the different stages of the building construction process of different types of housing projects with multiple dwellings (which form a significant part of the UK housing sector), and how they have influenced the PV system governance and the consequent inhabitants' practices. This is seen as an important and complex area to consider rather than just examining the role of single actors who have participated in simple installation projects within individual homes (e.g. PV installer). This approach can also help to understand the role of the governance network in influencing the agency and decision of an individual actor in relation to the system design and integration into homes which is discussed in chapter eight. It was important to find case studies that could cover all the variables that influence the governance of inhabitants' practice of their PV system and this created some practical difficulties in terms of precisely balancing the number of NPC (two case studies) against the PC (four case studies). However, at least two case studies are present for each of these two contrasting housing cases.

In order to allow for a greater degree of comparability (Flyvbjerg, 2006: 230), and to overcome the vulnerability of depending on a single case (Yin, 2013), four PC case studies were selected to represent different *sizes of installation (large and small), installation dates* and *different processes (retrofit and new build)* (Figure 4.4). The multiple case design also has analytical benefits in terms of showing replicated or contrasted situations between cases (Yin, 2013).

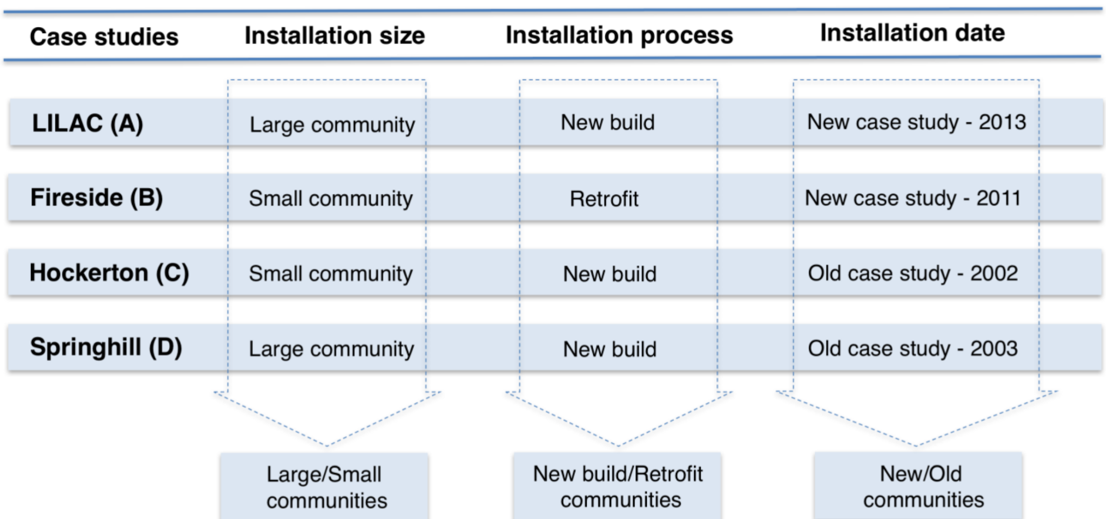

Figure 4.4: Installation characteristics of the four PC case studies

Two more case studies (E and F) were also chosen to enable a greater degree of comparability between two contrasting housing provisions in the UK (PC vs NPC) (Figure 4.5).

Case studies	Installation size	Installation process	Installation date
Brearley Forge (E)	Large community	New build	New case study - 2014
Green Street (F)	Large community	New build	New case study - 2012

Figure 4.5: Installation characteristics of the two NPC case studies

Adopting these various strategies for case study selection provides “a unique significance of information and conclusions according to whether it is viewed and interpreted as one or another type of case” (Flyvbjerg, 2006: 233).

4.3.3 Case study boundaries

This study focuses on PV technology only in England for a variety of reasons.

Firstly, 90% of the UK’s need for power is provided by non-renewable energy, such as coal and gas (Hammond et al., 2012). As a consequence, the UK has a fairly high greenhouse carbon emissions for electricity compared to other European Union countries after Germany (Eurostat, 2017). Moreover, the vast majority of these CO_2 emissions are in England, representing 79% of total GHG emissions in the UK in 2014, compared to Scotland (8.9%), Wales (7.8%) and Northern Ireland (4.1%) (Salisbury et al., 2013), which gives this area of focus a greater significance.

Secondly, there has been growing interest from the UK government in supporting on-site energy generation (Koch et al., 2012). This was achieved by supporting renewable energy schemes, such as community energy scheme in a larger scale and launching a new policy transition in April 2010, a shift from technology subsidies of the Low Carbon Building Program (LCBP) and towards market development policy of a Feed-in-Tariff (FIT). Later approaches aimed to encourage inhabitants to install on-site renewable energy (Hammond et al., 2012). Accordingly, the UK had the highest annual increase of PV installations among all the European countries (Bresson and Denefle, 2015), even in 2016, despite the big reduction in the FIT rate (EurObservER, 2017).

Thirdly, only grid-connected PV installations were considered when selecting the case studies. This is because the previous research on off-grid systems reached a consensus that limited electricity generation (provided only by micro-generation technologies) forces users to strictly adapt their consumption with their energy generation (Moore, 1991), which makes the comparison between the case studies, in terms inhabitants' engagement with their PV system and energy consumption as a result, less valuable due to this bias. Moreover, most PV installations in the UK are grid-connected and so the potential benefit of the findings will be greater in these mainstream applications, because the installations can reach more users.

The boundary criteria for the English case studies also ensure adequate representiveness in terms of location and size, due to the wide range of their geographical and sociocultural characteristics. Adopting this variation in PV provisioning and practice contexts can help with understanding the significance of various circumstances and situations.

4.4 Mixed methods approach

The methods and the design of the data collection strategy in this thesis were informed by the research question and objectives, the ontological standpoints of the chosen theories, and methodological approach. They comprise overall of: literature review, semi-structured interviews, ethnographic video tours, documentary reviews, observations, mapping and quantitative analysis.

Figure 4.6 demonstrates the methodological approach to this thesis in terms of how the various methods relate to each other and to the research objectives.

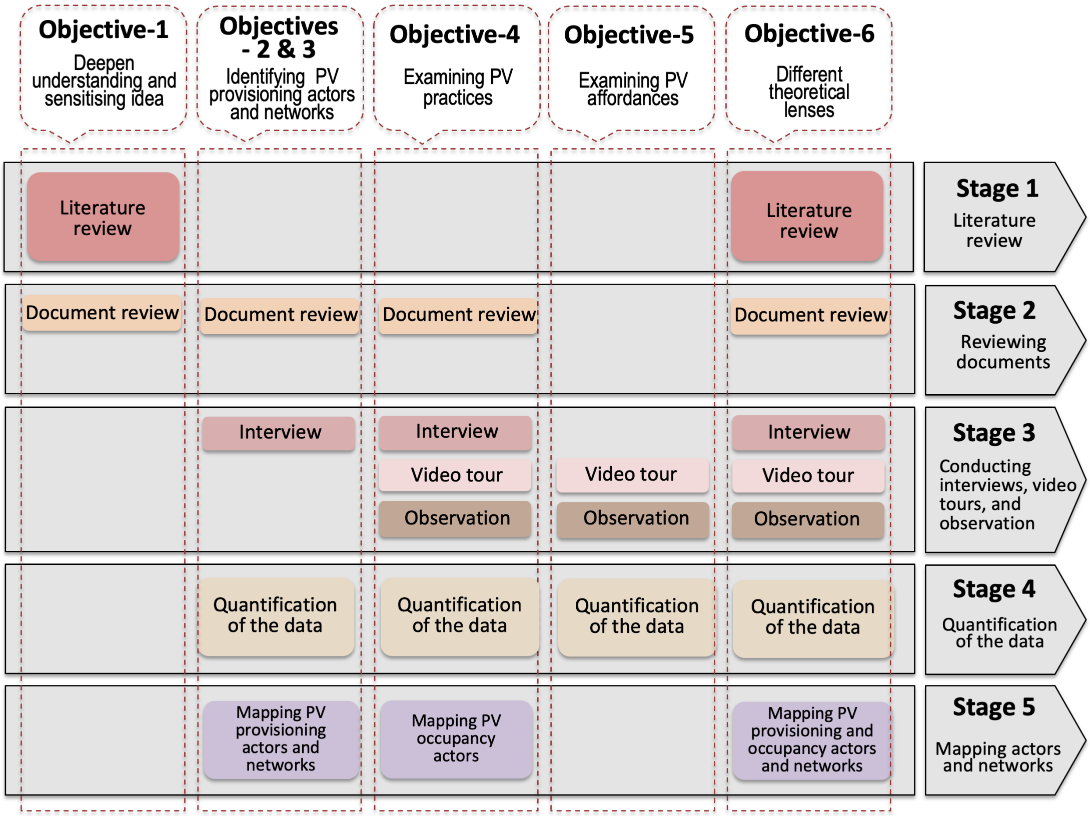

Figure 4.6: Research structure

A mixed methods (multi-strategy) design was adopted as a powerful strategy to examine a real world settings (Yin, 2013). This is to ensure an in depth understanding of the complex nature of PV provisioning networks and inhabitants' practices and associated actors and to reflect the objectives of the research underway. Combining information from various sources of evidence helps to produce a convincing and holistic account of a situation under study (Hakim, 2000, Robson and McCartan, 2016) by offsetting "the limitations of each method and approach while building on their strength, leading to stronger inferences" (Robson and McCartan, 2016: 179), thus, ensure validity from the data (Bell and Warter, 2005). One research method can also explain the finding generated from other methods, which is particularly useful to interpret the "unusual finding emerge" (Robson and McCartan, 2016: 179).

Given that all the PV provisioning data in the selected case studies is based on *after-the-fact* accounts, where the timing of all interviews with PV provisioning actors were well after the completion of the case studies, a combined analysis of various methods, such as a document review beside interviews and observation helps to reduce this limitation of the analysis of PV provisioning stage. This is particularly significant in terms of ensuring that the agency of non-human actors and their role in a network were richly investigated.

4.4.1 Literature review

A literature review refers to "the analysis and critical evaluation and synthesis of existing knowledge relevant to a research topic and problem" (Hart, 2018), mainly to uncovers areas where research is needed (Webster and Watson, 2002). The literature review is firstly used in this thesis to understand what has been done in relation to the PV provisioning and practice and what has not been done in order to define the research gap and the specific and valid research question in chapter one. The review is also used to identify important factors and concepts relevant to the PV provisioning and practice and to understand the subject, gaining new perspectives in chapter two (Hart, 2018). Further to that, the literature review also relates ideas and theory to the research question (chapter three) and identifies the main methodologies and data collection methods, and helps to determine an appropriate methodological framework (chapter four). Finally, the literature review is also used to shape a body of knowledge which can be related to the PV provisioning and practice findings in chapters seven, eight and nine and in the conclusion chapter (Hart, 2018).

4.4.2 Semi-structured interview

The semi-structured interview method with inhabitants is a knowledge-producing conversation between interviewer and informants with a purpose, which discusses predetermined questions about specific topics that the research aims to cover (Hennink et al., 2011). It offers the research participants flexibility to express their opinion without imposing any determinations, unlike more structured interviews (patton, 2001). This helps to provide a partial understanding of inhabitants' claimed practices of PV technologies and how they situate themselves with these technologies (Valentine, 1997) – the 4th objective of the thesis. The interview method also enables a researcher to examine the *differences* in inhabitants' claimed experiences of their engagement with PV equipment in different contexts when "… different interview participants provide different versions of the event or practice.", where these differences are of analytic interest to the researcher (Schwartz-Shea and Yanow, 2012: 41). This includes recording their self-identities and the objectives behind installing PV systems, describing the practices of PV systems in their context, identifying the problems and changes in the technology itself and/or their engagement with the technology, and their effects on the practice.

For the 2nd & 3rd research objective, the interview method is also used to identify the role of the different PV provisioning participants, including Provisioning Inhabitant (PI), when governing the system design, and the different *associations* that took place between actors when making PV decisions and the formation of a network during the PV provisioning process (Latour, 2005). It also explored how inhabitants' governance of their PV systems, through their PIs, developed the meanings that the inhabitants gave to the technology before they enacted the actual practices.

However, the interview method has been criticised for its inability to access *unspeakable* aspects of social practices (Spinney, 2009: 829, Bissell, 2010), particularly inhabitants' *tacit knowledge* (know-how) of enacting PV practices and of their understanding of the affordance offered in the system appliances, and their actual engagement with the PV appliances as a result, which can be only found in *real* practices, instead of finding it from verbal communication of objectified knowledge (Strati, 2007, Ingold, 2000). Equally, research on human memory and cognition shows that participants often forget details or recall them, based on their frame of mind, and are often motivated "to describe their practices in the best possible light" (Sussman, 2016: 12). To deal with these two criticisms, two further ethnographic methods are adopted: a home video tour and observations, after the initial inhabitant interview. A further criticism concerns the interview method's capacity to identify all the variables of the context that might affect the PV practice, due to the limited time and questions of the interview (Yin, 2013: 16) as well as the intermediaries that impact inhabitants' practices. This is dealt with next.

Two sets of interview questions were designed: one for PV inhabitants in the selected case studies and one for other actors who have participated in the PV provisioning process of these case studies. All the PIs were questioned using both sets of interview schedules ('inhabitant' and 'other actors') due to their participation in both PV provisioning and inhabitant occupancy practices. All interviews were based on a question guide across all participants' samples to create an adequate balance in responses. To optimise the interview process in terms of dealing with various circumstances and in case responses were not forthcoming, a variety of alternative prompts were introduced also (Hitchings, 2012). The provisioning team interview questions (see appendix 1) were classified into four main sections: PV governance actors and networks, PV governance changes, the design intention, and key lessons and recommendations. The inhabitants' interview questions (see appendix 2) were classified into four sections: general questions, PV actors and networks during occupation, PV practice, problems and changes during practice, and key lessons and recommendations. All the interview questions were generated in relation to the theoretical standpoint and literature review in the thesis and arranged according to the thesis objectives.

All interview participants were recruited using a snow ball method after initial identification of key participants in the case studies via the web and personal contact (both inhabitants and PV provisioning actors) (Section 4.5.1). The recruiting process was based on the strict ethics policy of The University of Sheffield (Section 4.5.2). The interviews with PV provisioning actors comprised of a mixture of face to face, Skype and phone, or questionnaire-based interview according to the availability of the participants. The interviews with inhabitants comprised of face-to-face and questionnaire-based interview. In total, 22 interviews were conducted with inhabitants in their homes and 16 with PV provisioning team (Figure 4.7). All 38 interviews lasted between 45- 90 minutes, and were recorded, transcribed and manually coded according to best practice (Schreier, 2012). Prior to conducting each of the interviews, the broad purpose of the research was explained to all participants and the information sheet which summarises the research goals was provided. They were also informed that their responses would be voluntary, confidential and anonymous, and that they had a right to withdraw from the discussion at any time during the discussion without having any responsibility for this (see appendix 3&4). The author asked the participants to sign a consent form just before starting to ask the questions and after reading the introduction section of the interview for the inhabitants, and in advance of conducting interview with PV provisioning actors (see Appendix 5&6). Figure 4.7 illustrates the overview of the interviews and ethnographic video tours conducted with both inhabitants and PV provisioning team.

Project	Type of actor	Number	Comment
LILAC	Inhabitants	4	Face to face interview, recorded and transcribed & video tours
	Provisioning Inhabitant (PI)	2	Face to face interview, recorded and transcribed
	Project manager	1	Skype interview, recorded and transcribed
Fireside	Inhabitants	3	Face to face interview, recorded and transcribed & 2 video tours
	Provisioning Inhabitant (PI)	2	Face to face interview, recorded and transcribed
Springhill	Inhabitants	3	face to face interview, recorded and transcribed & video tours
	Provisioning Inhabitant (PI)	1	Questioner-based interview
	Architec	1	Telephone interview, recorded and transcribed
	Monitoring group	1	Skype interview, recorded and transcribed
Hockerton	Inhabitants	4	Face to face interview, recorded and transcribed & 2 video tours
	Provisioning Inhabitant (PI)	2	Face to face interview, recorded and transcribed
	Architect	1	Questioner-based interview
Brearley Forge	Inhabitants	4	Face to face interview, recorded and transcribed & video tours
	Client representative	1	Face to face interview, recorded and transcribed
	Environmental manager of the client	1	Questioner-based interview
Green Street	Inhabitants	3	Face to face interview, recorded and transcribed & video tours
	Inhabitants	1	Questioner-based interview
	Project manager	1	Questioner-based interview
	Client- Project director	1	Skype interview, recorded and transcribed
	Architect	1	Questioner-based interview
	Inhabitants	22 18	Interviews Video tours
	Provisioning team	16	Interviews
Total		**38**	Interviews

Figure 4.7: Overview of the interviews and video tours with both inhabitants and PV provision team

4.4.3 Video tour

Conducting interviews with participants is not the only way to *get at* social practices. In order to a social practice to be better understood, discussions with participants need to be taken place within a situated action (Evans, 2011). In this light, home video tours (Stevenson and Rijal, 2010), developed from an ethnographic walkthrough method commonly used in an energy and building context, were conducted immediately after finishing the interviews with each inhabitant. This was to reveal the immediate complexities of inhabitants' practices in relation to their own PV systems, in a way that *retrospective* discussion cannot (Hitchings, 2012). Traditionally, walkthrough tours have been recorded only using interviews and questionnaires (Foulds et al., 2013, Powell, 2009). Being more "touchy, feely, looksee" than other qualitative methods (Crang, 2003: 494), a video tour enables researchers to explore collaboratively, the visual and practical knowledge of inhabitants of their PV controls both verbally and through them performing the actual practice in the context (Pink, 2009, Pink and Leder Mackley, 2013). Through the video tour, inhabitants commented on positive/negative aspects of their PV affordance and practice as they demonstrated and explained them, while the author videoed their responses. The video tour was also very useful to trace *non-human intermediary* actors in different situations that informed inhabitants practice of their systems during occupancy (2nd & 3rd objectives) (Silva, 2007).

Most significantly, the video tour helped reveal affordances (scripts) inherent in the PV appliances (e.g. PV meter, inverter, energy monitoring device), as decided by the provisioning actors, and what theses affordances did or did not offer the inhabitants (5th objective). This helped to understand how specific decisions made by PV provisioning actors influenced inhabitants' practices subsequently (Frances and Stevenson, 2018), and what practical knowledge, understanding and problems inhabitants had in relation to their PV controls in a real context (Pink and Leder Mackley, 2013, Spinney, 2009). This was achieved by asking inhabitants when visiting their PV appliances on the Video Tour to actually engage with their PV control there and then, and for them to instantly reflect on any problem they encountered. It was also useful to identify the changes in the availability of the PV affordances according to their needs, capability and the uniqueness of the event in place, all informing their practice.

All video tours were based on another question guide (see appendix 7) across all inhabitant samples, and prompts were again used to reflect on the different contexts in which they were operating in. In total, 18 video tours were directly conducted after finishing the interviews, as four inhabitants declined the video tour (Figure 4.7). The video tours lasted between 15 and 30 minutes each, depending on what issues came up and how long they were examined for.

4.4.4 Observation

Direct behavioural observation is a preferred method in a mixed-method approach in studies to understand the impact of physical environment on individuals' behaviour and practice (Zeisel, 2016). It can help to validate the self-reported behaviours (e.g. interviews) which have been critiqued for their accuracy (Bator et al., 2011). As such, an observation method was used to increase the "external validity" of the findings (Sussman, 2016: 12). This natural setting method means "watching people interact directly with their environment. What do they do? How do activities relate to one another spatially? It helps to get a sense of chain reaction and 'see the whole event' in a complex situation and its effect on the practice of use" (Zeisel, 1981: 111-115).

During the video tour, inhabitants were asked to perform their actual PV practice in a "naturally occurring context" (Silverman, 2006: 21), while a careful observational evaluation was made by the author focusing on the process itself as it unfolded, and observing any traits in the environment which revealed further information about inhabitants wider practices associated with the PV system (e.g. skill, meaning, etc.). The observation method also helps reveal whether, or not, the affordance provided by PV controls actually supports the practices taking place with it, especially the influence that the context has on these relationships (Zeisel, 1981). The observation method further helped to identify the role of various intermediaries, particularly the non-human ones, in shaping the type of inhabitant' occupancy practices (4th objective). Behavioural observation also revealed in a highly visual way: whether PV affordances were efficiently understood by the inhabitants and the flexibility of practices, the affordance appropriateness in relation to inhabitant and home differences; why a particular control worked well, or not, in a highly visual way; the deviation of practice and problems, and specific sociocultural meanings within a context that influenced the practices (Stern, 1998).

One critique of this method is that the observation method itself can influence the data. When inhabitants are aware they are being observed, they may alter their practices (Zeisel, 2016). The video tour data was carefully compared with data revealed from other methods to try and counter this potential bias.

4.4.5 Document review

A careful and comprehensive document review was used in this research as a complementary method to understand the different UK policies and regulations in relation to domestic PV systems and energy efficiency over time (Schwartz-Shea and Yanow, 2012). More specifically, reviewing the progress reports of UK policy related to CSH and FIT standards helped to understand the different views and stages in relation to these standards, and how their persistent changes formed the system design and practice when compared with data revealed by other methods (section 2.4.1).

When analysed using the methodological lens developed from the literature review (Chapter 2 and 3) (1st objective) the document review also helped to develop the interview schedules and explore certain aspects of PV provisioning and practices. In addition, examining publications about the case studies and community housing helped to provide a rich information context for the case studies to help decide the final list of the chosen case studies in this research. Reviewing case study publications and websites also enabled the author to choose the key participants, particularly to choose the PIs in the PC case studies who have participated in both stages of PV system: provisioning and occupancy practices.

The analysis of PV provisioning documents related to the case studies (e.g. commissioning reports, drawings, specifications, instructions, the designed and actual PV performance data and energy consumption data) helped to reconstruct the shifting networks around a particular issue or outcome (Kurokawa et al., 2016). These sources of information gave additional insights into how a network of actors, and the effective decisions made by them in their provisioning meetings, constructed the system design and inhabitants' practices of the PV system. The information also provides insights on how the PIs participation in the decision-making process influenced these decisions and practices. The PV documentation also helped to map out the context of the PV installation before the author engaged later with inhabitants directly using an interview and video tour techniques. This helped to make the later stage of data collection and evaluation more effective in terms of promoting interactive discussions with the inhabitants to understand their practices.

Reviewing PV drawings and specifications was also effective in terms of tracing the internal dynamic of any practice identified (Warde, 2005), by building up a background concerning the technical issues of PV systems in details, to help compare where changes might occur during occupation and the type of changes occurring (Stevenson and Rijal, 2010). This was mainly achieved by gaining access to the inhabitants' information pack provided by the developer to inhabitants when first handing over the homes. In case study C, detailed PV commissioning and progress reports were provided by the PI, while in case study A, the PI published the detailed building construction process of their case study including PV provisioning process in a book which was available at the time of conducting interviews. These detailed documents helped to identify aspects missing in the interviews and to develop a timeline of events as part of the context for practices and agency.

4.4.6 Mapping

All interviews and video tours data were manually coded into different themes (figures 4.9, 4.10) and innovatively *linked* to a mapping method so that all elements of a theme were clearly visible on the relevant map (Yaneva, 2012, Mayers and Vermeulen, 2005, Sova et al., 2016). This was done by physically and simply *drawing out* 'the relationship' between the actors in terms of the influence of one on the other, using connection lines and categorical lists on very large sheets of paper. These visual links and representation helped to clearly summarise a large amount of date including the critical actors (both mediators and intermediaries), and strong and emergent relationships between actors at different stages of PV provisioning process, which in turn influenced the PV design and inhabitants' practices for each case study, and their energy efficiency as a result (objectives 2 & 3) (Latour, 2005). Mapping of the PV provisioning data examined how power(s) transferred between the provisioning actors in the different building construction stages, and identified the shifts in actors' agency and capacity to make critical decisions governing the system design in each case study. Mapping was also used to understand why disintegration between PV actors occurred in specific stages and in relation to power transfer. This interrelated analysis helped to compare and understand the similarities and differences in the PV governance networks between the two contrasting sets of housing case studies. The mapping method was also useful to visualize how the various PV actors (both mediators and intermediaries) have influenced inhabitants' practices during occupancy (4th objective).

4.5 Research set-up

4.5.1 Selection of participants

Sampling and recruiting interviewees is the first stage in an interview process. At this point, a combination of different strategies was employed to enlist all the participants (both provisioning actors and inhabitants). A 'purposive sampling' approach (Bernard, 2002, Creswell, 2007) was used for targeting practitioners that met particular requirements (e.g. PV provisioning participation). This included: architects, project managers, the environmental manager, the monitoring personal, client representatives, and the Provisioning Inhabitants (PI) who actively participated in the PV provisioning process with the rest of the provisioning team (Figure 4.7). Participants were selected based on covering different areas of knowledge by selecting actors that played different 'roles' in the provisioning process, and to avoid over-emphasising a single case study actor. This helped to develop a 'bigger picture', through participants reflecting on their different practices, experiences and perspectives.

After the initial identification of key representative actors in the case studies via information obtained from the internet and by email correspondence, a 'snowball sampling' approach (Biernacki and Waldorf, 1981) was used to procure other participants. A 'maximum variation' method was used to secure information about the significance of various circumstances and situations when selecting inhabitants in relation to potential content. There were also not less than three inhabitants selected for each case study, to ensure generalisability of the findings (Flyvbjerg, 2006).

Given that the data for the PV provisioning participants was based on housing developments that had been completed for a number of years, the thesis did not cover the view of all actors who participated. This was because some of the provisioning participants had left their jobs and did not want talk about the case studies they had completed at the time of conducting interviews (F), while others in case studies (C, D) who agreed to participate in the research, did not recall many details because of the 15 years gap between the physical completion of the housing development and the time of conducting the interview. Some other provisioning actors, particularly the PV installers (A, B, D), and the architect (A), chose not to participate in this research without explanation. The PV provisioning data, thus, was largely based on information that was taken from the Provisioning Inhabitants (PIs) in the Participative Community (PC) case studies. In the Non-Participative Community (NPC) case studies, it was mainly based on the client representative (project director) (E & F) and the architect (F) (Figure 4.7).

4.5.2 Ethics

Ethical issues such as informant consent, privacy, anonymity and confidentiality have to be addressed throughout the research process (patton, 2001, Marshall and Rossman, 2010). As such, this study was conducted strictly according to the ethical policy of The University of Sheffield. After gaining ethical approval in 2014 (appendix 8), all the nominated participants were directly contacted by email/post. Some participants were indirectly contacted through their community email (for the community housing case studies), or through their company or office email (for the PV provisioning participants). Informed consent was received from all respondents, either by post or by email, prior to conducting any interview and video tour with them. All participants were informed in the information letter about the purpose of the research and how the data will be used. All the interviews and video tours were recorded after gaining permission from the participants and issues of confidentiality and privacy were verbally reiterated before starting the interviews. All these procedures gave confidence to participants to talk freely and express their thoughts.

Once the interviews and video tours were conducted, the data was kept securely and stored electronically on a password-protected computer, to which the researcher had sole access. All the participants' names were replaced with a code system at the start of analysis for anonymity (for example, inhabitant A1) and were kept confidential. The participants also all consented to their data being stored after the completion of the PhD for five years.

4.5.3 Pilot studies

A pilot study is a small-scale methodological test which is used to assess the feasibility of the proposed research methods of data collection, such as an interview or a video tour, or a particular research tool used (Perry, 2001). This is to ensure that the suggested methods will work efficiently in practice (Teijlingen et al., 2002), and to enhance the credibility of a qualitative study (Padgett, 2008). Piloting of qualitative approaches is also a very useful process for novice researchers, particularly when using the interview technique for the first time (as was the case for this author) (Holloway, 1997).

In this study, a pilot interview and video tour were carried out individually with two academic members in Sheffield University School of Architecture, who were familiar with qualitative research and post occupancy methods, prior to the main interviews. Piloting played a significant role in testing and refining the main interview and video tour questions and in shaping the final schedules. Practically, piloting also gave the author experience in interviewing people, and helped calculate the length of the discussion, evaluate the talk context in terms of the degree of noise, the appropriate distance between the interviewer and the participant, and to assess the quality of audio and video recording.

The main changes in the interview schedule and process resulting from the pilot study were:

- Re-grouping the interview questions into sections. This was to focus on specific topic in each section and to easily navigate the suggested time for each section when conducting the actual interview.
- Adding some filtering questions with the answer yes/no. This helped to jump from one question to another, depending on relevance, and save time.

- Increasing the suggested time for the interview from 30 minutes to 45 minutes in order to provide enough time to go through all the questions.
- Shortening the interview introduction to save time and participant attention.
- Deciding how and when to start the video tour method after the interview.
- Simplifying some questions into two questions which helped the participants to adequately answer both questions.
- Refining some broad questions to encourage more specific answers e.g "are there any influences in your life that have affected you?" was changed to "…that have affected your energy use?".
- Providing participants different choices in some questions to help them to clearly understand the question in the first place and to provide a more nuanced answer.
- Addressing problems with the pilot interview procedure. This included, asking questions in a way that participants could not understand, and talking too much rather than letting the participants talk.
- Gaining insight on potential areas that needed further exploration in detail during the interview, such as the load shifting experience and technical and affordance awareness.

The pilot study was also valuable when it came to write up the transcript. The main lesson learnt from this study was to ask the participants to speak slowly and clearly to catch all their comments and to leave enough pauses for the respondents to answer.

The main improvement from the pilot video tour schedule and process were:

- Changing the way of videoing inhabitants' engagement with their PV appliances from asking participants to video their specific engagement to the interviewer videoing the action. This helped the participants in the actual video tours to concentrate on the action and to answer questions.
- Introducing life size pictures related to the PV components and providing a brief description prior to conducting the video tour. This helped participants to recognise their PV components and visit them during the video tour.
- Improving the practicality of conducting the video tour using different tools at the same time, such as a recorder, a camera and the questions sheet. The

key problem was how to keep the recorder stable during the video tour in order not to affect the quality of the recording. This was resolved by using a more professional recorder than the used in the pilot study and to use the camera as a recorder as well.

Further iterations helped to improve some other key issues with the following changes:

- Introducing some simple questions in the start of each interview to help respondents to trust the interviewee.
- making no assumptions about the results when designing the questions.
- Identifying leading questions that need to be avoided.
- Being more inclusive when forming the questions and including ‘anything else’ options
- Adding prompts to some questions to clarify and respond to different situations and unexpected answers.

4.6 Data analysis

4.6.1 Thematic approach and coding

This section focuses on the research approach for data analysis to generate valid and credible results from qualitative data. The selected analysis approach and methods has to be able to work with the different epistemological viewpoints of the selected theories in this thesis: ANT, Practice and Affordance.

Thematic analysis was chosen for its capacity to work with a large volume of written and visual data, which can cause complications at the analysis stages (Denscombe, 2014, Schreier, 2012), and more significantly, for its *flexibility* to “be applied *across* a range of theoretical and epistemological approaches” rather than to be wedded to a specific theoretical framework, such as conversation analysis (Braun and Clarke, 2006: 78, emphasis original). This helps to better analyse the data and to frame rich and credible outcomes. Thematic analysis is a “foundational method for qualitative analysis”, (Braun and Clarke, 2006: 78). Another strength concerns its successful combination of two conflicting methodological principles: theory-guided investigation and openness (Gläser and Laudel, 1999). This comes from its potential to examine meanings, experiences and the reality of participants’ practices, and at the same time inspect the role of the sociotechnical contexts and networks in shaping these practices and realities (Willig, 1999).

This thesis identifies and reports themes within data through careful reading and re-reading of the data and linking them to the theoretical positions of the study. A *theme* "captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set[16]" (Braun and Clarke, 2006: 82).

Two key approaches of interpreting and analysing themes within data are referred to from the qualitative literature: *inductive* and *deductive* approaches (Schreier, 2012, Braun and Clarke, 2006). An *inductive* analysis is a data-driven strategy, which themes emerge directly from the data without trying to fit the data into a pre-existing frame. In contrast, a *deductive* analysis, or a *theoretical* thematic analysis, is a concept-driven strategy, generally driven by the research's theoretical interest in the area. However, a third approach of analysis – an *abductive* research process, is also used in qualitative research to develop the understanding of a phenomenon (Alvesson and Sköldberg, 2009) using an iterative dialogue between the empirical data and existing theories (Van Maanen et al., 2007, Dubois and Gadde, 2002). This approach is adopted for the thesis, due to its ability to provide a more comprehensive understanding of a phenomenon, and to advance an existing theory based on empirical setting (Dubois and Gadde, 2002). The *abductive* approach is used to identify themes within the interviews, video tours and document review data, and to make sense of the empirical data in light of the theoretical approach developed for this thesis.

The analysis of the interviews and video tours was *deductively* guided by pre-coding as a suitable means of focusing the research and prevented the analysis from deviating too far off topic (Schreier, 2012). The coding manuals were based on important topics previously derived from research that are interested in the theories adopted in this thesis and PV systems literature review, before looking at the data. These manuals are defined as "a statement of instructions to coder that also includes all the possible categories and sub-categories for each dimension being coded" (Bryman, 2012: 299). The Pre-coding categories/sub-categories (e.g. Role of actors:

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[16] Data set refers to "all the data from the corpus that are being used for a particular analysis" BRAUN, V. & CLARKE, V. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology,* 3**,** 77-101.

mediator/intermediary) were mainly derived from the key findings from the ANT, Practice theory and Affordance theory literature, and in relation to the identified thesis aim and objectives (Schreier, 2012, Guy and Moore, 2005, Pallasmaa, 2009, Blundell Jones et al., 2005). This helped to make sure that all important aspects of PV provisioning and occupancy practices were captured (Sarker et al., 2006). Figure 4.8 illustrates how the key Pre-codes in the thesis Pre-coding manuals emerged.

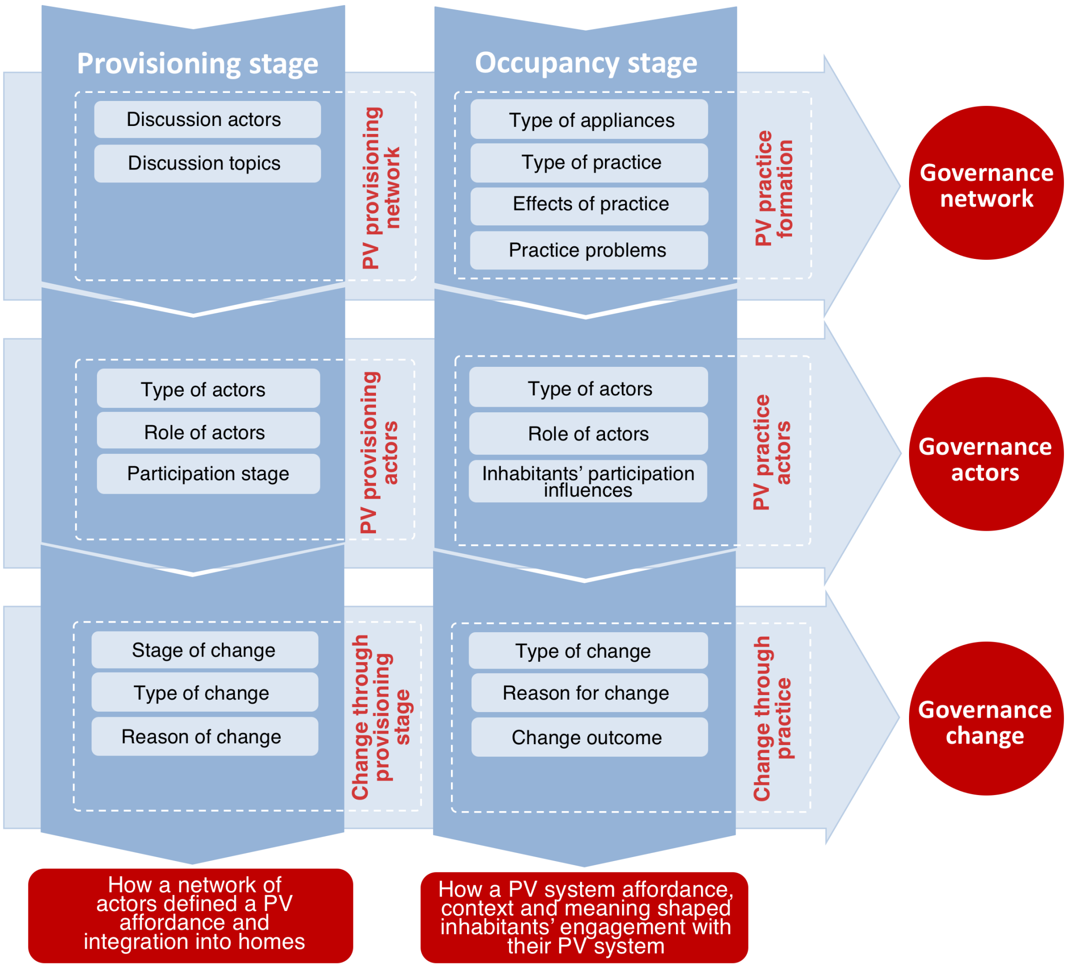

Figure 4.8: ANT, Practice and Affordance theories guiding the thesis Pre-coding manuals (categories & subcategories)

The individual Pre-codes in this thesis were developed in two dimensions as two separate Pre-coding manuals (Figures 4.9 & 4.10):

1- PV *governance* dimension - analysing the data was generated from the interviews with PV provisioning team and document review. This also analyses the data generated from the interviews with the inhabitants in terms of identifying the different actors that influenced inhabitants PV practice during occupation. The pre-fixed categories/subcategories in this dimension are (Figure 4.9): Provisioning team intentions in relation to inhabitants' practice of their PV system, PV provisioning and practice actors and networks, and PV provisioning changes, inhabitants' participation influences, and good practices and actors' recommendations.

2- The *practice* and *affordance* dimension - analysing the data was generated from the interviews and video tours with inhabitants in relation to their own PV systems practices during occupation. The pre-fixed categories in this dimension are (Figure 4.10): Inhabitants' motives to install a PV system, PV practice formation, problems, and changes, and good practices and inhabitants' recommendations.

Dimensions	Categories		Sub-categories	
Dimension (1) *PV governance (actors & networks)*	Provisioning team intentions in relation to inhabitants' practices of their PV system (1.1)			
	PV provisioning and practice actors (1.2)	Type of actors (1.2.1)	Human actor	1.2.1.1
			Non-human actor	1.2.1.2
		Role of actors (1.2.2)	Mediator	1.2.2.1
			Intermediary	1.2.2.2
		Participation stage (1.2.3)	Provisioning stage	1.2.3.1
			Occupation stage	1.2.3.2
	PV provisioning and practice networks (1.3)	Discussion actors (1.3.1)		
		Discussion topics (1.3.2)		
	PV provisioning changes (1.4)	Stage of change (1.4.1)		
		Type of change (1.4.2)		
		Reason for change (1.4.3)		
	Inhabitants' participation influences (1.5)			
	Good practices (1.6)			
	Actors' recommendations (1.7)			

Figure 4.9: Governance dimension Pre-coding manual

Dimensions	Categories		Sub-categories	
Dimension (2) *(PV practice and affordance)*	Inhabitants' motives to install a PV system (2.1)			
	PV practice formation (2.2)	Type of PV appliances (2.2.1)		
		Type of practice (2.2.2)		
		Effect of practice (2.2.3)		
	PV practice problems (2.3)	Type of problem (2.3.1)		
		Effect of problem (2.3.2)		
	PV changes through practice (2.4)	Type of change (2.4.1)		
		Reason for change (2.4.2)		
		Change outcome (2.4.3)		
	Good practices (2.5)			
	Inhabitants' recommendations (2.6)			

Figure 4.10: Practice & affordance dimension Pre-coding manual

While the Pre-coding manuals are very helpful in organising the data, their key disadvantage is that they furnish "a powerful conceptual grid" which takes attention away from uncategorised activities (Atkinson, 1992). One way to deal with this criticism in this thesis, was the use of the observational method due to its capacity to shift emphasis each time new data become available (Silverman, 2006). The observational data was very helpful in understanding inhabitants' know-how in relation to the affordances offered in the PV appliances, and within its physical context and meaning, discussed in chapter nine.

However, new codes were also introduced freely (Free-coding) during the coding process when looking directly at the data (Schreier, 2012). In terms of this research, Free-codes were developed on the basis as they appeared within the interviews, video tours and related documents data to generate new codes (both categories and subcategories) not included in the Pre-coding manual from the literature. This enabled additional specific patterns and tendencies in relation to PV provisioning and occupancy practices to be recognised directly from the data, which more directly reflected participants' reality and experience in situ. The new Free-codes created in this thesis in relation to inhabitants' practice are: 'practice patterns, drivers and understanding, change restrictions in relation to inhabitants' practice, inhabitants' conflicts and the influence of living in community housing on PV system' (see appendix 9). The new Free-codes related to governance were: ‘not discussed topics’, and ‘change outcomes’ (see appendix10).

The next stage in the coding analysis was to create a more comprehensive understanding of the meaning of each Pre-coding category/subcategory and to provide rules for assigning data segments to the categories (Graneheim and Lundman, 2004, Schreier, 2012). This helps to reduce the possibility of shifting and changing the meaning of the categories during the analysis, to avoid different understandings of the Pre-coding categories by different coders, and to address the problem of overlapping codes or codes that had similar content. This increases the validity and reliability of interpreting the data and was achieved by following the four stages suggested by Schreier (2012: 95): create a *name*, a *description* of what you mean by that name, *examples* and *decision rules*[17] ‘if needed’ (see next section). In the process of coding all the interviews and video tours data, each segment of the interview, video tour and related documents was assigned against the initial Pre-codes and in all cases. However, multiple codes were often assigned to a single piece of data, or new codes created as Free-codes. This was achieved by adopting a *key point* coding strategy to interpret the data rather than simply analysing individual *words* (Bryman, 2003).

This thesis also deployed some quantitative description of qualitative data (stage four in Figure 4.6), to enable numerical data to be presented graphically and indicatively, but with a limited role in the analysis overall, and providing no statistical evidence. This was done by creating spreadsheets and bar charts, after coding all the interviews and video tours data with both PV provisioning actors and inhabitants (Chapters 5&6), to quantify certain type of qualitative data including PV decision discussions (e.g. Figures 5.13, 5.15), PV engagement and affordance problems (e.g. Figure 6.7, 6.8), change restrictions (e.g. Figure 6.14), etc.). This helped to understand and articulate the indicative significance of the different categories/sub-categories in relation to PV provisioning and practice coding manuals (Figures 4.9, 4.10) and to compare between the two types of case studies presented in this thesis: PC & NPC. These charts also enabled a deeper discussion to be undertaken and revealed niche findings in chapters 7, 8, 9 and 10.

[17] Decision rules “tell the coders which of two overlapping categories to use. They should specify what is not to be included in a category and which category to apply instead”. SCHREIER, M. 2012. *Qualitative Content Analysis in Practice,* London, SAGE.

4.6.2 Inter-coder reliability

Coding interview and video tour data is susceptible to subjective code bias which is highlighted by Krippendorff (2004) as one major source of error in qualitative research that may lead to a lack of *reliability*. To overcome this problem, the coding needs to be tested for reliability in a pilot phase (Schreier, 2012). Both the author and the supervisor independently tested the Pre-coding of a selected interview transcript twice using the coding manuals. This was to confirm the conformability[18] of findings and to assess the trustworthiness of the research (Licoln and Guba, 1985). In the first test, the results had less than 50% similarity for coding. Following this stage, extensive discussions took place between the two coders, focusing on the units of coding that were interpreted differently, clarifying the reasons for that, and discussing any apparent difficulties in assigning some segments to a specific code. The differences were mainly attributed to the insufficient provision of a clear and detailed definition for each code, and the codes were subsequently clarified. As a result, the second test, the differences were reduced to a minimum level (less than 10%). As such, the degree of agreement was used as a test of the reliability of the measure and prior to conducting any further analysis.

The main Pre-codes (categories and sub-categories) emerging from literature review which related to the *PV governance dimension* (1) (Figure 4.9): were:

A- Provisioning team intentions in relation to inhabitants' practices of their PV system (1.1). This main category examines the PV provisioning actors' viewpoints in terms of whether, or not, inhabitants need to engage with their system appliances, and why.

B- PV provisioning and practice actors (1.2). This main category discusses three key aspects:

- *Type of actors (1.2.1)*. This category has been split into two sub-categories: human actor (1.2.1.1) and non-human actor (1.2.1.2).

[18] Conformability means that "the data accurately represent the information that the participants provided and the interpretations of those data are not invented by the inquirer" POLIT, F. & BECK, T. 2008. *Nursing research: Generating and assessing evidence for nursing practice*, Lippincott Williams & Wilkins.

- *Role of actors (1.2.2)*. This category has been divided into two sub-categories: mediator (1.2.2.1) and intermediary (1.2.2.2) which were clearly defined in chapter 3.2.1.3.
- *Participation stage (1.2.3).* This category has been split into two sub-categories: provisioning (1.2.3.1) and occupation (1.2.3.2) stages. The provisioning stage codes the actors that have *only* participated in the PV provisioning process during the housing construction, while occupation stage starts from the day that inhabitants move into their houses and start to practice the PV system in their homes, coding all actors involved at this stage.

The PV practice actors' (categories and subcategories) were deliberately coded within the PV practice and affordance manual (dimension 2) when conducting the actual coding, rather than coding them within the PV governance manual as originally designed. This is due to using a *key point* code strategy to interpret the data where multiple codes have been assigned to a piece of data, which in many cases related to categories from both the coding manuals. This helped to avoid repetition of the same data in both coding manuals, and to better understand and code those actors, and their critical influence on inhabitants' practice of the system appliances.

C- PV provisioning and practice networks. Two main areas needed to be coded and discussed in order to provide a comprehensive insight for the PV provisioning network. These were:

- *Discussion actors (1.3.1)*. This category refers to all the actors that have participated in the PV provisioning discussion meetings, resulting in a specific decision made in relation to PV system. This includes both the specific one-to-one discussions or group discussions between PV provisioning people, the discussion between the PI and other provisioning team, and the discussion between the PI and other community members during the construction stage.
- *Discussion topics* (1.3.2). This category refers to all the issues/topics that have been discussed between the actors through their meetings in relation to the PV system.

D- PV provisioning changes (1.4). This category refers to all the changes that were made by the PV provisioning actors in the original design of the PV system or in relation to its integration into homes. Three main aspects need to be addressed when examining changes during the PV provisioning stage.

These are: stage of change (1.4.1), type of change (1.4.2) and reason for change (1.4.3)

- *Stage of change*. This category identifies the particular stage (preparation, design, installation) when a change was made by the PV actors during the provisioning process.
- *Type of change*. This category classifies the different types of PV changes, such as technical changes or context change.
- *Reason for change.* This illustrates the main reason(s) for the PV provisioning actors making a specific change, such as to adapt to a specific design of a home or to react to an expected problem in the PV design.

E- Inhabitants' participation influences (1.5). This category refers to the consequential influences from the inhabitants' participation in the PV provisioning process on the process of the inhabitants' PV system practices during occupation.

F- Good practices (1.6) and actors' recommendations (1.7). The difference between 'Good practice' and 'actors' recommendation' is that the former refers to something that has been done during the PV provisioning process and actors want to recommend it to others, while the latter refers to something that has not been done but they think should be in future practices.

The main Pre-codes (categories and sub-categories) emerging from literature review which related to the PV practice and affordance dimension (2) (Figure 4.10) are:

A- Inhabitants' motives to install a PV system (2.1). This main category identifies the key reason(s) why inhabitants decided to install a PV system in their houses, such as to generate free energy which could reduce their energy bills, or to reduce their negative impact on the environment by using a renewable energy.

B- PV practice formation (2.2). This main category discusses three key aspects:

- *Type of PV appliances* (2.2.1). This category codes all the appliances that inhabitants are engaging with during their occupation of the houses, such as PV meter, inverter, etc.

- *Type of practice* (2.2.2). This refers to the type of activities that are undertaken by inhabitants during their practice of PV appliances, such as taking meter reading or observing the system performance.
- *Effect of practice* (2.2.3). This category codes the impact of inhabitants' PV appliance practices on their energy production and consumption. The given example addresses the positive impact from an inhabitant practice of her PV meter: "Yes, of course, reducing my energy bill" (A4).

C- PV practice problems (2.3). This main category discusses two key aspects:

- *Type of problem* (2.3.1). This category examines and groups the different problems that inhabitants have experienced when practicing their own PV system. Examples includes, problems concerning the system design or the immediate environment surrounding the PV appliances.
- *Effect of problem* (2.3.2). This category codes the impact of the different highlighted problems by inhabitants on their PV system practice. For example, the impact of allocating the PV panels in inaccessible roofs disabled inhabitants from cleaning their dirty panels, which in turn reduced the energy generation from the system.

D- PV changes through practice (2.4). This category refers to all the changes that were made by inhabitants when practicing the system in their sociotechnical context. Three key aspects need to be focussed when examining inhabitants' changes during practice:

- *Type of change* (2.4.1). This category classifies the different types of changes made by inhabitants when encountering their own PV system, such as changing their practice in relation to energy practice, or making technical changes in relation to the system design and integration into homes.
- *Reason for change* (2.4.2). This category codes the main driver(s) for inhabitants to make a specific change in their PV practice. For example, the main reason/driver for inhabitants to change their energy practices is to adapt their overall energy consumption patterns to their individual PV energy generation patterns.
- *Change outcome* (2.4.3). This refers to the consequential effects from the implemented change made by inhabitants during their PV system practice. For example, the key positive outcomes from inhabitants matching their energy

loads were both financial by reducing their energy bills, and environmental by reducing their CO_2 emissions in the environment.

E- Good practices (2.5) and inhabitants' recommendations (2.6). 'Good practices' refers to the positive practices that were performed by inhabitants in relation to their PV systems and their desire to recommend it to others. By contrast, 'inhabitants' recommendations' refers to aspects that have not been done by inhabitants, but they think it is important to be done in future practices concerned their interaction with PV system.

4.7 Sub-conclusion

In this chapter, the research methodology was set out and justified, drawing on several theoretical lens through a qualitative mixed methods approach for data collection and analysis within the case study approach. The key critique of the qualitative case study research in terms of its vulnerability to provide credible and generalisable outcomes (Denscombe, 2005) was addressed in this thesis by designing a clear system to formalise the research data into valid results and employing a rigorous sampling strategy. The suggested *exemplars* method (Flyvbjerg, 2006) for case study selection provides an exploratory approach to research drawing on three theoretical viewpoints (ANT, Practice and Affordance) for gaining new knowledge, while the *extreme cases* method enables a comparison between two types of housing provisioning in the UK: PC and NPC case studies, in relation to PV provisioning and occupancy practices.

Various methods are combined for data collection to help ensure the validity of the outcomes and to provide a complete understanding of PV provisioning and occupancy practices. After documentary reviews and site visits, the subsequent coding of 38 semi-structured interviews and 18 home video tours provides a general understanding of the PV provisioning and occupancy networks and practices, as well as examining how affordances offered in PV appliances are understood and engaged by inhabitants in their context. Some quantitative analysis of qualitative data is used to understand and articulate the indicative significance of the different categories/sub-categories derived from the coding of PV provisioning and practice. A mapping analysis then illustrates and compares the governance networks of the different PV provisioning case studies. The mapping strategy centres on ANT's concepts of actor-network and power translation– an entirely novel strategy introduced via this thesis - as none of the previous PV energy efficiency studies have mapped actors' agencies through the provisioning and occupancy stages, emerging from coding the interview and video tour data, and the related documents. A pilot study was conducted to improve the interview and video tour schedules and processes, and to increase the credibility of the qualitative methods selected. An inter-coding technique was used to increase the reliability of the outcomes.

The *thematic* approach for analysing a large amount of qualitative data was selected for its potential to work with two contradictory methodological standpoints at the same time: theory-guided investigation and openness. To do so, an *abductive* approach, combining deductive and inductive approaches, was adopted to generate research outcomes.

Following this, chapters five and six will demonstrate the key results that align with the 2nd, 3rd, 4th and 5th objectives of the thesis through coding, while chapters seven and eight will discuss these findings in relation to ANT's notions of actors' agency and networks through mapping. This shifts the focus away from the fixed interest of actors to an explanation of actor networks by which PV design and practices are specified and governed. Lastly, chapter nine will further discuss these findings in terms of inhabitants' actual practice of their PV system appliances in relation to how their governing role in the provisioning of their PV systems influenced their practices.

CHAPTER FIVE: PV PROVISIONING JOURNEY

5.1 Introduction

This chapter discusses the rich context of the PV provisioning process in the selected case studies. The first section provides a descriptive account of each case study for both Participative Communities (PC) and Non-Participative Communities (NPC), focusing on PV provisioning and occupancy practices. The second section provides an overview of the findings resulting from the documentary review and the coded PV professional interviews. This helps to understand the governance of various PV provisioning actors and networks in the two different sets of low carbon housing communities situated in various parts of England as specific contexts.

5.2 Case study descriptions

This section describes the six chosen housing case studies (four PC and two NPC) in more detail to set the scene before the first analysis of provisioning activities. Figure 5.1 shows the location of the case studies.

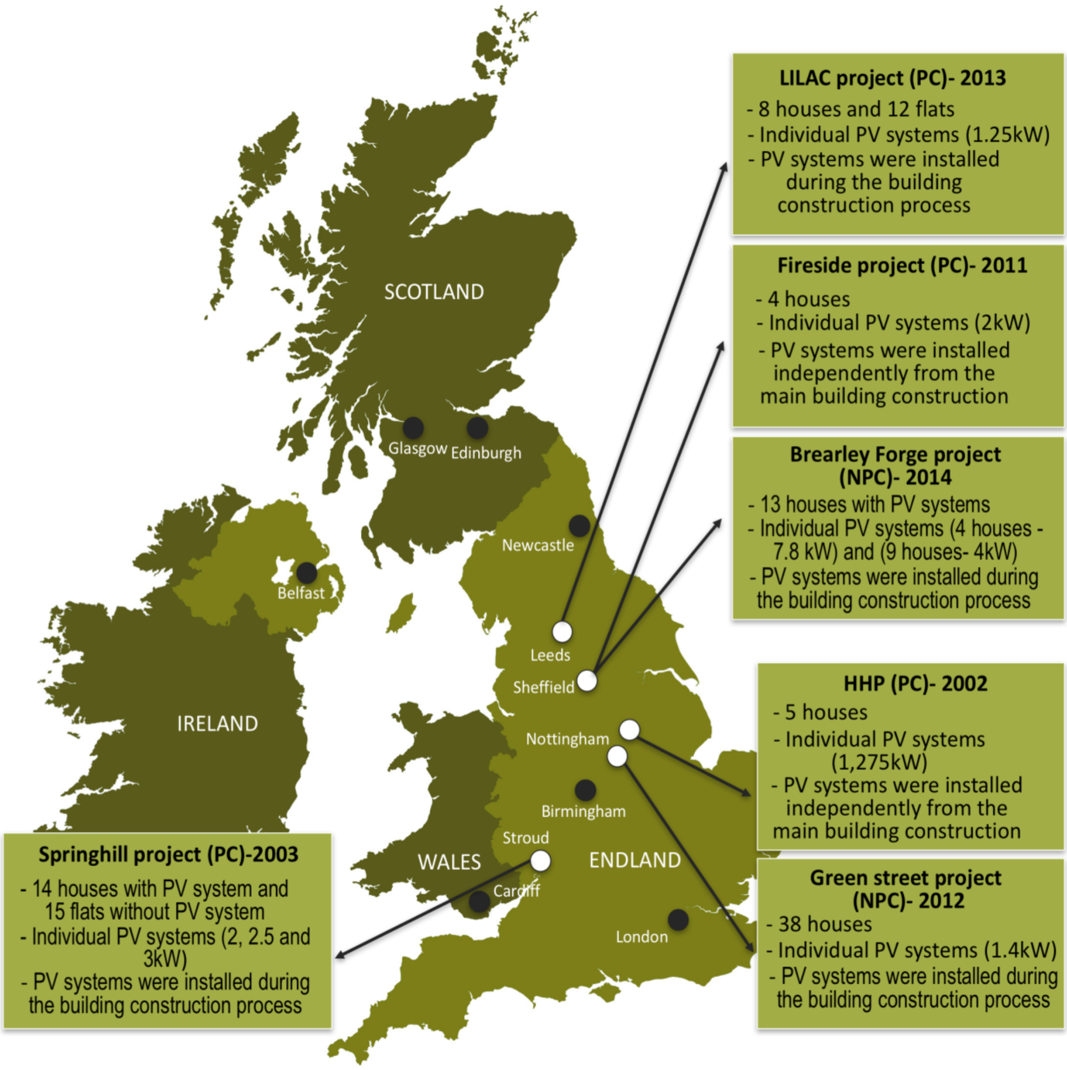

Figure 5.1: Location of the selected case studies

5.2.1 Participative Community (PC) case studies

Four PC case studies were selected as exemplary cases of established community housing developments: LILAC in Leeds, completed in 2013 (A), Fireside Co-operative in Sheffield, completed 2011 (B), Hockerton in Nottinghamshire, completed 2002 (C) and Springhill in Stroud, completed 2003 (D). In all cases, some inhabitants – the Provisioning Inhabitant(s) (PI) - took part in discussions with the design team during the actual PV provisioning process, while the whole community acted as a client, having regular meetings with the PI's to ratify the decisions made by the PI's and other provisioning actors. The PC as a whole was then responsible for the PV maintenance.

5.2.1.1 LILAC

The Low Impact Living Affordable Community (LILAC) in Leeds is a relatively recent highly innovative and outstanding low energy Co-housing development in England. This Mutual Home Ownership Society (MHOS) offers innovative solutions for sustainable living and collective grassroots governance (Figure 5.2, 5.3). LILAC allows everyone their own privacy while encouraging them to share resources. The case study comprises of eight houses and 12 apartments. The site also includes communal facilities, including a communal house, gardens, a play area and car parks. The environmental concern of the 20 households and their commitment to two grant bodies- (the UK's Department of Energy and Climate Change (DECC), and Home and Communities Agency (HCA), through their low carbon investment) led to a novel selection of natural materials - strawbale and timber (Modcell) - for construction. This was to help meet the UK Code for Sustainable Homes (CSH) level four required by the supporting housing agency, and to reduce individual household energy consumption from the grid and carbon emissions (CO_2) as a result (Chatterton, 2013). To achieve their CSH 4 target, the community had to invest in additional energy measures, identified by an external energy consultant employed to design the energy strategy for the case study in the early stage of the building construction process. These included 29kW or more solar PV installations, higher performance insulation in the windows, doors, roofs and floors (Chatterton, 2013). Other measures to reduce energy consumption during occupation included locating washing machines in the common house and connected to 4kW PV array. (Chatterton, 2013: 126).

A number of community members (PIs) participated during various stages of the building construction process in order to represent the community interest during the process. A project manager specialising in Co-Housing projects and housing management was employed during the entire building construction to help the PIs to make correct decisions through their discussion with the other professionals (e.g. architect, main contractor, quantity surveyor). Two PIs were interviewed for this thesis. However, one of them (A3) was clearly the main PI.

Each individual home PV system consists of five panels (1.25kWp) designed to generate 1073kWh annually, a meter, a convertor and an isolating switches (Chatterton, 2013). A pioneering home handover process was commissioned by the main contractor. This involved the Mechanical & Engineering (M&E) subcontractor informing selected LILAC inhabitants about how to use their home technologies in general, so that these inhabitants could pass on their knowledge to all other community members (Baborska-Narozny et al., 2017). This was to reduce the cost of the hand over process. All the energy generation and consumption is recorded by the maintenance team which is also responsible for producing collective energy generation and consumption graphs. However, all the inhabitants are individually responsible of taking the energy generation and consumption readings to give them to maintenance team.

Figure 5.2: LILAC community housing case study as built, showing PV panels on the roofs

Figure 5.3: LILAC community housing case study as built, showing the flats which also have PV panels on the roof

5.2.1.2 Fireside

Fireside Co-operative Housing is a shared ownership development of four Victorian terraced houses and shared garden based in a multicultural area in Sheffield (Figure 5.4 & 5.5). The Co-operative community recently conducted a comprehensive retrofit programme in 2011 including, triple glazing and high level of wall insulation, as well as the installation of a self-financed installation of a 2kW PV system in each house. Although this Co-operative was principally established to provide affordable self-managed housing, it also demonstrates social and environmental commitment, sharing resources, food growing and aiming for energy improvement.

All the individual household PV systems were installed independently in 2011 from the main building extension and retrofit. The two PIs interviewed in this thesis had direct contact with the PV installer to discuss various issues, such as the system size, cost, locations and installation time frame. All the PV decisions were made by the PIs and the installer, and then ratified collectively by all the community members based on advice from the PIs. All the PV panels were attached to the south face of the roofs (Figure 5.4), while all the internal appliances were located in the cellars. The installer later explained the systems to the PIs which they in turn explained to the other community members, as part of the handover process.

The energy generation and consumption meter readings have been taken weekly by one of the PI's on a voluntary basis, then analysed and collective graphs were then produced. This helped the community to assess the performance of the PV systems and to identify problems instantly (PI-B1). Discussion concerning the energy consumption management took place between all the inhabitants when the PV systems first started up, but it stopped later as it generated tensions between people who really wanted to reduce their carbon footprints, and other inhabitants who were not concerned about it (PI-B1).

Figure 5.4: Fireside co-operative showing the front south face with PV systems

Figure 5.5: Fireside co-operative showing rear retrofit extension

5.2.1.3 Hockerton Housing Project

The exceptional Hockerton Housing Project (HHP) was the first sustainable and zero energy residential development in the UK, located in Nottinghamshire and completed in 2002. The case study consists of five low-energy, earth covered houses incorporating a number of energy conservation measures, such as high levels of insulation and thermal mass, south-facing conservatory and renewable energy installations (Figure 5.6 & 5.7). All the inhabitants are committed to living in an environmentally sensitive way during occupation (Energy saving trust, 2003). The case study also consists of a Sustainable Resource Centre (SRC) building with shared facilities, which is separated from the main terrace houses. Throughout the building construction, two inhabitants with experience in low-energy building, acted as a PI and builder, while once again the whole community acted as a client.

Two types of renewable energy were installed to generate energy to meet all the community electricity requirements: a 6kW Proven wind turbine and a 7.65kW roof-mounted photovoltaic (PV) system. The PV system was fitted post construction, and funded by the Department of Trade and Industry (DTI) domestic field trial grant, with some match-funding from Powergen (HHP report, 2002). The communal PV system consists of six identical 1.275kWh arrays, designed to produce 6000kW annually. The majority of the PV panels were mounted along the conservatory parapet using a proprietary ConSole[19] structure to support the panels, while 14 panels were attached to the end elevations of the case study (Figure 5.6). The internal PV appliances (meter, inverter, analogue energy generation device and isolating switches) were installed in the Porch. The long process of getting permission to install PV systems from the planning authority forced the inhabitants to make a decision to have On-grid PV systems in place of desired self-sufficient Off-grid PV systems (PI- C1). Two monitoring systems were installed which allow inhabitants to collectively monitor their PV performances as a requirement of the grant body (DTI). The inhabitants still continue to collect the data, 2 years after grant body requirement finished. Easy access to the roof is available due to the earth sheltered nature of the houses which helped inhabitants to clean their panels quarterly and trim the weeds, based on advice from the installer and the PI (HHP report, 2002).

In 2013, the community installed a second communal 6kW PV system on the flat grass roof of the SRC building. This was to help close the gap between the total energy production and consumption. The planning permission was granted easily, because the site was already home to another PV array. For this second phase, all the panels were mounted on aluminium brackets instead, but they were not sufficiently weighted down by the installer and high winds resulted in some of the PV panels being damaged that year.

[19] ConSole: Plastic boxes filled with stone ballast.

Figure 5.6: Hockerton community housing case study as built (online published image)

Figure 5.7: Hockerton housing case study showing the PV panels fitted on conservatory parapet (online published image)

5.2.1.4 Springhill

Springhill in Stroud, Gloucestershire is another ground-breaking new-build Co-housing development completed in the UK in 2003, which is planned, owned and managed by the inhabitants (Figure 5.8 & 5.9). Inhabitants have participated actively in the design and operation of their community, but crucially not in the construction stage and the provisioning of PV systems, which was discussed and decided through a single representative inhabitant (PI). The inhabitants of Springhill became part of the free-hold development as equal directors of Springhill project. Most people who choose to live in the community tend to be environmentally conscious (Egan, 2004). The case study comprises of 15 flats, 14 terraced houses and six large semi-detached houses. The site also includes a communal house at its centre, shared car park and gardens. Laundry facilities are located in the common house, but inhabitants are free to have a washing machine individually in their house. Once the general design of the whole project had been agreed, individual inhabitants were able to customize their homes. As such, the internal layout of the houses varied, resulting in inhabitants having difficulties to find a credible contractor to build the houses within the allocated time and cost (Architype website).

The homes have an ecological construction, with timber frames filled with 150mm Warmcel[20] insulation and triple glazing is used to reduce heat loss (Egan, 2004). All homes are south-facing (solar orientation) with south oriented windows where possible. All the houses (not the apartments) have PV tiles sized at 3.0kW on six larger houses, 2.5kW on six middle houses and 2kW on eight smaller houses within an overall 49kW PV system (Pasquale et al., 2013). A £320 000 government grant from the DTI enabled the installation of PV systems and generated payments in 4 stages: design, provisioning, installation, and monitoring over a further 2 years, as a grant body requirement.

All the inhabitants are responsible for maintaining the shared facilities, but they also have an individual responsibility to maintain their own houses including cleaning their own PV system. All the PV systems consist of: energy generation and export meters located near the main entrance, a convertor and isolating switches located in the upper floor, and PV tiles which take up a large area of the roof. For every three houses, a monitoring logger was installed to monitor the generation performance of the individual PV systems. The household energy consumption was also monitored from initial installation for two years as a part of the government grant that subsidised them, and then extended to another three years due to inhabitants' desire to monitor their collective PV and energy performance patterns. All the inhabitants were involved in the monitoring process through reading their PV and energy import and export meters and all the monitoring data were sent monthly to researchers at Loughborough

[20] Warmcel is manufactured from 100% recycled newspaper.

University who analysed the data and produce collective graphs which were sent back to all the inhabitants.

Figure 5.8: Springhill Co-housing case study showing the PV tiles

Figure 5.9: Springhill Co-housing case study as built

5.2.2 Non-Participative Community (NPC) case studies

Two relatively recently completed non-community housing developments were selected as exemplary NPC case studies: Brearley Forge housing in Sheffield, completed in 2014 (E) and Green Street in Nottingham, completed in 2012 (F).

5.2.2.1 Brearley Forge

Brearley Forge housing case study is the first phase of a ground-breaking 15 year program commenced by the Sheffield Housing Company (SHC)[21] in 2012 which aims to build 2300 new homes built for sale and affordable rent of the highest quality in Sheffield (Figures 5.10 & 5.11). The relatively large case study consists of 142 homes situated in the Parson Cross area in the north east of Sheffield and was completed in 2014 (Sheffield Housing Company, 2016). Sheffield City Council required all new homes in this phase to be built with 10% renewables to achieve the Code for Sustainable Homes (CSH) level 4 and above. Consequently, 10 houses were provided with 4kW PV system in order to achieve the level four of CSH, while four houses were provided with 7.8kW PV system to achieve a zero carbon level of performance (CSH-6) and together these PV enabled homes form the case study (two CSH-4 & two CSH-6 houses). The main layout of the overall project was also designed with a passive solar orientation to maximise the benefit from future PV installations, with roofs designed to carry PV panels in the future (Participant- E6).

All the PV systems were designed and installed by a sub-contractor (a PV installer) employed by the main contractor. However, the PV demonstration process for the inhabitants was carried out by an external agent of the main contractor as a part of the main home induction process. All the CSH-4 houses contain a PV meter, an inverter with a display screen and isolating switches, and PV panels. Energy monitoring devices were only installed in the CSH-6 houses because the client developer aimed to improve the energy efficiency in these houses by enabling inhabitants to match their energy production and consumption loads via the use of the monitoring devices. The PV meter in all the houses was located in a box next to the main entrance to the home, while the inverter and the isolating switches were located in the attics without inhabitants having access to them (Participant- E6). All the PV

[21] SHC is a unique private developer established in 2011 as a partnership between Sheffield City Council, Keepmoat Ltd. and Great Places Housing Group

panels were attached to the south faced roofs without inhabitants having access to clean them if needed.

Figure 5.10: Brearley Forge case study showing the PV panels on the CSH-6 house

Figure 5.11: Brearley Forge case study showing the PV panels on the CSH-4 house

5.2.2.2 Green Street

Green Street is another exceptional development of 38 high quality three and four bedroom terraced houses built for sale near to the River Trent in Nottingham's Meadow area, and was completed in 2012. All of the homes comprise of a ground-level court yard and large roof terraces, while most of them have balconies and private car garages (Figures 5.12). Several sustainability factors were considered at different stages of the project to achieve CSH-4 of the Code of Sustainable Homes (CSH) and an Energy Performance certificate (EPC) rating A including: maximising the use of natural light, insuring a high level of insulation and airtightness, whole-house heat recovery and installing an individual I.4kW roof-mounted solar panel system in each house. All this helped to make use of passive solar gain and to maximise energy efficiency (Igloo, 2013).

All the PV systems were designed by the Service Consultant (SC) of the main contractor and installed by a sub-contractor, while the main contractor, the client and the architect collectively decided on the location of the internal PV appliances and the method of fitting the PV panels on the roofs. The position of the PV panels on the roof was decided by the architect who provided the installer guidelines on acceptability of appearance on the roofs. All the PV meters were installed near the main entrance of the houses, while all the inverters and isolating switches were installed in a cupboard in the terraces. In the second phase of the case study, the main contractor changed from fixing the panel mounting brackets directly into the timber deck through the roof to using free standing PV panel support frames. This new method helped to avoid one of the main sources of roof leakage in the all first phase houses, due to the penetration of the roof membrane by the panel structure fixings. All the PV systems were handed over by an external agent of the main contractor to the inhabitants as a part of the main hand over process of the houses.

Figure 5.12: Brearley Forge case study as built

5.3 PV provisioning analysis

Having set the rich context for the six case studies, this section examines the findings resulted from analysing the PV documentary review and interviews with building construction professional in terms of the methodology and coding methods (both pre and free coding) described in chapter four in relation to PV governance dimension (1).

The analysis draws on ANT theory to help understand how the PV systems were designed, installed and introduced to the inhabitants via a network of actors in the two sets of contrasting low carbon housing communities in the UK: PC and NPC case studies. Within each housing set, the findings in this chapter are divided into two parts: PV provisioning actors and decisions, and PV provisioning changes resulted from the coding process. These will then be considered together in relation to actors' agency (mediator vs intermediary) and integration in a PV governance network and wider network, as discussed in chapters seven and eight. The more detailed findings related to coding categories and subcategories and the type (human vs non-human) and role (mediator vs intermediary) of the actors during the provisioning stages will also be analysed and discussed in detail in chapters seven and eight, to avoid repetition.

5.3.1 Participative Community (PC) case studies

5.3.1.1 Provisioning actors and decisions

In all the Participative Communities (PC), the Provisioning Inhabitants (PI) were the key participating actor in the PV provisioning process in terms of making decisions, while the whole community acted as a client having regular meetings with the PIs' to ratify the decisions made by the PIs' and the other provisioning actors before installation. The overall PV discussion topics (Figure 5.13) during the preparation and design stages of PV provisioning process show a clear weighting in the coding manuals toward whether to install them or not in the first place and the financial returns from the system in the preparation stage, as well as the scale and cost of the panels in the design stage. However, the limited capacity of the research methods used in this thesis for identifying the installation process (the interview and the video tour) was the main reason for the installation stage remaining an 'unknown' in terms of its overall impact.

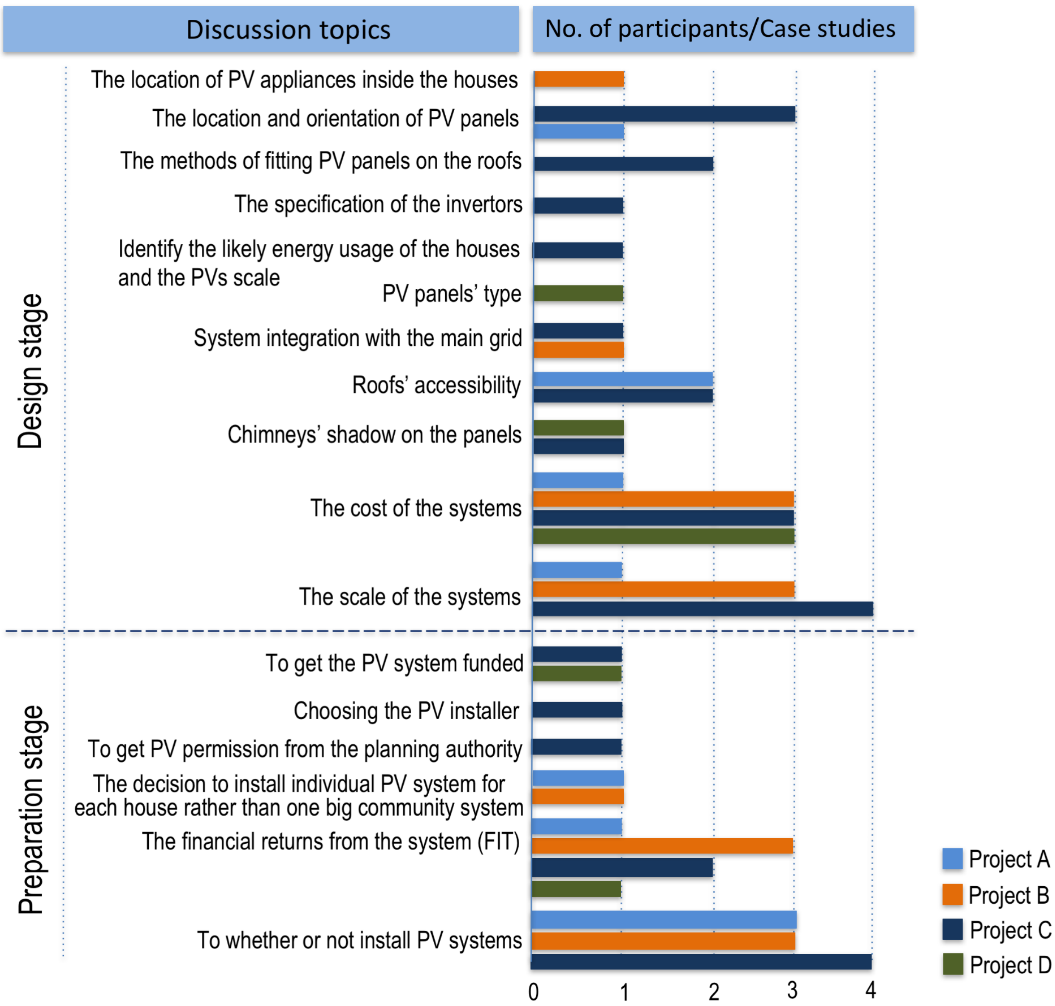

Figure 5.13: PV decision discussions as coded

Preparation stage

The decision whether to install PV systems in the PC case studies A, B and C, was the key discussion between inhabitants in the preparation stage. In case study A, the decision to install PV systems and the scale (0.75kW for each individual house) was finally made by an external energy consultant, employed by the PIs in the early stage of building construction to outline the project energy strategy, based on compliance with Code for Sustainable Homes (CSH) level -4 and modelled building characteristics. Other discussions concerned the dramatic reduction in the UK's FIT rate which in turn led the inhabitants in all these case studies to make decision to install their PV systems as soon as possible in order to get a higher FIT rate. The interesting decision to install an individual PV system for each house in the case studies A and B, instead of having one big community system will be discussed in detail in the next section (see 5.3.1.1.2 - system design changes). In the case studies C and D, financial discussions took place only between the PI and the grant body consultant after which the PI in the case study C changed to a new method of fitting the PV panels on the roofs in order to comply with the conditions laid down by the governing body for the grant (DTI). In the case study C, a discussion took place between the PI and the planning authority to get permission to install PV systems which resulted in the inhabitants themselves making decision to install on-grid instead of their desired off-grid systems (see 5.3.1.2 - system design changes). Other discussions took place in the individual case study (C) between the PI and other community members which is illustrated in Figure 5.13.

Design stage

In case study A, the PIs and main contractor changed the scale and cost of the PV systems, which was previously decided by the energy consultant (see 5.3.1.2), without the architect's involvement in the process. In the case studies B and C, where the PV systems were installed independently from the main building construction process, it was the responsibility of both the PV installer and the PI in terms of designing the systems. The later network of governance (B, C) helped the PIs to discuss the system design and appliances types and locations with the installer and to improve their knowledge in terms of system operation and maintenance. In case study D, the PV systems were primarily designed by an installer and then redesigned and installed by another installer with no meaningful participation by the architect and PI. This type of contract (A, D) reduced inhabitants' governance of their system design which was confined to only getting agreement for any change that influenced the cost of the system.

In general, discussions in the design stage focused mainly on the scale and the cost of the systems in case studies A, B and C, while in case study D, the total scale and cost was identified by the grant body consultant (DTI). This was because in all case studies, the FIT determined the number of the PV panels that would be installed on the roof of each home. However, how much energy would be consumed on site was poorly discussed and calculated in the case studies A, B and D, while it was fairly well discussed in the case study C between the inhabitants before contacting the PV installer. Discussion concerning the influence of chimney overshadowing on PV systems occurred in the case study C between the PI and the installer, and D between the PI and the architect. However, it did not occur in the case study B resulting in the 4 identical systems in this development performing quite differently in terms of their energy generation: “We have different chimneys on the roof and this made each system different through operation in terms of the performance” (B3). Interestingly, these discussions led to significant changes made in the PV context which will be discussed in the next section.

Access provision was raised by the PI and the installer in case study C when discussing the location of the PV panels on the roof, so that inhabitants could access their PV panels, but this discussion did not occur in the other case studies resulting in all other PV panels being inaccessible for regular cleaning which would ensure optimal power production. More critically, the PIs in case study A made a negative decision to completely remove the roof access point from the main design for cost reasons based on advice from the main contractor, without consulting the architect (see 5.3.1.1.2 - context changes). At this stage, there was no effective governance by the PIs in case study A, B, and D in relation to the location and position of the PV inverters and meters, performance targets, maintenance, physical context influences and load matching considerations, when discussing the PV design. The influences of these governance limitations will be discussed in detail in chapter 7.2.2.2.

The level of inhabitants’ participation in the PV discussions with other provisioning team was very high in case study C (14 topics) compared to a very low level of participation in case study D (5 topics) (Figure 5.13). This is because of:

- *Inhabitants prior knowledge of PV system*. Clearly, the prior knowledge of the PIs’ in case studies C and B gave them the confidence to discuss issues with the installer and to be more influential in the decision-making process. Inhabitant C3 commented:

> "For renewables, C1 (author comment: PI the name is anonymised) had the most influence. (Interviewer: Why?). Because, he is an engineer and he had lots of technical knowledge and he designed the system"

By contrast, in case study A, the key PI had to base his decision on the assumptions made by the other provisioning professionals.

- *Having an independent PV agenda*. Installing PV systems independently from the main building construction process in case studies B and C allowed the inhabitants to have individual PV meetings and discussions between them and with other provisioning teams, particularly with the PV installer. This was very informative and empowering for the community.
- *Having a PV installation for free*. Paradoxically, government funding actually reduced inhabitants' motivation to participate responsibly in the PV meetings to consider the design in case study D. Their participation was more focused on simply getting the funding paid, rather than optimising the energy generation and the potential savings from the system. The monitoring director commented:

  > "One problem is because the systems were fully funded, people are putting them (author: PV panels) in not quite the right place, because they got them for free, and people would be happy even if the systems were not generating energy perfectly" (D6).

- Contract Type. This will be discussed in detail in chapter eight.

5.3.1.2 Provisioning changes

Five types of changes in PV provisioning process were identified in the interviews with the PV provisioning team:

- Technical changes
- System design changes
- Context changes
- Agency changes
- Process changes

There were 11 specific changes identified overall within these provisioning changes as shown in figure 5.14 below.

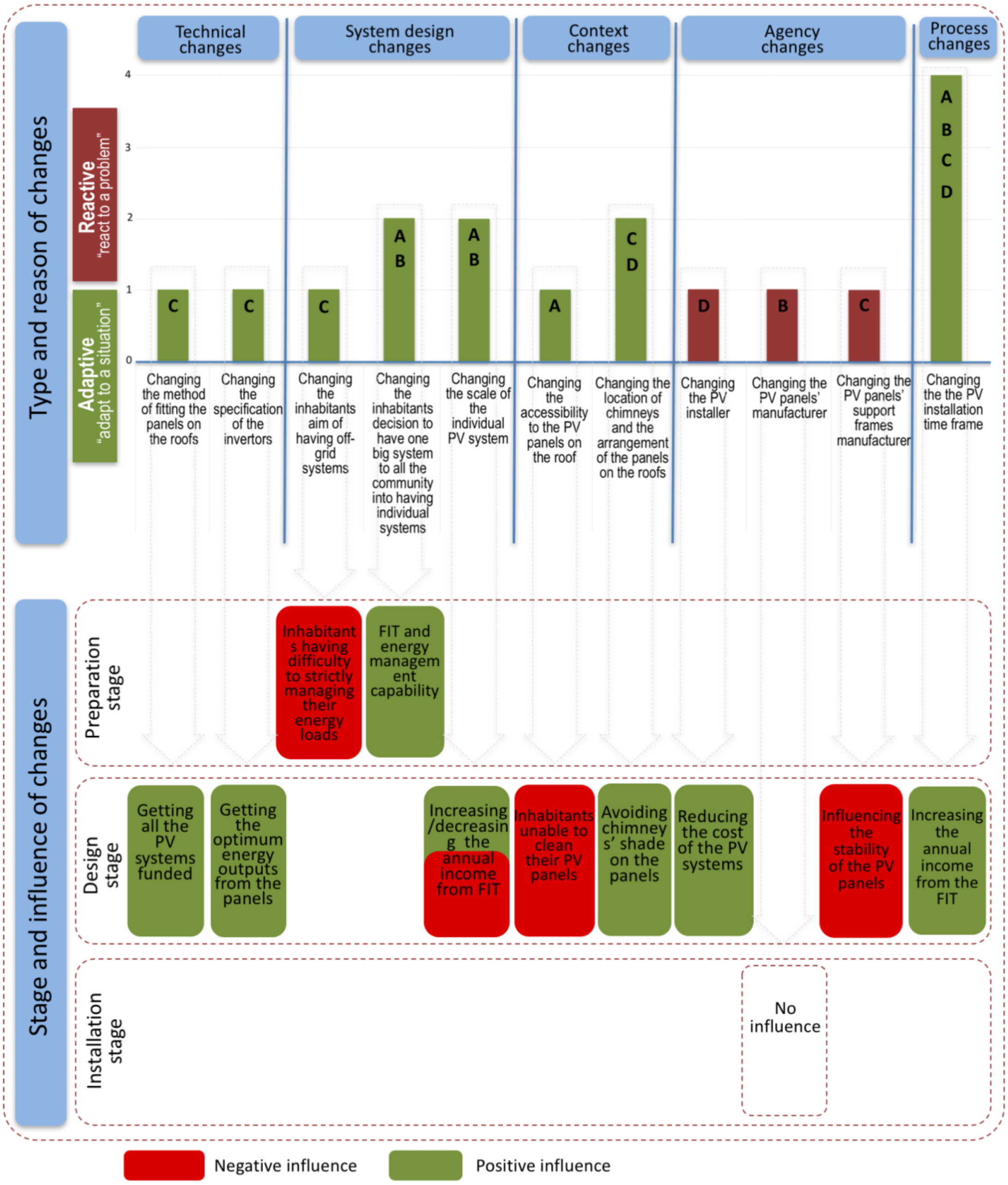

Figure 5.14: PV provisioning changes over stages

In general, the decision made by inhabitants to change the PV installation time was the only change identified in all the case studies while two common changes were identified in case studies A and B (changing the system scale and installing individual PV systems instead of a collective system) and one common change in case studies C and D (location of the chimneys) (Figure 5.14). The majority of these changes were made by the PV provisioning team in order to adapt to specific circumstances or conditions (technical, system design, context, and process changes), while changes in agency were made to react to emerging problems.

Technical changes

The PV provisioning team pointed out two technical changes in relation to PV systems in case study C:

1. A change was made to the method of fitting the PV panels on the roofs. As a consequence of the initial failure to get funding from the TDI for the PV systems, the PI (C1) changed the method of fitting the PV panels of the roofs in their second trial. This was to comply with the grant's body requirement (DTI) in terms of introducing an *innovative* method of fixing the PV panels on the earth-covered roof (flat roof application) which enabled them to get the fund and install the systems. All the panels in the previous case studies were attached directly to the roofs.
2. A change was made by the installer to the specification of the inverters. This was to match the size of the six inverters with the designed generative capacity of the combined PV panels. The maximum performance of the PV system was dictated by the size of the originally specified inverter, regardless of how big the output of the solar panels was; the output was cut off by the inverter. Getting the optimum energy outputs from the panels by changing the inverter specification was the main positive consequence from this change.

System design changes

Three changes in the system design were highlighted by the PV provisioning team:

1. A change was made to the inhabitants' goal of having off-grid PV systems in case study C and instead installing on-grid PV systems. This was in order to adapt to the planning authority requirement which stated that PV permission had to be applied separately from the main building construction permission. Exporting energy to the main grid and importing the same amount again at different times was the main negative financial consequence of this change as the energy import tariff was much higher than the energy export tariff. The PI suggested in his interview that very careful consideration should be given to the time that the planning process can take.
2. A change was also made to the inhabitants' original decision of having one big communal system for all the community houses in case studies A and B

and instead having individual PV systems. Having one large system means having only one large inverter for the whole community instead of 20 inverters and less amount of wiring that connects the PV appliances with each other. All these reduce a system efficiency by 10-25% due to losses in the inverter and wiring (Denholm et al., 2010). This change had to be made, however, to adapt to the FIT payback polices in terms of inhabitants' eligibility to apply for the FIT.

3. A change was also made to the size of the PV systems in case studies A and B. The PIs in case study A made a decision to *increase* the scale of their individual systems from 0.75 to 1.25kW (10kW for the whole community), in order to trade off the positive annual benefits of the change (an increase of £1700 income a year) in relation to the additional total cost (£8000). By contrast, in case study B, the PV installer *decreased* the designed scale of the systems because inhabitants decided to leave spaces on their roofs for future solar thermal installations and save on capital costs initially.

Context changes

Two changes related to the physical context of the PV systems were identified across all the case studies, and are discussed below.

1- A change was made to the accessibility to the PV panels on the roof in case study A. The PIs decided to remove the potential access to the roofs from the original design for cost saving reasons. This was to bring the building cost in line with the total budget of the case study. The inability of inhabitants to go on the roofs to clean their panels was the main negative consequence of this change and the PV panels cleaning process had to be assigned to a professional cleaner, with cost implications.

2- The architect changed the location of chimneys in all houses in case study D, in order to take account of the shading produced by these elements, after the completion of the whole design of the houses and before starting the construction process, and the PI changed the arrangements of the PV panels on the roof by leaving a 1m gap behind each chimney in case study C.

Agency changes

Two PV agency changes were identified across all the case studies when conducting interviews with PV provisioning team. These were:

1- Changing the PV installer in case study D - a decision made by the PI. This was due to poor communication with the PV installer and high cost issues.

2- Changing the PV panels' manufacturer in the case study B – a decision made by the installer. This was due to the lack of availability of the PV panels in the market.

The main positive consequence from changing the PV installer in case study D was a financial saving. This was due to reducing the cost of the total PV installations, and having better communication with the new installer when discussing the systems. Changing the PV panels did not have any particular consequences.

Process changes

A decision by the inhabitants to install PV systems rapidly was the only common change during the PV provisioning process across all the PC case studies. The main reason for this change was the need to adapt to the changes in the FIT payback rate. The consequence was positive, as it led to a higher rate of FIT payback in these case studies. The PI commented:

> "the FIT was about to change by going down, but at the time of installing the system it was good, but it was also about to go down. So, there was a discussion about the time frame… how quickly could we finish the installation process?" (PI- A3).

5.3.2 Non-Participative Community (NPC) case studies

5.3.2.1 Provisioning actors and decisions

In case study F, the key participating actors in the PV provisioning process were: the client/developer, main contractor, architect, project manager, service consultant, PV installer and the home demonstrator. All the systems were designed and specified by the service consultant of the main contractor, and installed by a sub-contractor (an installer). The key responsibilities of the architect were confined to merely deciding on the acceptable aesthetic appearance of the PV panels from outside, and deciding the location of the PV appliances accordingly. This was done through discussion of the aesthetic issues with the client/developer and the main contractor. Limited discussions took place between the Service Consultant and the other professionals in the design team during design stage of the PV provisioning process, and between the PV installer and other professionals during the preparation stage. The PV demonstration was commissioned by the main contractor agent, which proved to be problematic due to one inhabitant saying during the interview:

> "It was rubbish. It was very inefficient…it lasted just 5 minutes, gave me a gift pack of documents and information, but without going in details. It was not useful" (F1)

As a consequence, all inhabitants, to different degree, during the video tours showed limited understanding of their PV meter and inverter affordances, FIT, maintenance requirements and load matching opportunities (see 9.2.1). In case study E, the principal participating actors were the client/developer, main contractor, architect, sales agency, project manager, PV installer and the home demonstrator of the main contractor. The installer specified and installed all the PV systems as a sub-contractor, while the client and the main contractor decided the location of the appliances in the houses. The architect at this stage decided with the main contractor and the client on the best orientation of the houses in his design (solar oriented roofs). All the PV panels and inverters were unfortunately located in inaccessible places based on the client and the main contractor assumptions in relation to inhabitants' interaction with these appliances (see 7.2.1.2). The main contractor then introduced the systems to inhabitants, through an external agent as a part of the whole home induction process to reduce cost, instead of introducing the systems independently through the PV installer, which would have been more accurate and appropriate. This resulted in all inhabitants being completely unaware of their systems existence, due to the external agent's lack of knowledge:

> "She just explained that it is better to use energy during the daytime. That is all she knew…she did not know whether it is for heating water or for generating energy. She though it is for water" (E1)

Preparation stage

The key discussion in both NPC case studies during the preparation stage concerned the design of the low energy strategies in terms of achieving the CSH-4 target for their houses (Figure 5.15). These discussions led the clients and the main contractors to install PV systems in all houses and to decide on the required scale to achieve this standard. However, cost issues stopped the client in the case study E from installing PV systems in all houses in the case study. Clearly, CSH standard and cost had a major influence on these discussions as actors (see 7.2.1.2).

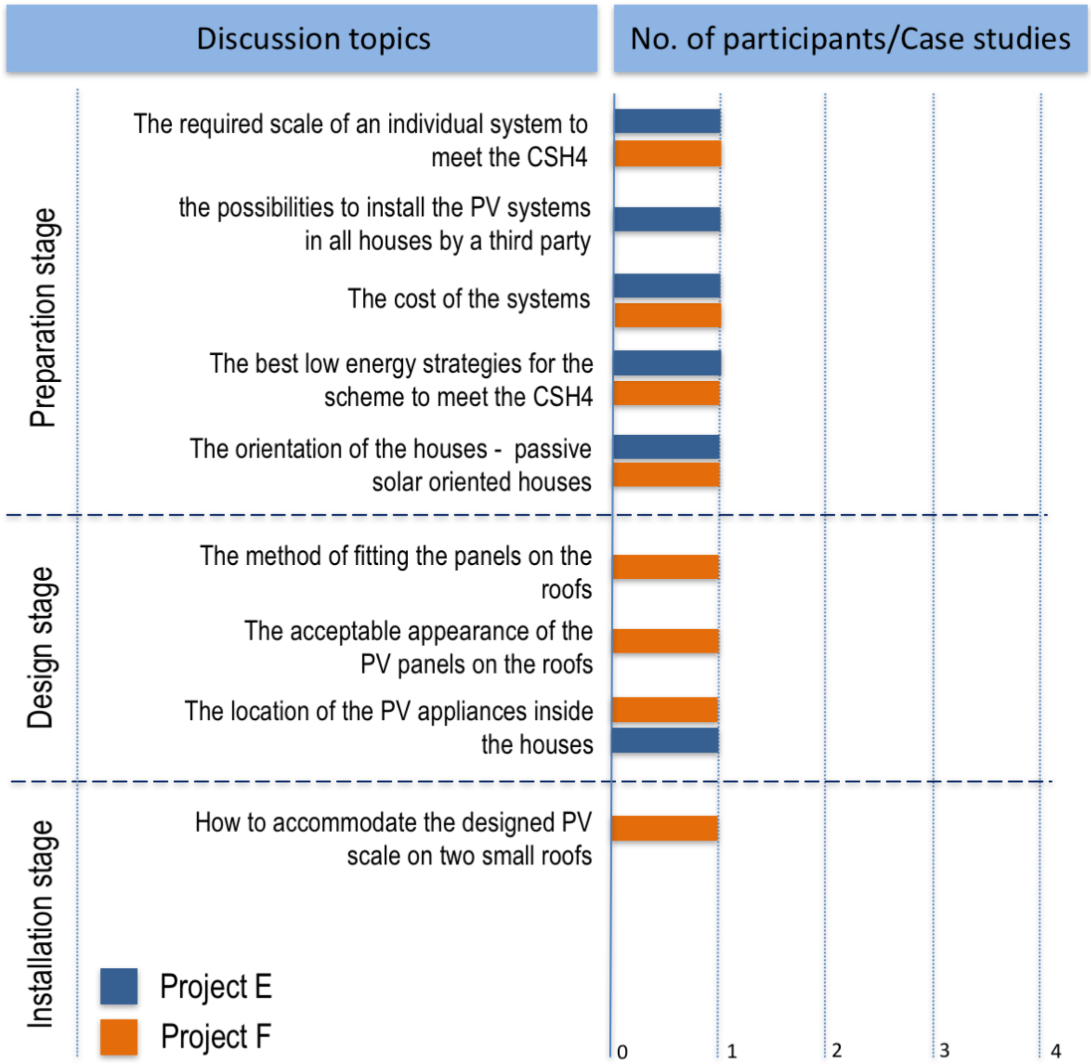

Figure 5.15: PV decision discussions as coded

Designing the correct solar orientated layout for both the passive and active solar systems in the houses was another key decision point made collectively by the architect and the client in both case studies:

> "Because the aspiration in phase two was putting a PV system on every house, the solar orientation was a key part of the early thinking" (client representative- E6).

Finally, the developer decided not to install PV systems in all houses using a third party, for reasons will be discussed in detail in section (see 7.2.1.2).

Design stage

Aesthetics and the practicality of fitting PV panels on the roofs were the two key decision topics in the design stage in case study F between the architect and main contractor. In case study E, the only discussion occurred between the installer and the main contractor in relation to the location of the PV appliances in the house. In the latter case study, the PV installer was responsible for designing and installing the systems independently from the other provisioning actors. The client representative commented: “The PV system was designed by the sub-contractor who was a company called Clean Air Solution. So, they were the supplier and the installer … The installer said: ‘This is our equipment, and this is the specifications” (E6).

In case study F, the integration of the PV appliances into homes was decided by the main contractor, the PV installer and the client. Aesthetics influenced the decision to hide the PV panels on the roofing in the case study F (see 7.2.1.2), which proved to be problematic according to the inhabitants. The developer and main contractor in the first phase of case study F decided to fix the PV panels mounting brackets directly into the main roof timber deck in order to increase the stability of the panels on the roofs. In the 2nd, 3rd and 4th phases of the case study, they changed it to a weighted down system (free standing mounting brackets). This was to avoid any problem with fixing penetrations causing rain leakage in the roofs. The former method resulted in a major roof repair having to be undertaken by the developer in all houses after occupation to overcome the leaking roofs. The latter method allowed the workforce to carry out the waterproofing more effectively, which significantly reduced the possibility of leakage in the new houses.

Installation stage

The small size of the roofs for two houses that were dedicated for PV installation in case study F, led to an extensive discussion between the developer and the installer in terms of how to accommodate the designed PV panels on roofs. These discussions ended with a decision to install a smaller amount of PV panelling than originally designed for (see 7.2.1.3), reducing the amount of PV energy that could be produced.

5.3.2.2 Provisioning changes

Two types of changes in PV provisioning process occurred in case study F according to the provisioning team:

- System design changes
- Technical change

However, no change was identified in case study E. This is very different to the PC case studies, where more/less/similar changes occurred.

System design change

A change was made to the scale of the PV system in two houses compared to the original design in case study F. The design of the PV system was adapted with the physical constraints of the houses (the roof size). The negative consequence of this discussion will be discussed in detail in section (7.2.1.3 - predominant intermediaries).

Technical changes

A change was made to the method of erecting the PV panels on the roof in the 2nd, 3rd, and 4th, phases of the case study F as described earlier in this section, with negative consequences.

5.4 Sub-conclusion

The first section of this chapter provided a brief description of the six identified case studies focusing on the PV governance network and practices. In the second section, the governance of PV system provisioning teams was analysed through the case studies to partially start to answer the 2nd and 3rd research objectives in terms of identifying and showing how a network of PV actors (both human and non-human) shaped the system design and consequential provisioning practice. This underpins the discussion in chapter seven and eight of this thesis concerning new critical areas for improving the governance of PV provisioning.

Provisioning Inhabitants (PIs) were identified as the key decision-making actors in PV provisioning network in the PC case studies, while the developer and the main contractor were identified as the key actors in the NPC. This type of governance network in the PC case studies, in theory, can empower inhabitants to govern their PV system. However, this does not always happen and, significantly, power can remain mainly with the PIs, as will be discussed more deeply in the next chapter.

The key focus of decision-making was related to the scale, the cost and the financial returns of the PV systems in the PC cases studies, while in the NPC case studies the key focus was how to meet the CSH standards. This shows that deciding the scale, cost and financial return of a PV system is a more flexible process for PC inhabitants than for NPC developers, and depends on the financial and environmental meaning of the system for inhabitants. The performance decision-making in the PC case studies mainly concerned the shade cast by the chimneys on the PV panels, whereas the decision-making in relation to inhabitants PV practices took account of the accessibility of the roof only in case study C. However, no discussion took place in relation to the affordances offered by the PV appliances in any of the PC case studies, despite the PIs' extensive involvement in the PV provisioning process. This is a particularly significant finding in relation to notion of effective and practical energy consumption management by inhabitants during occupation, and affordances were simply not part of the provisioning agenda – this point is discussed more deeply in the next chapters (discussion and conclusion).

There was insufficient governance by the provisioning team, including the PIs, when discussing the PV design in all PC case studies in relation to the location and position of the PV inverters and meters, performance targets, maintenance, physical context influences and load matching considerations. The significance of these limitations in terms of their critical consequences on inhabitants' engagements and practices will be discussed thoroughly in chapter seven.

Overall, five kind of governance change were identified during the provisioning process in the PC case studies: system design, technical, context, agency, and process changes, whereas only very limited changes were identified in the NPC case studies (system design and technical changes). The majority of these changes were made in case B and C, where the PV systems were installed independently from the main building construction process. Changes made by PIs, who generally (but not always) champion the needs of the inhabitants, aimed to increase the financial benefits from the system for the inhabitants and reduce the overall cost of the building construction, while changes made by other PV provisioning team intended to ensure the system performance as designed and within cost. The majority of changes to the PV systems were made during the design stage of PV provisioning process. This was either to adapt to the specific contextual conditions of housing projects or to comply with the overriding governance at national level, such as the FIT requirements.

The Professional participants also made a number of recommendations during the interviews in relation to PV policies, meaning, maintenance and inhabitants' engagement. The PIs' recommendations focused on maximising the size of the PV systems and having a greater influence on where to locate their internal PV appliances. By contrast, the PV contractors and installers recommendations emphasised improving inhabitants' engagement with their PV appliances in order to use their PV electricity efficiently and providing inhabitants with a better demonstration of their PV system during the home induction process - the key missing aspects in the PV provisioning process by the contractors and PV installers. Other suggestions made by the PIs concerned improving the resilience of PV systems following grid failures as discussed in detail with other recommendations in appendix 11.

In order to build up an understanding of the consequential significance of the decisions and changes made by the various PV provisioning actors in terms of impacting inhabitants' practices, the next chapter discusses the initial findings related to PV practice, problems and changes during occupancy, that resulted from the interviews and video tours with inhabitants in the six housing case studies. These are then cross-related to the governance issues identified in this chapter, in chapters seven and eight, before moving onto a more detailed discussion of practice in Chapter nine.

CHAPTER SIX: PV PRACTICE JOURNEY

6.1 Introduction

Following an initial examination of the provisioning actors and networks, this chapter analyses and presents the initial findings derived from coding the inhabitants' interviews and video tours transcripts, and associated documents in relation to the practice and affordance dimension (2) generated in chapter four (Figures 4.10), drawing on affordance theory and Practice theory. The coding findings are again quantified to understand the significance of the various coding categories/ subcategories, and to compare, between the two sets of housing provisioning, inhabitants' practices in relation to the affordances offered in their PV appliances. This is a step towards achieving the 4^{th} and 5^{th} objectives of this thesis in relation to understanding how PV systems in low carbon housing case studies are practiced, or not, and in relation to the affordances offered in the system appliances in the two different sets of case studies.

The analysis in this chapter is divided into three main strands: PV appliances, problems and, changes across both types of housing provision: PC and NPC case studies.

6.2 Participative Community case studies (PC)

6.2.1 Type of PV appliances

The PV system components have been previously described (see 3.2). The PV energy generation meter was the principal PV technology that inhabitants were engaged with in their home across all the case studies while solar panels were the least common PV technology engaged with. Figure 6.1 illustrates the number and types of inhabitants' engagements with their PV appliances in all the PC case studies.

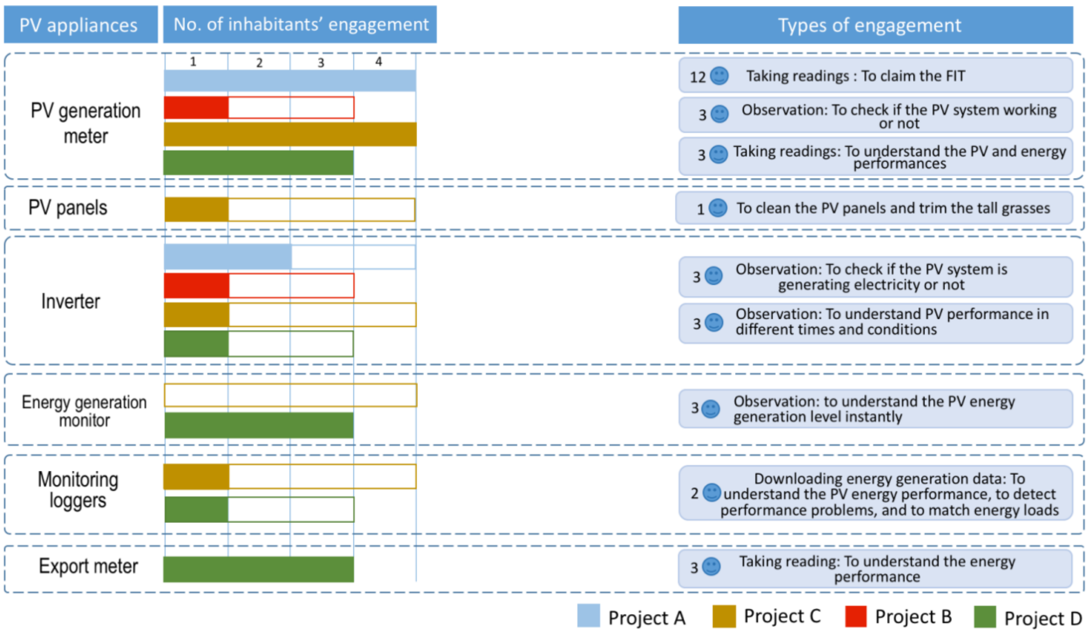

Figure 6.1: Number of inhabitants per engagement across case studies

6.2.1.1 PV generation meter

12 inhabitants out of 14 across all case studies were engaged with their PV generation meter regularly (meter readings, observation). This was to claim the FIT as a key driver (see 7.3.2.1) and to monitor their PV and energy performances individually and collectively (see 7.3.1). This was mainly achieved by taking meter readings and observing if the system was producing energy or not by looking at the built-in green light indicator in the meters.

The inhabitants highlighted several positive effects from their engagement with the meter in relation to energy efficiency. The importance of this issue is indicated by the number of inhabitants' responses (Figure 6.2):

- Understanding the PV and energy performances individually.
- Load matching and detecting technical and underperformance problems.
- Detecting problems (both technical and performance)
- Energy consumption reductions.
- Understanding if the system is producing energy or not.

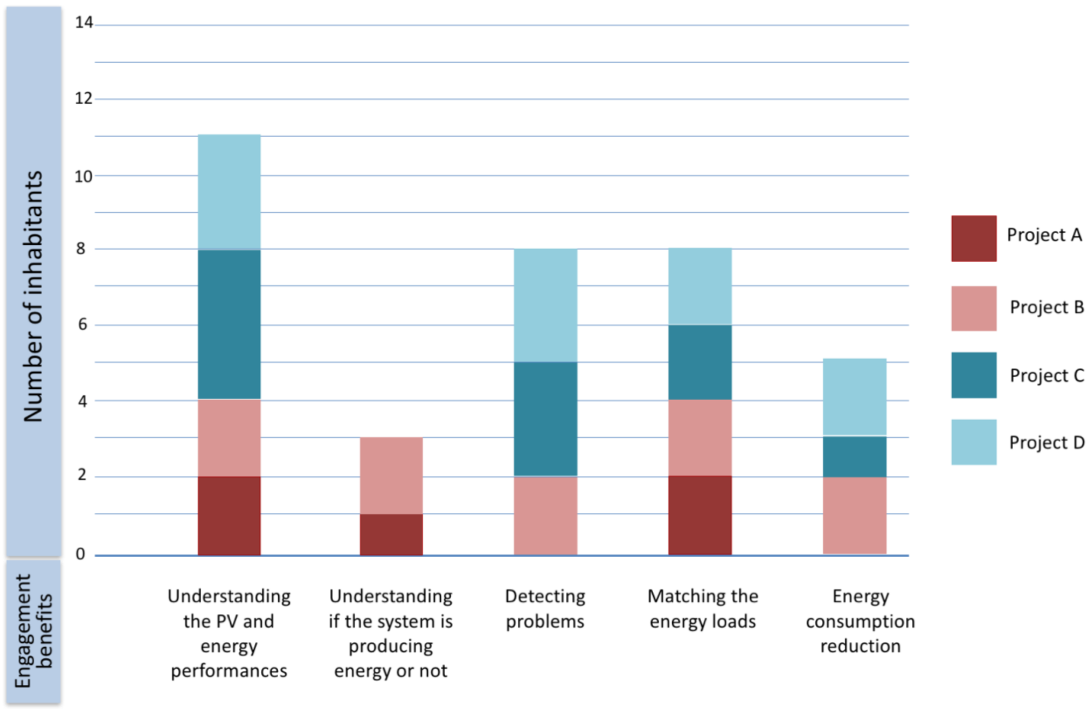

Figure 6.2: Positive effects from inhabitants' engagement with PV meter

6.2.1.2 Solar panels/tiles

Solar panels/tiles represented the PV technology that inhabitants were engaged with least in their home. Only one inhabitant (cases study C) across all the PC case studies, regularly cleaned the PV panels (Figure 6.1). This was to improve the PV energy performance via cleaning and trimming the tall grasses and weeds covering or shading the PV panels. Only one inhabitant in the case study D tried to clean the panels, but soon gave up because of not having safe access to clean them. In case studies A and B, the inaccessibility of the PV panels and inhabitants' uncertainty in terms of the necessity to clean the PV panels were the main reasons for the inhabitants not cleaning their PV panels: "For the panels, we would not expect for anyone in this community to do work on the roof (authors comment: engaging with the PV panels)" (PI-B1). In case study A, all the PV panels were cleaned by a professional cleaner, while in case studies B and D the PV panels have never been cleaned. All the inhabitants in case study C and two interviewed inhabitants in case study D understood, however, the benefits of cleaning their PV panels in terms of improving their PV energy generation (Figure 6.3).

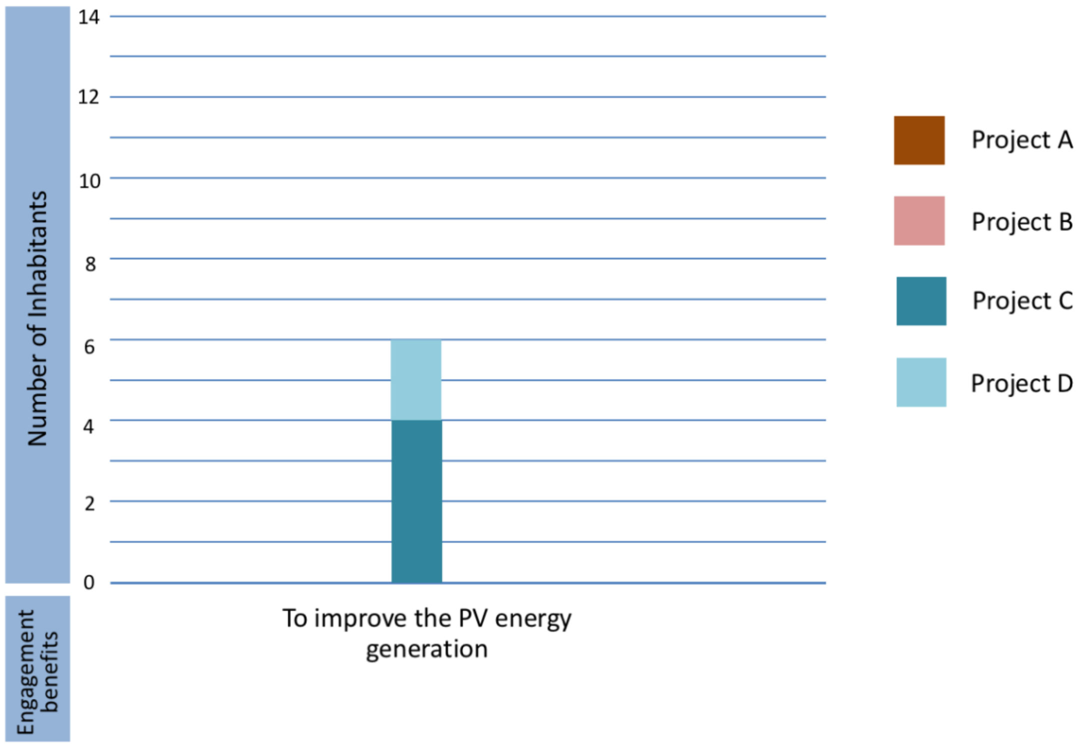

Figure 6.3: Positive effects from inhabitants' engagement with PV panels

6.2.1.3 Inverter

Only five inhabitants across all the PC case studies were engaged with the PV inverter in their home. The engagement with the inverter was largely irregular in case studies A, C and D while it was regular in case study B. This engagement was to individually monitor their PV performance by looking at the inverter's display screen in order to understand the energy generation level at a specific time (A, B) and to observe if the system is producing energy or not by looking at the built-in green light indicator (C, D) (Figure 6.1). As inhabitant B1 commented, they made sure: "to regularly check the systems are working by looking at the inverters and take meter readings every week for all the houses". In case studies C & D, the inverter did not have a display screen, which did not help to promote engagement.

In case study B, it was the responsibility of one inhabitant to monitor the PV and energy performances for all the houses and that was paradoxically the main reason for other inhabitants in this community not engaging with their inverters and meters (see 7.3.2.1). Although the same collective monitoring process was conducted in the case studies A, C and D, the inhabitants were individually responsible for reading their PV meters and observing their inverters. The main benefits of inhabitants' engagement with the inverter were (Figure 6.4):

- Understanding the PV performance.
- Understanding if the system is producing energy or not.

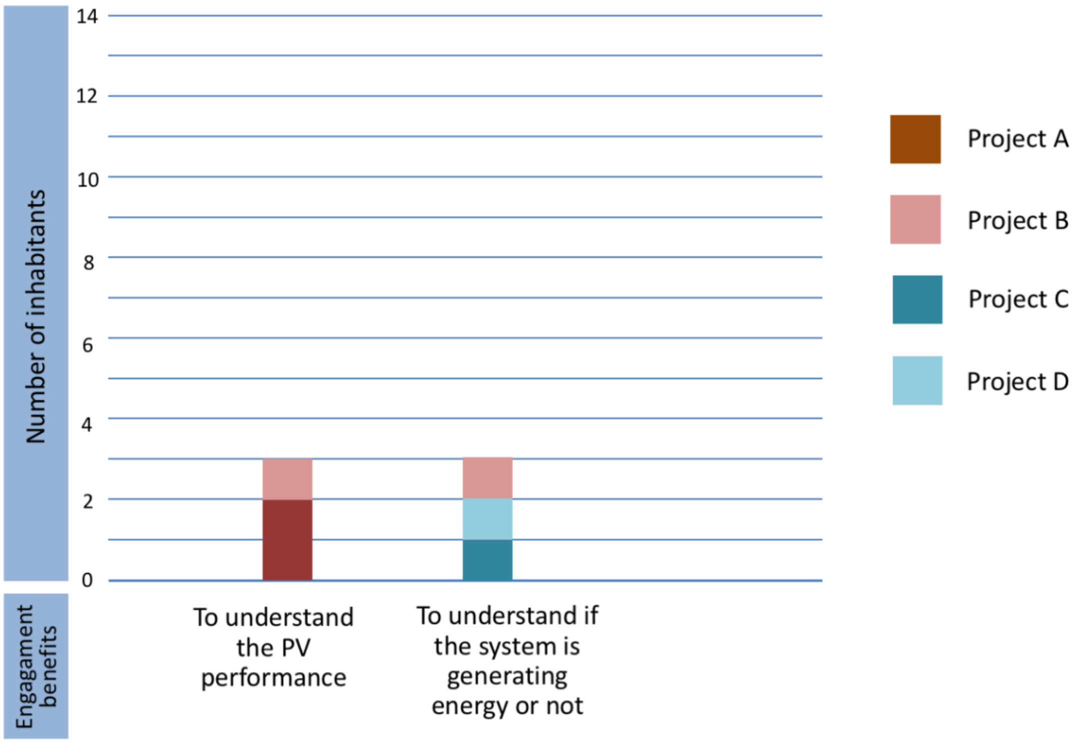

Figure 6.4: Positive effects from inhabitants' engagement with inverter

6.2.1.4 Energy generation monitor

All the inhabitants in case study D were engaged with their PV energy generation monitor to understand the PV energy generation level instantly at different times and in different weather conditions. Although the same device was installed in all homes in case study C, the inhabitants did not mention any interaction with it (Figure 6.1) for reasons discussed in chapter 7.3.2.1. In case studies A and B, no energy generation monitor was provided by the installer. The main benefit of observing the energy monitor was to manage energy consumption by understanding the amount of energy generation level instantly (Figure 6.5).

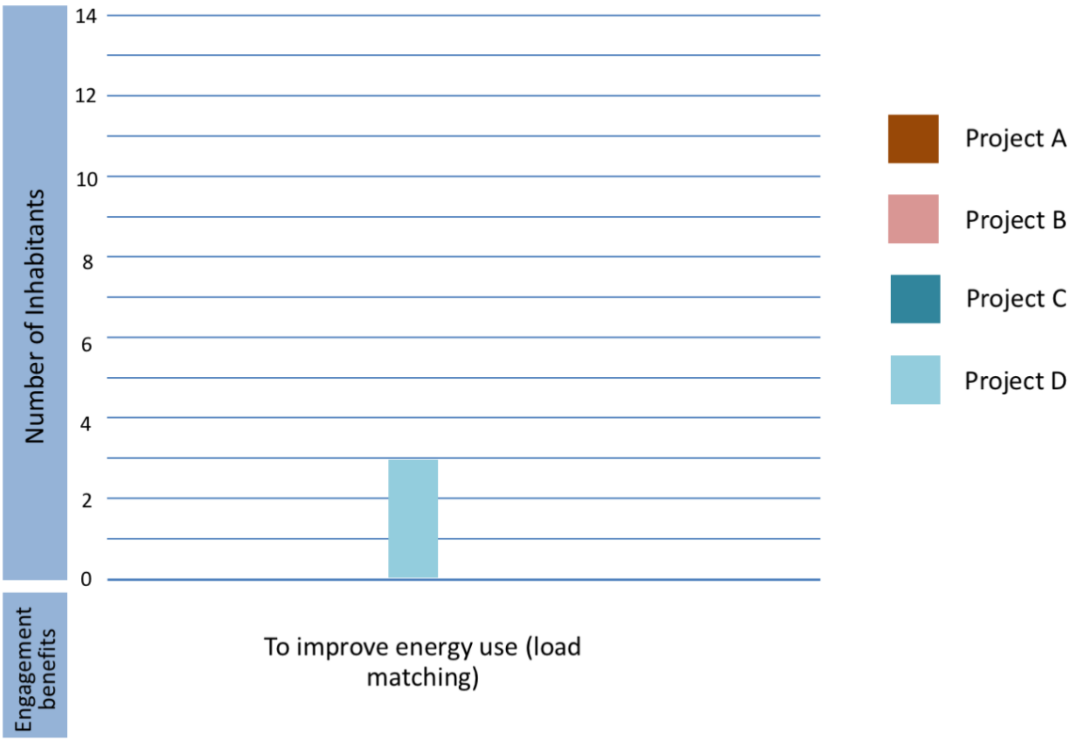

Figure 6.5: Positive effects from inhabitants' engagement with energy generation monitor

6.2.1.5 PV monitoring logger

The monitoring equipment was installed separately from the PV systems by technicians and funded by the grant bodies in case studies C and D. The inhabitants who were in charge of running the monitoring process of all the PV systems (only one inhabitant in each PC case study) were regularly downloading the PV generation data during the day from the monitoring logger, producing spreadsheets and sending the data to both inhabitants and the grant body consultant to assess the efficiency of the PV panels as a part of their contract (Figure 6.1). Significantly, these inhabitants stopped monitoring their system efficiency in case study D after the end of the agreed period with the grant body consultant, while in case study C, the inhabitants continued monitoring their PV systems by downloading the data from the monitoring logger, which will be discussed further in chapter 9.4.

Three inhabitants out of four in case study C and two inhabitants out of three in case study D cited detecting PV underperformance problems as the main positive effects of engaging with their PV monitoring loggers, while all inhabitants in case study C and two inhabitants in case study D cited understanding their PV performance as another positive consequence. Only two inhabitants in case study C cited load matching as a further positive effect (Figure 6.6):

"Because we could know how much energy we are producing during the day and therefore, we could match our use according to our production." (C1).

Figure 6.1 refers to the number of inhabitants that were actually engaging with the monitoring loggers in the case studies C and D, while Figure 6.6 refers to the number of inhabitants that mentioned the benefits of engaging with monitoring loggers during their interviews.

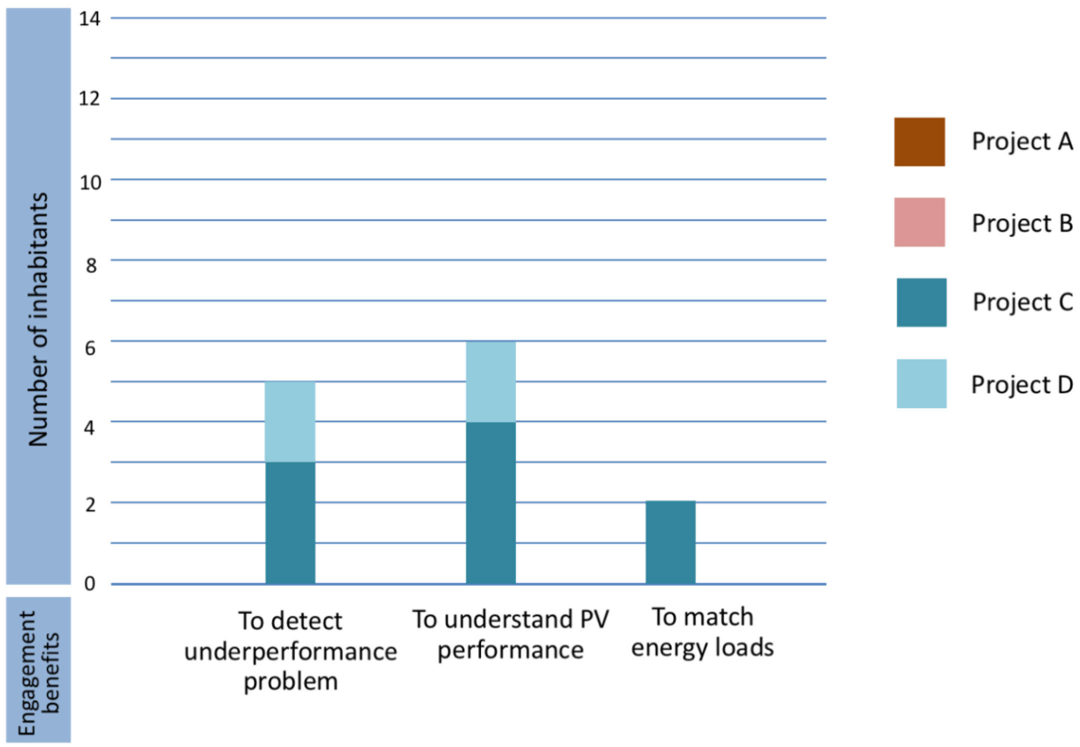

Figure 6.6: Positive effects from inhabitants' engagement with PV monitoring logger

6.2.1.6 Energy exported meter

All the inhabitants in case study D regularly engaged with the energy export meter installed in their home as a part of their obligation with the grant body. This was to individually monitor the overall energy performance in all houses by taking the exported energy readings from all the meters. All inhabitants stopped doing this task after the end of the agreed period with the grant body. The other case studies do not have this meter.

6.2.2 PV practice problems

Three types of practice problems were identified by inhabitants: engagement, affordance and context problems.

6.2.2.1 Inhabitants engagement problems

An unacceptable PV induction process represented the key source of engagement problems, highlighted by 10 inhabitants out of 14 across all the PC case studies (Figure 6.7). The failure to provide inhabitants with an efficient home induction process in case study D, and confining it only to selected inhabitants in case study A, and to the PIs in case study B, was the main cause of the poor PV induction. Moreover, insufficient provision of a simple and an interactive Home User Guide (HUG) for the whole PV system in the case studies A – C, and of a HUG in the case study D, was another reason for the poor PV induction problem:

> "I was bullying the architect to produce a HUG after we all moved in and nothing ever happened, and I just kept on and on, and he finally produced something fairly flimsy." (D1)

The PV manuals and booklets provided in these case studies were either too general or too technical, and intended for specialists, across all the case studies. This resulted in a learning gap, leaving many inhabitants unaware about various aspects of their PV system in the case studies A, B and D and unable individually to achieve the efficient use of energy generated from their PV systems. As expected, the poor PV induction process resulted in five other problems related to inhabitants' engagement of their PV systems (Figure 6.7).

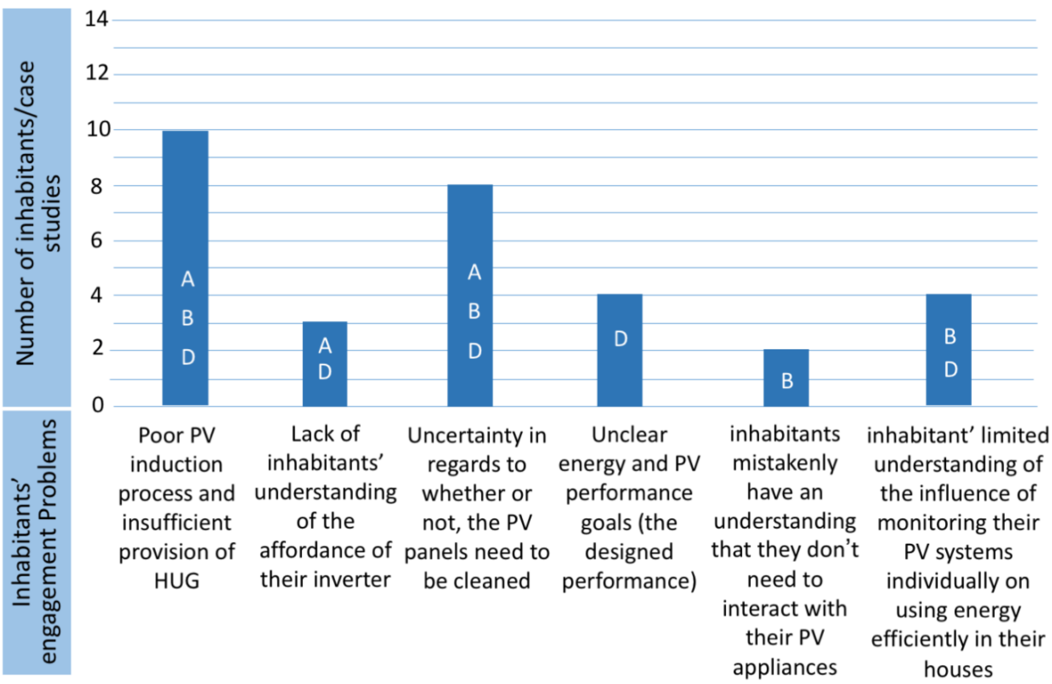

Figure 6.7: Inhabitants' engagement problems

6.2.2.2 PV affordance and system design problems

The problems concerning the PV system design and affordance varied across all the PC case studies. The most critical affordance problem cited by inhabitants in all case studies was the limited provision of visual and direct feedback for PV energy generation and overall energy consumption in an individual home, instantly and synchronously. The next key critical affordance problems concerned the lack of PV meters and inverters with Wi-Fi capability to download the PV energy generation data during the day by inhabitants individually in all the case studies and the limited provision of visual feedback for energy consumption pattern (A – C) (Figure 6.8).

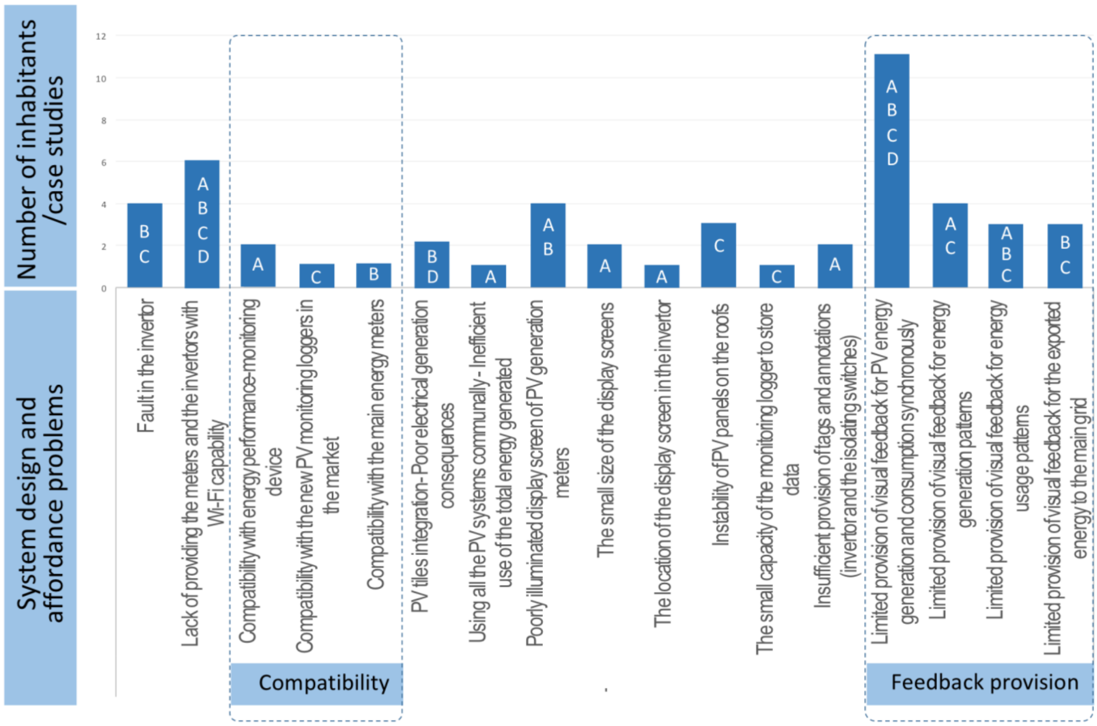

Figure 6.8: Affordance and system design problems

The other critical affordance and functional problems, which were related to the system design, concerned the poorly illuminated display screen of PV generation meters in the case studies A and B (Figure 6.9), the problem of the instability of PV panels on the roof (C), insufficient provisioning of labels in the inverter (A), and the integration of the PV panels/tiles in terms of poor electrical generation consequences (B, D). The PV panels in case studies B and D were wired and connected in series. This meant that if a panel/tile was in the shade (due to chimneys, clouds, trees) the whole system suffered at once and energy generation fell dramatically.

One inhabitant described the PV meter lighting problem very specifically:

“Oh, I think there is a problem with the meter. It does not have a lighted screen; I need to shine a torch on it at a certain angle when I’m looking at the numbers. I think it is the same problem with anybody else. It is not easy to read” (A4)

Figure 6.9: Poor illuminated display screen in the PV meter

Three inhabitants out of four in case study C pointed out that the PV panel support frames in the second PV installation were not sufficiently weighted down on the roof by the installer. As a consequence, high winds resulted in some of the PV panels being blown onto the ground and damaged. The inhabitants undertook all the repair work at their own cost because the installer had gone out of business - another concern for inhabitants.

A misunderstanding occurred in case study A in relation to understanding the amount of PV energy generation at any specific moment when trying to read the inverter. This resulted from the insufficient provision of information labels on the inverter.

“There are ten sections in the display screen and one of them is displaying now. It is working about 10% at the moment, and presumably, it is just producing 2-3 Watt of electricity, which is not enough for the store light (20 watt) … I learned later that each section produces 95 watts” (A2)

Locating the display screen in the lower part of the inverter and in parallel with the very low position of the inverter on the wall, as well as the impaired vision of inhabitant

A4, meant that inhabitant ceased to observe the inverter and highlighted it as a problem (Figure 6.10).

Figure 6.10: Very low position of inverter's display screen

A fault in PV appliances was identified as another type of technical problem across all the PC case studies. One inverter in both case studies B and C stopped working and they were changed by the installer as a consequence, while in case study C a monitoring logger also stopped working. The lack of availability of the monitoring logger in the market stopped the inhabitants in case study C from monitoring the PV performance of three houses.

6.2.2.3 PV context problems

Two types of PV context problems have been identified across all the PC case studies:

1- Macro context problems.
2- Micro context problems.

The micro context refers to the physical environment that directly surrounds the PV appliances, while the macro context mainly refers to the broader technology arrangements inside and outside of the homes. Shade cast by trees and chimneys on the PV panels themselves in case studies B – D was the most critical macro context problem after the principle problem of lack of accessibility to clean the PV panels (Figure 6.11).

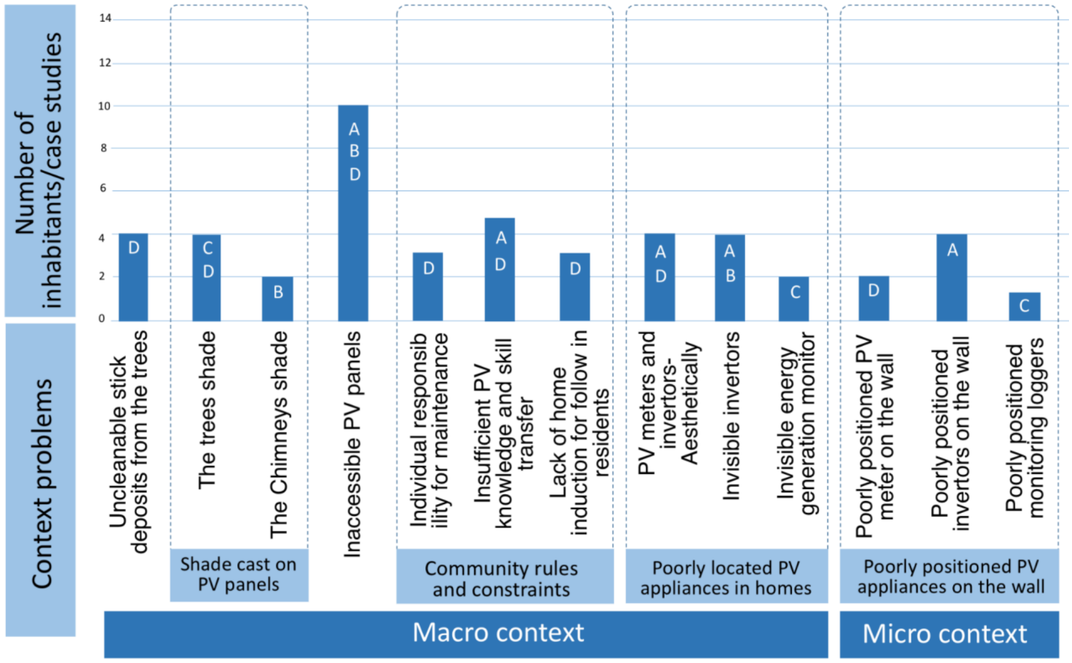

Figure 6.11: Context problems

Research conducted by (Pasquale et al., 2013: 8) demonstrated that the roof-integrated PV arrays in case study D performed well (between 90-114%) when they were unobstructed. However, “the eastern homes were flanked by a large row of oak trees to the south, which visibly overshadowed the roofs in satellite photos” (Figure 6.12). These homes only produced between 38-89% of their installed rating.

Figure 6.12: Satellite photo. Trees shadows on PV panels Source: (Pasquale et al., 2013)

For case study D, the next significant problem concerned the immovable sticky deposits dropping from the trees onto the panels in terms of the poor electrical performance of the panels, which will be discussed in detail in section 7.2.1.3. The invisible location of the inverter (A, B) and the energy generation monitor (C) was highlighted by six inhabitants as a critical problem. By contrast, the inhabitants were aesthetically very dissatisfied with the visual appearance of the PV meter (A) and the inverter (D). These results and the consequences will be discussed in detail in chapter 7.3.1.1 (non-human intermediaries).

From a non-technical perspective, the key cited problems by inhabitants in terms of running the houses for case studies A and D were the internal policies and regulations of the community, and the absence of home demonstration for any follow on residents after initial residents in case study D. The community context in case study D enabled the inhabitants to understand their PV and energy performances and to detect problems through internal Email discussions and publishing collective energy generation and consumption graphs (see 7.3.2.1), but it did not provide them with opportunities to implement the solutions.

Insufficient know-how transfer in relation to the PV system and energy efficiency was highlighted as a problem in case studies A and D. This was due to the limited discussions that took place between the inhabitants in relation to using energy efficiently, despite having good graphs related to their energy generation and consumption. This problem resulted in most of inhabitants, particularly in case study D, having analysed the energy graphs individually by comparing energy performance to the other residents, but without having a group discussion around the defects. This was highlighted as another problem by two inhabitants (D) as a consequence of the know-how transfer problem.

The key micro context problems concerned the position of the PV appliances on the wall, such as the overly high position of the PV meter (D) and the monitoring loggers (C), and the low position of the inverters (A). As one inhabitant commented:

> "… the cable connection is very high because the boxes (authors comment: monitoring loggers) were located in a very high place in the porch so we need to use a ladder to connect the cable" (C2)

The main negative consequence of the macro-context problems was a reduction in the PV energy generation levels in case studies B, C and D. In particular, the sticky deposits from the trees and over shadowing had major negative effects in case studies C and D followed by the inaccessible PV tiles (and the consequential inability to clean them) and the shadow of the chimneys (B) respectively. The negative consequences arising from the micro context problems discouraged the inhabitants from engaging with these high/low appliances in order to match their energy loads.

6.2.3 Changes in practice

This section discusses the changes made by inhabitants when enacting the actual practice of their PV systems in context. There were three kinds of changes identified when coding the inhabitants' interviews and video tours data (Figure 6.13):

1. Practice changes.
2. Technical changes.
3. Context changes.

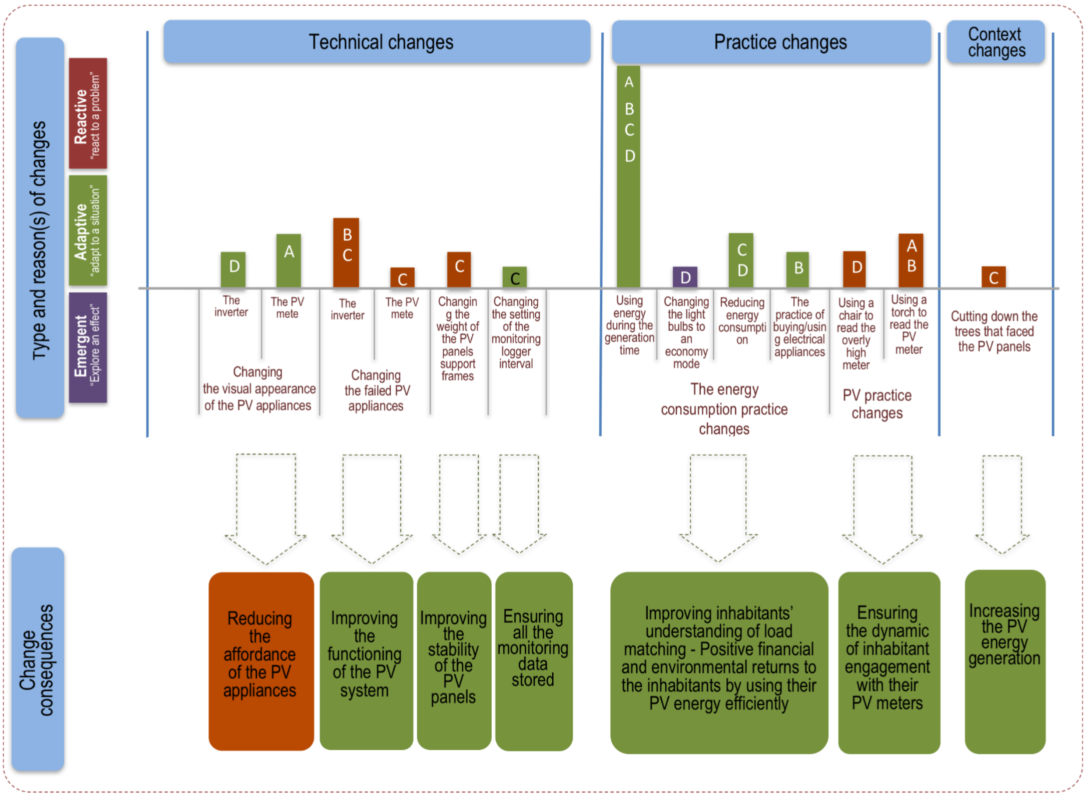

Figure 6.13: Changes in practice

6.2.3.1 Practice changes

6.2.3.1.1 Energy consumption practice changes

The changes in inhabitants' practice in relation to energy consumption, particularly using energy during the day (energy load management) were most significant across all the PC case studies. The next major changes in inhabitants' practice were:

- Reducing energy consumption in case studies C and D.
- A change in practice in terms of buying/using electrical appliances during the day in case study B. As one inhabitant commented:

  > "… before we only had a gas kettle and we only had a gas grill for toast…and after the PV, we bought an electric kettle and an electric toaster to use electricity from the PV during the day. So, that is probably the main thing … also, using washing machines during the daytime rather than in the evening" (B3)

- Changing the high energy light bulbs to low energy economy ones (D).

The main drivers for making the practice changes were principally *adaptive* learning – inhabitants individually adapting their overall energy consumption patterns to the individual PV energy generation patterns, as shown across all the PC case studies, and *emergent* learning - inhabitants' exploration to understand the effects of changing their energy consumption practices on the total energy performance in their homes in case study D.

6.2.3.1.2 PV practice changes

Two main changes from the expected inhabitants' practice with their PV meters were identified:

- Using a torch to read the PV meters in case studies A and B for the reasons discussed in the previous section which related to the small size of the display screen, and the poorly illuminated PV space and display screens.
- Using a chair to stand up on and read the PV meter by inhabitants in case study D, due to the overly high position of the PV meter on the wall. However, one inhabitant D2 commented:

  > "… it is ridiculous (authors comment: the location of the PV meter and the fuse box). I know I could use a chair to get up there to read the meter for the FIT, but it is not usable if I'm 75 years. So, the fuse box and the other stuff here should be totally available to you to turn them on and off"

6.2.3.2 Technical changes

The change of the visual position or appearance of the PV meter and the inverter was the most common change across all the PC case studies – this was done in order to adapt the equipment to inhabitants' aesthetic values, as discussed in the next chapter (7.3.2.1). The next common technical change was the technician replacing the failed PV appliances, mainly the dead inverters in case studies B and C, and replacing number of damaged PV panels in case study C. In case study C, the high level of participation by the inhabitants in the PV provisioning process, particularly the PI, gave him and them the confidence to implement other positive changes when experiencing problems. These changes were:

- Increasing the light weight of the PV panel support frame by adding extra steel strips to the frames' boxes as a consequence of ill-fitting PV panels.
- Inhabitants changing the time setting of the monitoring logger intervals. The design of the logger enables inhabitants to change the time setting of the monitoring intervals from 5 minutes to 60 minutes as a result of losing some PV data due to the limited capacity of the logger in terms of how much data it could take. As one inhabitant said:

> "… some gaps occurred in some of the data files. The reason for the gaps was found to be that the memory in the Sunny Data Control boxes (authors note: PV energy monitoring equipment) was full… following, HHP has continued collecting the data with 1 hours monitoring intervals rather than 5 minute intervals" (PI- C1)

In other case studies (B – D), the inhabitants claimed that they could not improve the affordance of their PV system by adding Wi-Fi connectivity to their inverter or meter in order to reduce the imported energy from the grid by downloading the energy generation patterns and comparing it with the energy consumption pattern to learn how to best load match; these inhabitants would have had to replace the old appliances with new ones which they said was too expensive.

6.2.3.3 Context changes

Cutting down the trees that faced the PV panels, and caused overshadowing of these panels in case study C, represented the only significant macro context change in any of the case studies. This change was a reaction to the underperformance of the PV energy generation. Although the same problem occurred in the case study D, and resulted in a significant reduction in the PV energy generation level, the inhabitants took no action there (see 7.3.2.1).

6.2.3.4 Change restrictions

In terms of practice, technical and context change restrictions, cost was the primary concern in terms of inhabitants not upgrading their system affordances (all PC case studies) and having their PV panels cleaned by professionals (D) (Figure 6.14). The community context in case study A was another restriction on making physical changes due to their restricted community rules which meant that inhabitants could not make any changes without getting permission first from the all community members. Both the cost and community context restrictions are discussed in chapter 7.3.2.1 as significant intermediaries that impacted inhabitants to not upgrade their PV system.

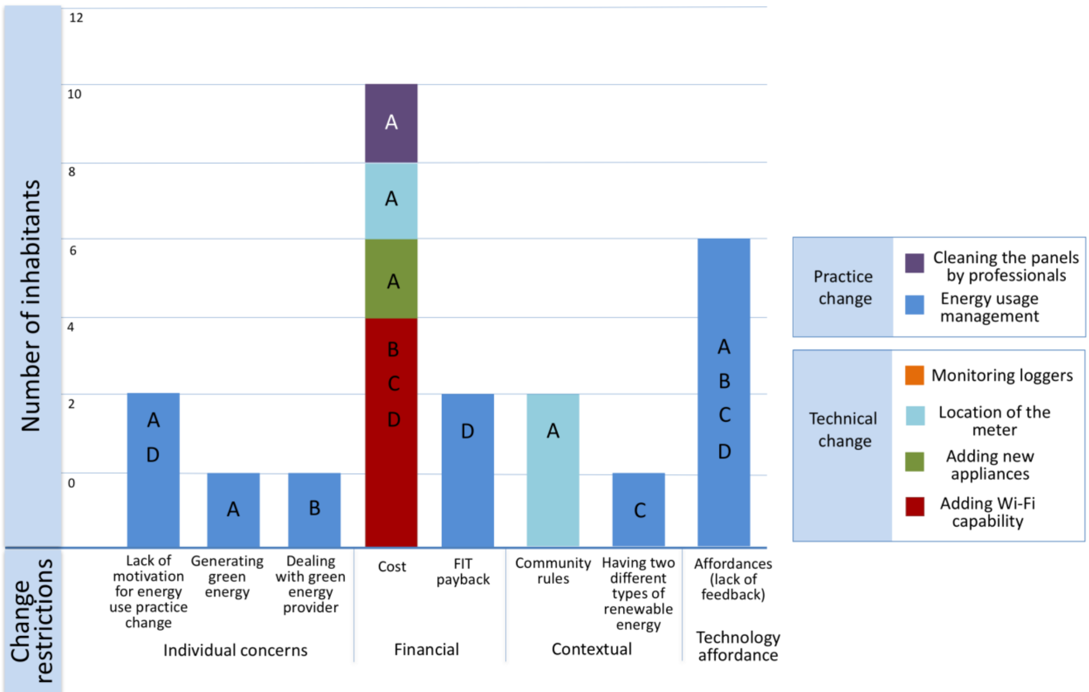

Figure 6.14: Change restrictions

In terms of the practice change related to 'load matching', the high rate of FIT payback (D), and the limited affordance provided in the PV systems (particularly the energy feedback provision) in all case studies, were the main obstacles for inhabitants not making changes in their energy consumption. This is discussed in more detail in chapter 7.3.2.1. Other reasons for no changes were further identified individually by inhabitants as:

1. Having two different types of renewable energy (solar PV and wind turbine) in case study C. This reduced the inhabitants' capability to match their energy

loads during the day because of the inhabitants' uncertainty in knowing whether or not they were actually exporting energy to the main grid.

2. Generating green energy in case study A. One inhabitant ascribed the reason for not changing his energy consumption practice after installing PV system to the fact that "… I'm generating a lot of energy. I'm happy to still use the energy as well. I feel less guilty about using energy because I'm already generating it" (A3). This is a challenging rebound finding in relation to PC inhabitants' practices.

3. Dealing with a good green energy provider in case study B. This gave inhabitants' satisfaction, with them feeling that they therefore have very little negative influence in terms of the global environment, and do not need to change things – another rebound finding.

6.3 Non-Participative Community housing (NPC) case studies

6.3.1 Type of PV appliances

As with the PC case studies, the PV energy generation meter was the key PV technology that inhabitants were engaging with in all the NPC case studies, while the least common PV technology engaged with was the PV panels in case study E and the PV inverters in case study F. Figure 6.15 illustrates the number and types of inhabitants' engagements with their PV appliances in the NPC case studies.

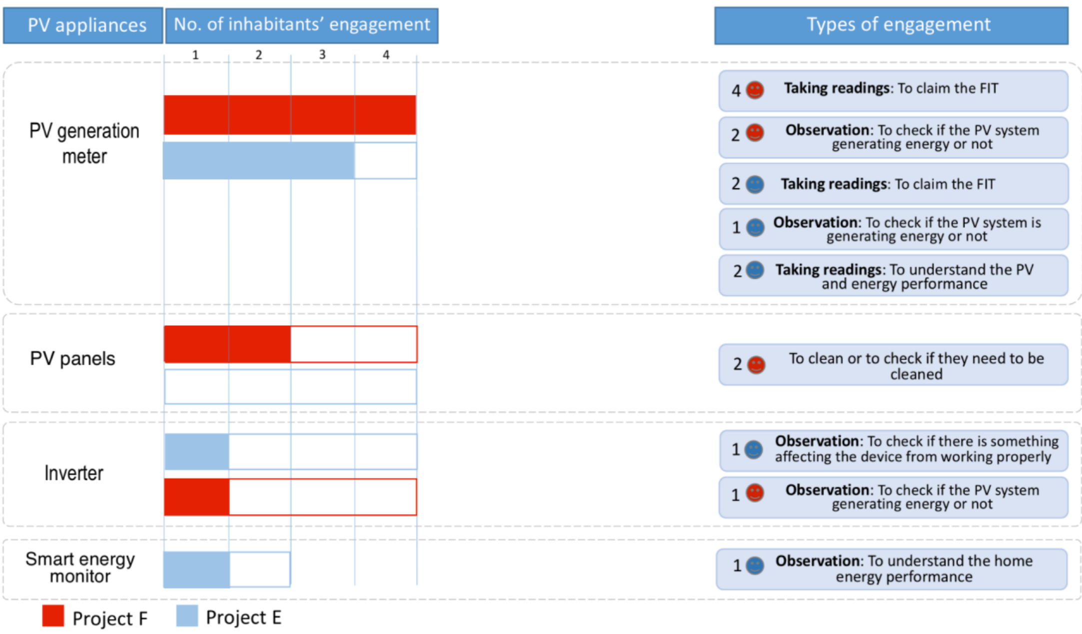

Figure 6.15: Number of inhabitants per engagement across case studies

6.3.1.1 PV generation meter

7 inhabitants out of 8 in case studies E and F were engaged with their PV generation meter regularly (meter readings, observation). All inhabitants in case study F were taking their PV meter readings quarterly to claim the FIT as a key driver, while only two inhabitants out of four did so in case study E. This is because the other two inhabitants were tenants and their company landlord (The Great Places Housing Group) was not eligible to apply for the FIT for reasons that will be discussed in chapter 7.3.1. As a consequence, nobody in one home looked at the PV meter or even knew if the PV system was generating energy or not.

Another driver for two inhabitants in case study E was to understand how much energy the PV system was generating for a period of time (a day, a week, etc.) and how much energy the inhabitants were consuming for the same period (Figure 6.16). However, only one of these two inhabitants tried to strictly match these two energy loads. Three inhabitants in both case studies were looking at the built-in green light indicator in the PV meter at irregular times to try to understand if the system was generating energy or not.

Several benefits were highlighted by inhabitants as a result of their engagement with the PV meter in relation to energy performance. As with the PC case studies, the importance of this issue is indicated by the significant number of NPC inhabitants' responses:

- Financial benefits.
- Understanding if the system is producing energy or not.
- Understanding how much energy the system is generating at different time and conditions.
- Matching energy loads.
- Detecting problems. As one inhabitant commented: "…one of the PV wire connectors was broken on the roof and we weren't generating energy for probably a month" (F4)

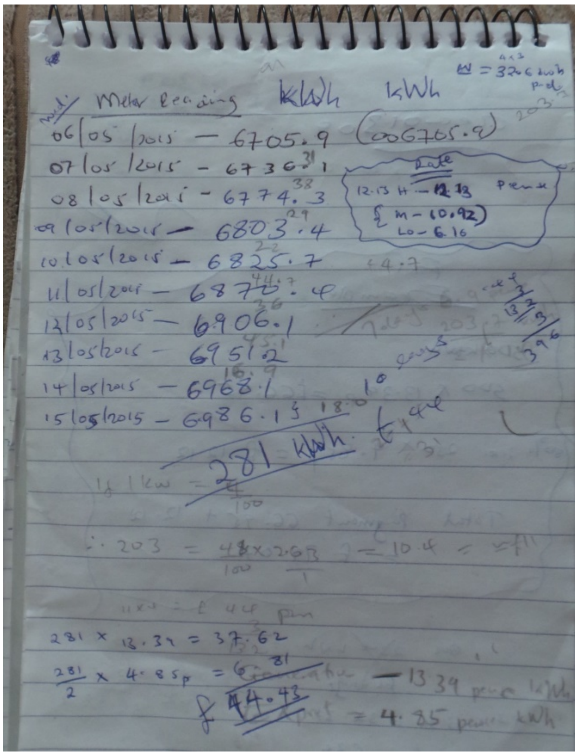

Figure 6.16: An inhabitant record of her daily energy generation and of the FIT returns

6.3.1.2 PV panels

In spite of the insufficient provision for safe access to the roofs in both case studies, two inhabitants out of four were irregularly visiting their PV panels in case study F to clean them where needed, while in case study E, no inhabitants engaged with their panels. The flat roof design of the houses and a balcony enabled these inhabitants in case study F to use a step ladder to go on to the roof. However, one inhabitant (F4) felt that using a step ladder was still unsafe which discouraged her from visiting the PV panels:

> "No. I don't think it is safe, because we need to use a ladder and the tiles are very slippery, So, I have never looked at them … I would like to see what is happening on the roof, and to see if the PV panels are clean, because Geese fly over as we live near the river" (F3)

Other issues that led inhabitants not to clean their panels will be discussed comprehensively in chapter 7.2.1.3.

6.3.1.3 Inverter

Only one inhabitant out of four engaged with their PV inverter in case study F to try to observe whether the system was producing energy or not by irregularly looking at the built-in green light indicator in the inverter. This was the only benefit indicated by her from this engagement. In case study E, only one inhabitant out of the four visited the inverter in his home to check if something was stopping the device from working properly, such as dust, but the inhabitant did not look at the display screen. The other 3 inhabitants in this case study did not even know that their PV system had an inverter or its location in the home, for reasons will be discussed in detail in chapter 7.2.1.3.

6.3.1.4 Smart energy monitor

Only the CSH-6 houses in case study E were fitted with a smart energy monitor, and even then they were not fitted in all the houses that were provided with a PV system. No other NPC case studies had these devices fitted. The main intention for installing the monitoring device by the developer was to explore how much inhabitants could reduce their energy consumption and thus reduce their bills in these houses compared with the similar houses in the case study. Although this device had high potential in terms of increasing the inhabitant ability to match their energy loads by instantly and synchronously visualising their energy generation and consumption pattern, only one interviewed inhabitant out of two (who had this device) engaged with it; the other inhabitant ignored it for reasons will be discussed in chapter 9.3.

6.3.2 PV practice problems

Three types of problems were similarly identified when analysing the inhabitants' data: engagement, affordance and context problems.

6.3.2.1 Inhabitants' engagement problems

As with the PC case studies, the unacceptable PV induction process was the key reason for poor engagement identified by all inhabitants in both NPC case studies. All these inhabitants felt they had received limited inductions to their PV system in their homes and most of them struggled to get to grips with the overly complex and technical manuals. Some inhabitants preferred to adopt a trial and error approach to understand their PV system while others turned to neighbours for advice on how to engage with the system:

"… just with my neighbour. He moved here two months ago. I had a lot of discussions about how to apply for FIT, because I did not know about the FIT. He helped me to know how to apply" (E2)

The inhabitants pointed out four main causes for the engagement problems (Figure 6.17):

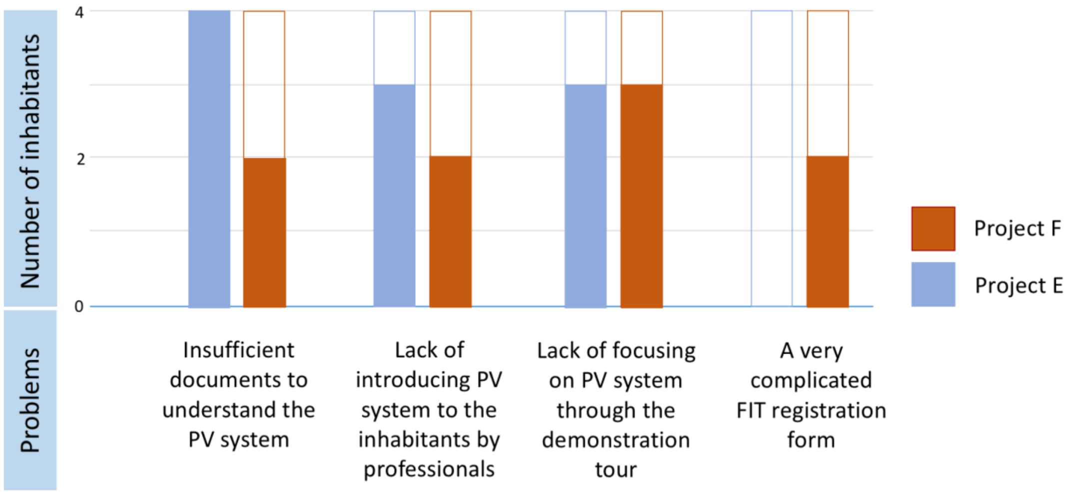

Figure 6.17: PV induction problems

1. Insufficient documents to understand the home technologies, including the PV system.
2. Lack of focus on the PV system during the home demonstration tour in both NPC case studies. The time of the introduction tour for each house was very limited and very general, and it was confined to showing the inhabitants the PV appliances in their homes in case study F, and just the PV meter in case study E.
3. Lack of PV system introductions by the professionals to the people responsible for the house induction tours in both case studies. The people responsible for the house induction tours did not have sufficient information about the PV system, leaving many inhabitants equally unaware of the purpose of their PV system. One inhabitant said:

   "She just explained that it is better to use energy during the daytime. That was all she knew; she did not know whether it is for water or electric. She though that it is for water" (E1)

Another inhabitant highlighted that:

"… there is a lack of professionalism in terms of introducing the homes to their users … So, they (authors comment: the government) need to start from the beginning to prepare professional guys for each technology. Even if there is no policy by the housing construction companies, there should be a government policy. Because the government is doing a lot of investments about ecology and reducing CO_2 emissions, but it is not providing the champion who actually can educate the users how to use their technologies" (E3)

4. A very complicated FIT registration form which was difficult to understand for two inhabitants in case study F. As a result, they asked their neighbours to help them to complete the form.

The insufficient PV induction resulted in a learning gap in terms of inhabitants' engagement with their system components (E), affordance (E, F), FIT registration requirements (E, F) and maintenance engagement (E, F) (see 9.5.1). A poor PV induction process resulted in other problems related to users' engagement with their PV systems as illustrated in Figure 6.18.

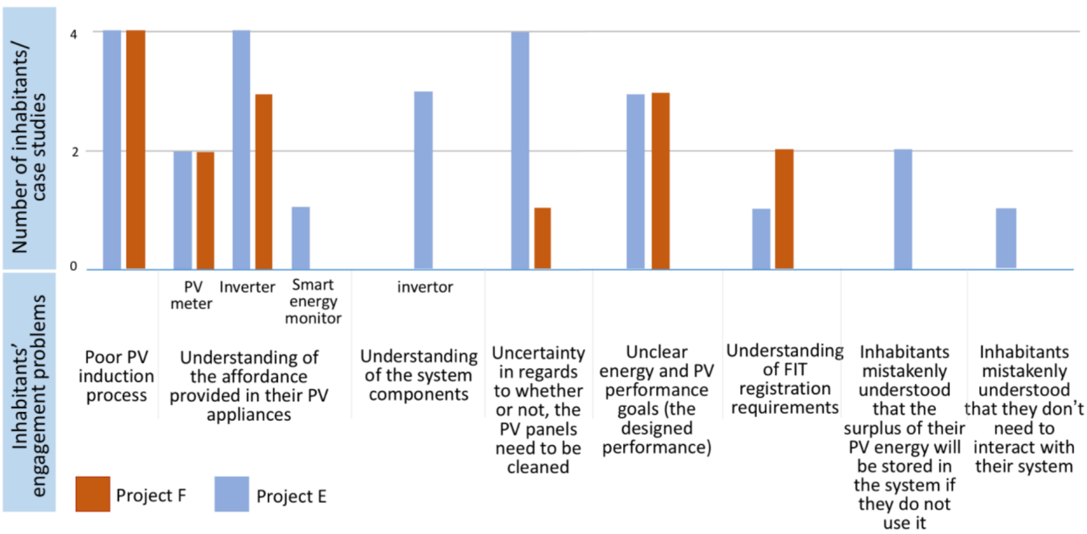

Figure 6.18: NPC engagement problems

6.3.2.2 PV affordance and system design problems

As with the PC case studies, a variety of problems were identified in relation to PV affordance and system design in both NPC case studies (Figure 6.19):

The most significant affordance problem in terms of the number of inhabitants' responses concerned the lack of providing inhabitants technical means, such as a battery bank, to use their PV energy efficiently, followed by the limited provision of visual and direct feedback for PV energy generation and overall energy consumption in an individual home instantly and synchronously. Inhabitant F2 said: "… without storage of PV electricity, you cannot use electricity very well, so there are limitations".

A battery bank is a device that, in some case studies, adds unused surplus PV energy to the PV system instead of exporting it to the main grid. No battery bank was provided in any of the PC and NPC case studies.

As a consequence of these two major problems, the majority of inhabitants in both case studies claimed that the PV technologies did not enable them to make the best use of PV energy in their homes independently without having to change their energy practice during the day.

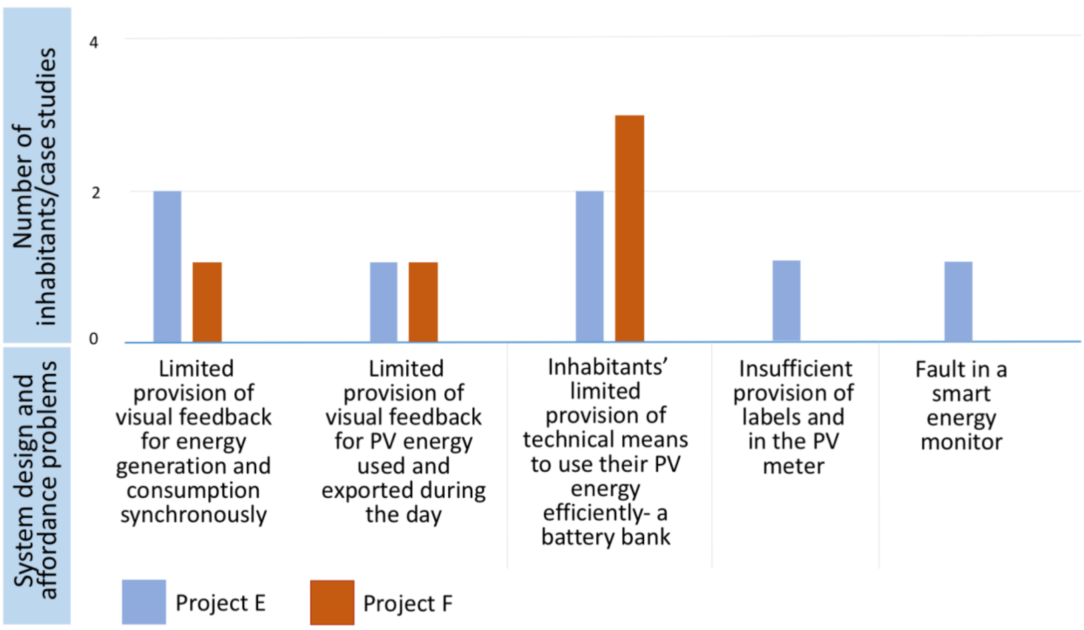

Figure 6.19: Affordance and system design problems

The next system design and affordance problems concerned the insufficient provision of labels in the PV meter (Figure 6.20) and a fault in a smart energy monitor. The former problem prevented one inhabitant in case study E from differentiating between his PV meter from the main energy meter with both located in the same store. He stated during the video tour: "This is our meter, but I'm not sure if it is for PV or not, because there is no information label" (E1). The faulty monitor further impeded the inhabitant from using the smart energy monitor and understanding his overall energy performance as a result.

Figure 6.20: PV and main grid meters in the same house – no labels to distinguish them

6.3.2.3 PV context problems

Two types of PV context problems were identified across the two NPC case studies, as with the PC case studies (Figure 6.21):

1- Macro context problems.
2- Micro context problems.

The insufficient provisioning of accessible PV appliances to the inhabitants represented the most critical macro context problems in both case studies. This related to inhabitants having inaccessible PV panels in both case studies, and inaccessible inverters in case study E (Figure 6.21).

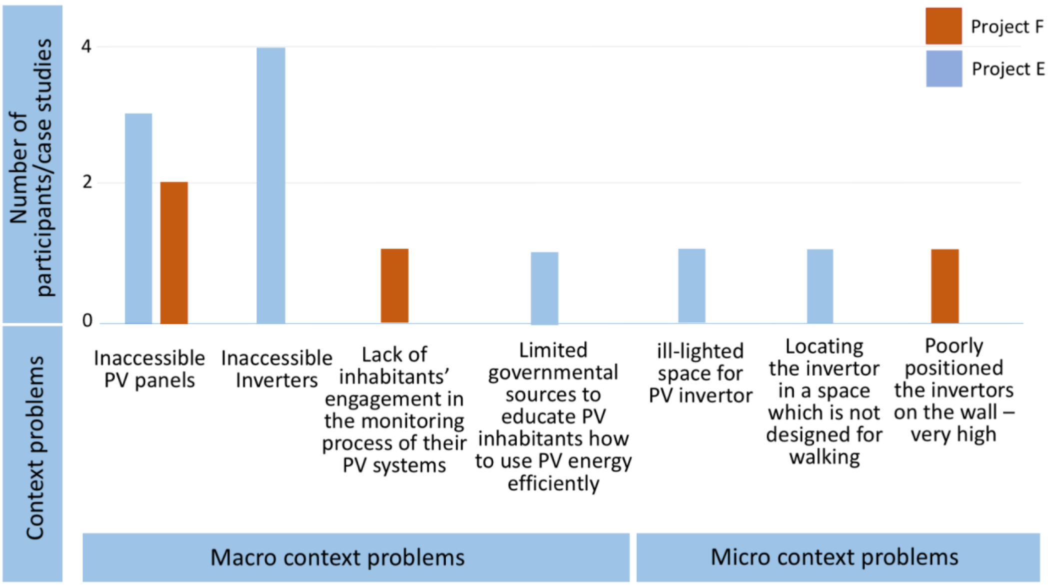

Figure 6.21: PV context problems

Six inhabitants in both case studies could not clean their PV panels as a consequence of their inaccessibility, while the other two inhabitants in the case study F claimed that they were only able to go up on the flat roof of their houses using a step ladder. Having an inaccessible inverter resulted in three inhabitants in case study E not even knowing if their PV system had an inverter as they were not told about it by the house demonstrator (Figure 6.22).

Figure 6.22: inaccessible PV inverters (E)

From non-technical perspective, the lack of inhabitants' engagement in monitoring their PV and energy performance (F) and limited government sources that could have educated inhabitants in terms of how to use their PV energy efficiently (E) were the key cited problems by inhabitants:

> "The government should also provide extra information about how to use these houses. What is the point of building eco-house where people cannot use them efficiently" (E3)

One inhabitant even claimed during the video tour that she had no idea about the monitoring equipment in her house, or even how to engage with it. She added that the 'monitoring people' did not provide her with any feedback in relation to her PV or energy efficiency. This indicates that the main aim of monitoring the PV systems for the housing managers was to be able to assess the efficiency of the systems independently from the inhabitants' involvement. This has considerably disempowered inhabitants from being able to match their energy loads.

Three micro context problems were highlighted by two inhabitants in both NPC case studies. In case study F, the problem concerned the overly high position of the inverter on the wall which restricted one inhabitant from effectively engaging with it:

> "The inverter was fitted about 8-9 feet high up in the balcony for sensible reason. So, we can see the display and read it, but the actual control buttons are out of reach" (F4)

The other micro context problem in case study E was even more critical. The attics, where the inverters were located, were not designed for walking in and were poorly lit, thus, they were not safe to be visited by inhabitants even by those who were very actively motivated to reduce their energy consumption (Figure 6.22).

6.3.3 Changes in practice

The change of inhabitant practices in relation to energy consumption, particularly in terms of using electric devices during the day to use up 'free' PV energy, was the only common change by all inhabitants in both NPC case studies, with one inhabitant stating it was: "Just mainly to take advantage of the sunshine and try not to waste it. So, that is the only change in our energy use" (F2).

Using less energy more consciously in the evening represented another practice change underlined by one inhabitant in case study F. The lack of affordances offered in PV appliances in terms of inhabitants understanding of their energy generation and consumption patterns, among other problems, restricted them from being able to rigorously change their energy consumption practice.

Various recommendations were made by both PC and NPC inhabitants to improve their PV affordances and practices in order to achieve the desired energy savings from the PV system. In the PC case studies, the inhabitants wanted to have a deeper understanding of their energy generation and consumption patterns in order to use their PV energy efficiently. The solutions suggested were to install additional devices that would help them to visualise these patterns instantly and synchronously (A – D) and to locate them in visible places inside the houses (A – C), as well as, when designing the system, to specify PV devices with a Wi-Fi capability for downloading data (A – D) (see appendix 11):

> "It would be very useful if we have some visual kind of display in our home to enable us to manage our energy usage for different times. I think, adding figures to the display would be easier to understand and remember

than numbers" (A4)

By contrast, the NPC inhabitants focused mainly on the need for technical components, mainly a battery bank, to manage their own energy loads by using the surplus exported PV power generated during the day to offset imported power from the main grid needed for the evening, as stated by one inhabitant: "Using a battery to store the surplus of electricity instead of exporting it to the main grid so you can use it later in the day" (F2).

To Improve their PV demonstration, inhabitants in the PC case studies wanted to have a better HUG, as an effective artifact in relation to their home induction process, as one inhabitant suggested to provide:

> "Just simple guidelines rather than a huge amount of very complex information. You can go and look at all complex things later when you start using them, why it works, how it works and everything else" (A4).

She also added that people want:

> "…to have an easier bullet point version rather than pages of information. These bullet points would help people first when they first move in … this human nature not just me. People always prefer to go to the point directly, and if it is interesting, they go and find out more".

In the NPC case studies, the inhabitants preferred the idea of having sufficient time for PV introduction during the house demonstration and for the PV system to be demonstrated by professionals. Both PC and NPC inhabitants preferred to obtain the necessary information verbally from the PV installer or any other provisioning team actor, rather than being given a complex bundle of booklets and documents. This preference for verbal dissemination was highlighted incidentally by one inhabitant:

> "Interviewer: In this document, they said here that the estimated energy production from your PV system is 1175kW a year"

Since accessibility has been quoted as one of the major context problems for both PC and NPC inhabitants in terms of cleaning and maintaining their PV panels, many PC inhabitants wanted an easy access to the PV panels on the roofs to clean them and an education on how to clean them (A, D). By contrast, only one inhabitant in the NPC case studies actually recommended the provision of safe access to the roof to clean the PV panels. This indicates that the majority of NPC inhabitants were confused by the ambiguity that surrounds the maintenance process for PV panels in the UK, particularly given the PV installers' underestimation of the influence of the sedimentation (e.g. dust or dirt particles) in reducing the power output, due to lack of cleaning (Denholm et al., 2010, Sarver et al., 2013, Roslizar et al., 2019). Choosing a better specification for PV panels was also suggested by inhabitants in the PC case studies B and D to overcome the shade problem that reduced their energy production from the PV systems and to improve the system performance as a result. Other recommendation made by inhabitants (both PC and NPC) are summarised in Chapter 10 and Appendix 11.

6.4 Sub-conclusion

This chapter presents key findings which begin to inform the 4th and 5th thesis objectives in terms of identifying initially how domestic PV systems are being practiced by inhabitants in various contexts, and in relation to the affordances offered in the system appliances. The analysis of the inhabitant interviews and video tour data in this chapter enhances an understanding in reality of inhabitants practicing their PV appliances and how their practices are affected by the different provisioning of PV affordances and contexts.

This chapter highlights critical PV practice problems, changes and inhabitant understanding of their PV system components, affordance, performance and energy management potentials. The video tour method proved useful to reveal further problems in context resulting from inhabitants' practices, such as poor positioning of PV appliances on the wall and poorly illuminated the small display screen. It also revealed inhabitants' tacit knowledge and know-how when engaging with their appliances and the system affordances. The video tour crucial revealed other engagement changes made by inhabitants in the areas of practice and affordance, which were not been highlighted by the interviews, such as using a chair to stand up on and read the overly high meters and using a torch to read the poorly illuminated PV space.

There were a number of crucial similarities between both the NPC and PC case studies in terms of inhabitant practices and the affordances available to them. In both the PC and NPC case studies, the key engagement by inhabitants was with their PV meter. They took readings quarterly to claim their FIT, which was a main driver. The next key engagement was observing their inverters to understand if their PV system was generating energy or not. PV panels were technology that inhabitants engaged least with.

The inhabitants understanding of PV components, affordances and engagement with maintenance, were negatively influenced, to different degree, by the poor PV induction processes in both the PC and NPC case studies.

By contrast, the inhabitants uncertainty about whether the PV panels needed to be cleaned or not was the most reported problem by the PC inhabitants, while in the NPC case studies, it was the inhabitants engagement with their inverter, as a key component in their PV system and the affordances offered in these inverters. The top system design and affordance problems related to the inhabitants lack of energy production and consumption feedback in both the PC and NPC case studies and lack of a battery bank in the NPC case studies, as well as the inhabitants inability to download the energy generation and consumption data in the PC case studies for their own use.

All these failures reduced the inhabitants' ability to use PV energy efficiently by matching their energy loads to save grid energy consumption, with no particular difference in terms of whether inhabitants coped better in the PC or NPC case studies. This would seem to suggest that PC governance does not necessarily present a particular advantage over NPC governance in housing developments when it comes to specified affordances and resulting practices for reasons will be discussed in chapter eight.

Other problems identified in this chapter concern the context of PV systems. This relates to the poor way that PV appliances are integrated into homes, such as locating the PV panels in inaccessible roofs and the inverters in a hidden place in the house in both the PC and NPC case studies. All these problems reduce inhabitants' engagement with the PV systems. Shade cast on the panels by trees and chimneys in the PC case studies was another contextual problem which influenced the system performance in terms of energy generation. Community rules was another key context problem highlighted by the PC inhabitants which will be discussed in chapter nine as a key practice element influencing PV practices.

This chapter has identified several PV affordance changes made in the PC case studies, while in the NPC case studies, no affordance changes were made. The key changes identified were: improving the stability of PV panels on the roof, and reducing the visibility of PV appliances due to their poor aesthetic appeal.

The implications of all of the above initial findings will be considered more deeply in Chapters seven, eight and nine.

The inhabitants also made numerous practical recommendations about how to improve their energy consumption management. The inhabitants in the PC case studies wanted to have a deeper understanding of their energy generation and consumption patterns to help improve their energy consumption management. They suggested choosing PV devices with Wi-Fi capability to download the data when designing the system and installing additional devices that would visualise these patterns instantly and synchronously. The NPC inhabitants, by contrast, suggested adding a battery bank to the PV system to improve their energy consumption management. Other suggestions concerned PV maintenance by providing an easy access to the roofs to clean the PV panels. All the recommendations made by both PC and NPC inhabitants in relation to their PV affordance and practice were classified into four key categories according to the positive consequences that inhabitants could achieve when using their appliances: energy consumption management, PV induction and maintenance, and aesthetics (see appendix 11).

Given the above findings and the very practical recommendations put forward, some key questions now arise in relation to how the poor affordance and integration of PV systems identified in chapters five and six, came about in the first place:

1) *How is the PV system envisioned by the PV provisioning actors and policy makers in the first place?*
2) *How are these visions outlined in the governance of the PV system by the different provisioning teams, in terms of deciding the affordances offered and the integration of the appliances into homes, taking into account the wider and extended[22] issues of networks and arrangements[23]?*
3) *How is the inhabitants' governance of the PV provisioning process influenced by the PV provisioning governance networks and arrangements in the first place, and does inhabitant governance improve their subsequent practice?*

[22] A wider and extended network refers to all the participating actors beyond the boundary of the contract and building professionals that influence the PV provisioning networks and practices.

[23] The word 'arrangements' in this chapter (in relation to ANT's notion of network) means the positioning of actors within a network

These questions relate to how PV systems come into play during the design and construction of a project. They also relate to how various people and objects are involved in a network to construct practices that relate to the provisioning and inhabitants' engagement with PV systems. Finally, they relate to the role of wider and extended networks in enabling/disabling effective PV networks and practices. The next chapters (seven & eight), thus, further analyse and discuss the different agency of actors in terms of making PV decisions (chapter seven), and the role of governing networks, including wider networks, in enabling/disabling these agencies and the integration/disintegration between the various actors (chapter eight). In the next chapter, the agency and role of various PV actors (both humans and non-human) in terms of influencing the governance of PV provisioning and inhabitants' practices will firstly be discussed through the theoretical lens of intermediaries and mediators and sociology of translation, according to ANT theory.

CHAPTER SEVEN: THE GOVERNANCE OF INHABITANT PRACTICE: PV INTERMEDIARIES AND MEDIATORS

7.1 Introduction

This chapter introduces a distinctive approach to addressing the energy performance gap associated with the practice of domestic PV technologies. ANT's notions of mediator and intermediary is related to provisioning process of these technologies, and the consequential inhabitants' practices of them. This is done by identifying all the PV provisioning actors when coding the interviews with PV professionals and the related documents, and critically *mapping* the relationship between them in all the PC and NPC case studies according to their agency and roles in the PV governance network. This novel method is used to investigate how these actors define the materiality of the PV system and its integration into homes based on their vision of the system in terms of the inhabitants planned engagement. This addresses the 2nd, 3rd, 4th and 5th objectives of the thesis and follows on from the initial exploration of provisioning governance and the changes made during the provisioning stage (chapter 5) as well as the examination of affordances in relation to actual inhabitant practices (chapter 6). The focus in this chapter will be on actors as intermediaries and mediators (Latour, 2005), and their crucial influences/impacts on the system design and inhabitant practice. The chapter will be separated into two main sections: PV provisioning governance and PV governance of practice.

7.2 PV provisioning governance

7.2.1 Governance by provisioning team

This section discusses provisioning team governance of the PV system during the PV provisioning stage and the consequence of this on inhabitants. Accordingly, the section discusses the different role of PV provisioning actors (both humans and non-humans) in terms of the agency and the type of action they performed when constructing the system design (affordances) and integration into homes (arrangements).

The distinction between mediators and intermediaries in this chapter is significant for three key reasons: firstly, it reveals hidden power dynamic associated with the decision-making process of multiple actors, which influence the design and subsequent practice of inhabitants. Secondly, it explores whether the PV system governance is a fixed model of production or unpredictable. Thirdly, it helps to understand and explain the role of non-human actors as mediators in the governance of the PV system and their impact on the decisions made by the provisioning actors by acting as intermediaries. 'Provisioning actors' here refers to both professionals (the design and construction team such as the architect, contractor, PV installer, etc.) and other participating actors who have participated in the governance of the PV system e.g the selling agency and local planning authority. The Provisioning Inhabitant (PI) and community group, as key provisioning actors in the PC case studies, are discussed in the next section. Figure 7.1 analytically maps the critical relations between the different actors (both mediators and intermediaries) in all case studies during the PV provisioning process and the relative importance of each intermediary in terms of how many case studies were affected and in what ways.

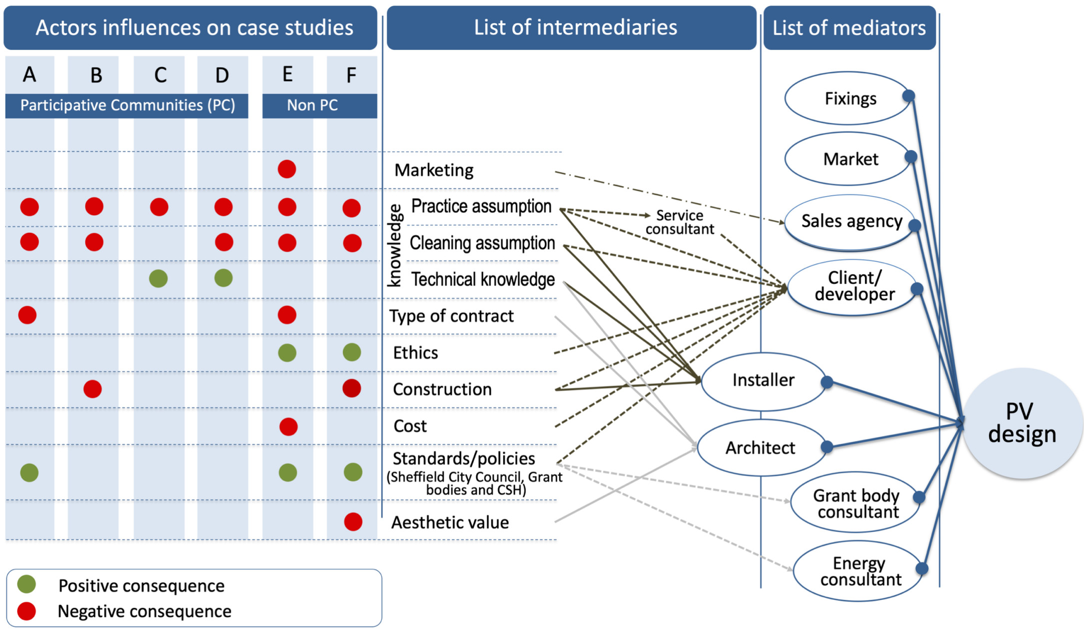

Figure 7.1: Intermediaries impacting on provisioning team agencies

7.2.1.1 PC case studies

Five key actors (both professionals and other participating actors) performing as human mediators were identified in the PC case studies: *architect*, *installer*, *energy consultant*, *grant body consultant* and *main contractor*, while PV *fixings* and *market* were the main non-human mediators identified. The PI in case study A employed an *energy consultant* to frame the project energy strategy at an early stage of the provisioning process who specified PV systems with a minimum size of 0.75kW in each house in his final report. The non-human *grant body policy*[24] was a key intermediary impacting on the energy consultant decision, in terms of ensuring that the homes were built to Code for Sustainable Homes (CSH) level 4 standard. The *grant body policy,* passing on the governance of grant body people, also acted as a significant intermediary in case studies C and D by requiring monitoring systems to be installed in the PV systems (C, D). This improved the system affordance in terms of increasing inhabitants' capacity to download and compare their PV performances, thus, giving them the potential to match their energy loads and to identifying underperformance problems. As one inhabitant put it, "Because we were monitoring the systems, so we picked these problems up very quickly" (D3). The architect in the case study A performed as an intermediary by connecting the PI with the grant body consultant as stated by the PI:

> "… just after Christmas 2009, X (author: architect- the name is anonymised) emailed me, excited about the opportunity of a grant from the UK's Department of Energy and Climate Change, and Home and Communities Agency (HCA), which aimed to get fledgling supply chains off the ground specializing in natural materials…" (A3)

The *grant body consultant* performed a key human mediator role by determining the total scale of all the systems (D). The mediator *grant body consultant* also enabled the inhabitants to install their PVs by making the decision to fund the systems (C, D). The *main contractor* as a mediator decided the location of the PV meter and inverter inside homes (A), as discussed below.

The *Fixings* of PV panels was another non-human actor that negatively influenced the provisioning of PV systems in case study C, with the *Fixing* switching from intermediary to mediator role through virtue of unpredictably changing the condition and causing a break in the system during occupancy. The Fixing of the PV panels' frames was expected to perform as designed by the PV installer and the PIs, but they did not, resulting in them being blown over and damaged in adverse weather conditions, as highlighted by all interviewed inhabitants. The Fixings of PV appliances, potentially caused by actors in the PV network thus, should be discussed and assessed carefully, as key intermediaries that can become mediators, and that have an agency in terms of their capacity to change and transform the outcomes, rather

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24 Homes and Community Agency, England as an organisation was the policy maker

than understanding them as just an intermediary decided by humans which always function as a predictable ‘black box’.

Market was another non-human actor that negatively influenced the provisioning of PV systems in case study C in relation to delivering the PV appliances on time to ensure that the housing programme would be completed on time. The PV meter installation in this case study was significantly delayed by the PV *Market* (manufacturer/supplier), delaying also the monitoring process undertaken by the PI. As the PI said:

> “The process of commissioning monitoring systems took 176 days from the completion of the installation compared to the 33 days planned. The main cause of the delay was commissioning the meters” (C1)

The non-human *Market* actor in this case study also switched from intermediary to mediator role when an unpredicted delayed delivery of the PV meters occurred, changing and transforming the outcomes as a result. This is significant actor that should be also discussed carefully and understood by human actors, as a key intermediary that can become mediator.

Figures 7.2—7.5 analytically map how the different actors were connected to inform the system design and inhabitant practices of using their own PV systems, in each of the four participative case studies, A, B, C and D respectively. The arrows vary in shading from light grey to black in order to link the correct intermediary/mediator with the actual influences on the governance.

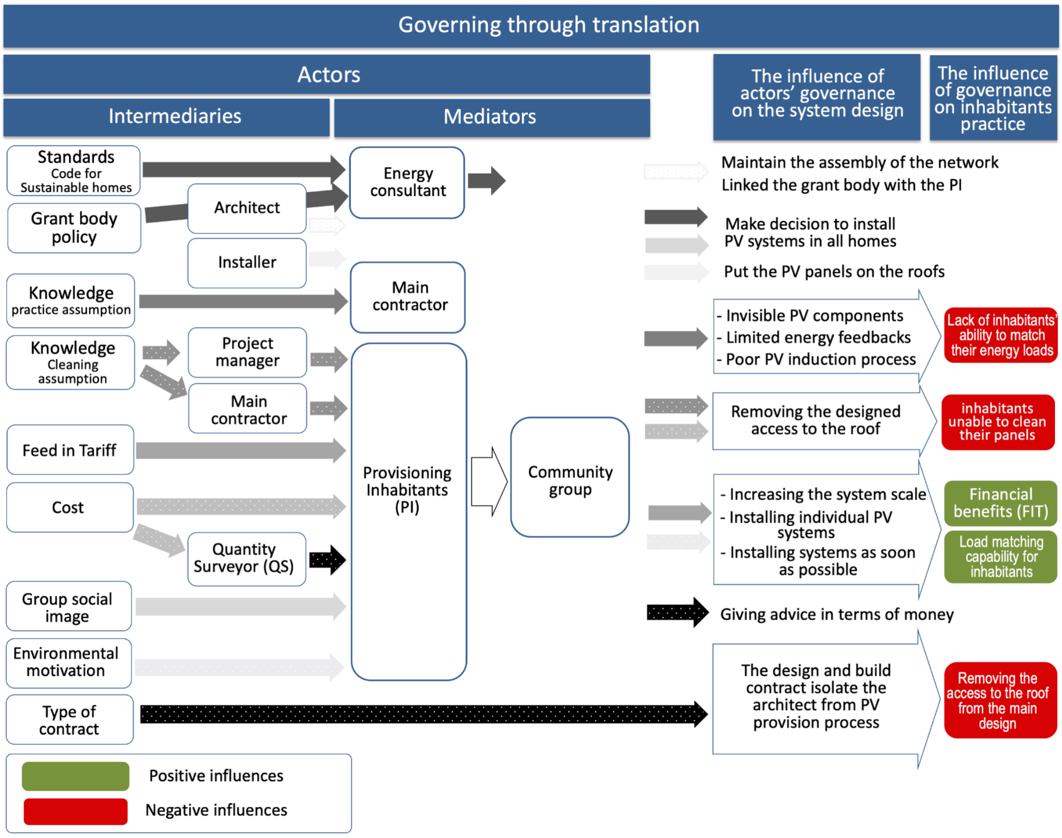


Figure 7.2: Provisioning team and inhabitant governance – Case Study A

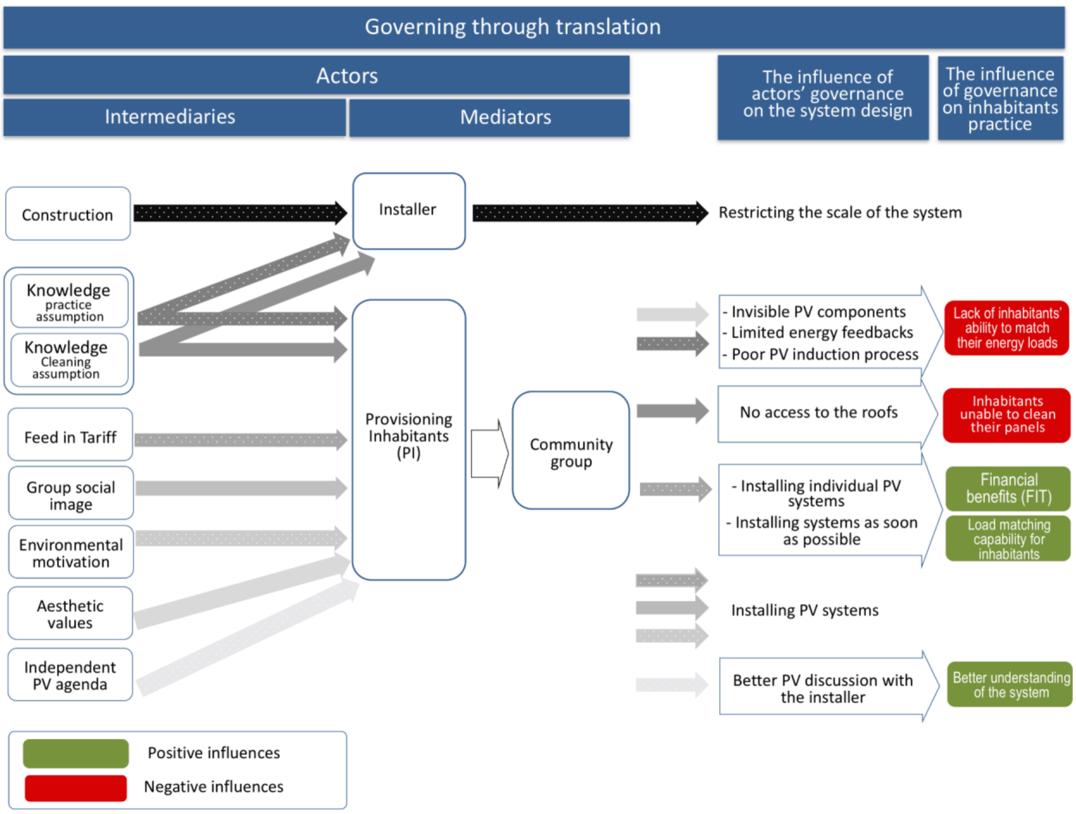


Figure 7.3: Provisioning team and inhabitant governance – Case Study B

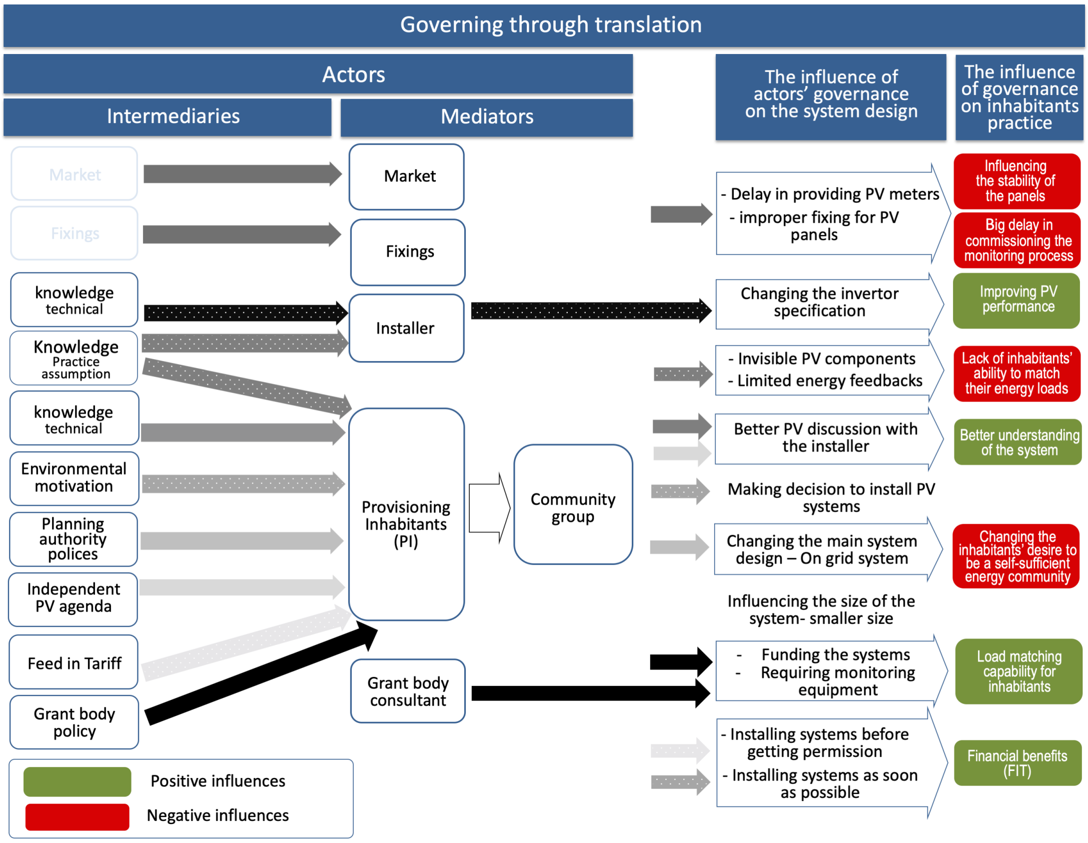


Figure 7.4: Provisioning team and inhabitant governance – Case Study C

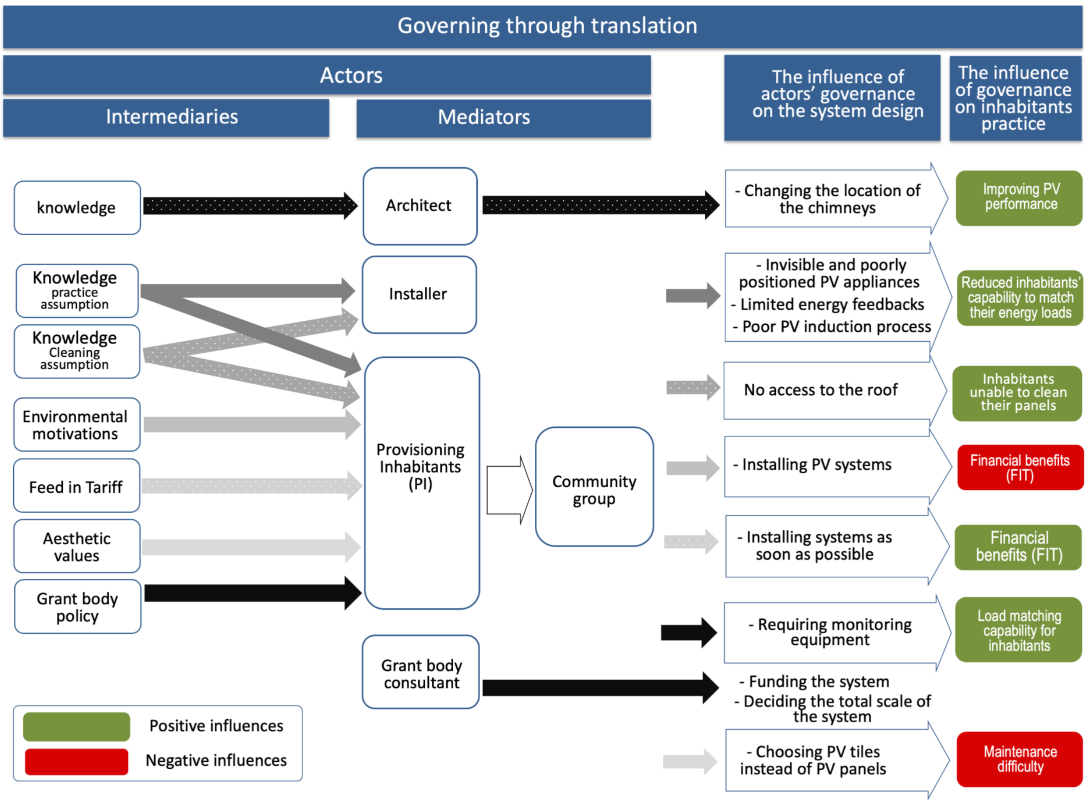


Figure 7.5: Provisioning team and inhabitant governance – Case Study D

7.2.1.2 NPC case studies

In the NPC case studies, the key human mediators were the *client/developer*, *main contractor*, *sales agency* and *architect*. The non-human intermediary of the *Sheffield City Council (SCC) planning authority policies* obligated the client to build new houses with 10% PV installations in case study E according to its new requirements. The sustainable *ethics* certificate of the client/developers as a non-human intermediary in case studies F and E impacted their decisions to install PV systems as highlighted by the architect in case study F: “The client is an ethical developer and will only build new properties with a CSH score of 4”.

The normative *aesthetic values* (section 2.6.3) acting as an intermediary impacted one architect (F5) to individually decide to position the PV panels invisibly on inaccessible flat roofs, saying: “We set the parameters that we felt we could accept aesthetically”. His decision stopped inhabitants being able to see whether their PV panels were dirty or not by looking at them from the ground level. As one inhabitant put it: “So we should maintain that, and I may buy a little drone or a camera to see if the roofs and PV panels are dirty or not” (F4).

The *aesthetic values* clearly overrode the functionality of the panels in terms of maintenance. The high *cost* factor of the PV installation acted as an intermediary to impact on the client’s intention and capacity to install PV systems in all homes (E). As a result, only 10% of the case study homes had PV systems. The client representative suggested funding the PVs by a third party. However, this idea was rejected by the *sales agency* as a key mediator.

> “So, there were a couple of issues, around the saleability and perception, that stopped us going with this idea, with the sales agency saying: ‘well every property we want to sell and if they have got a lot of PVs on the roof that would be impediment to a sale. My own believe was that it was not” (E6)

Figures 7.6 and 7.7 analytically map the overall mediators and their subsequent influences on the system design and inhabitant practice in case studies E and F. They also map the impact of different intermediaries on the mediators’ decisions.

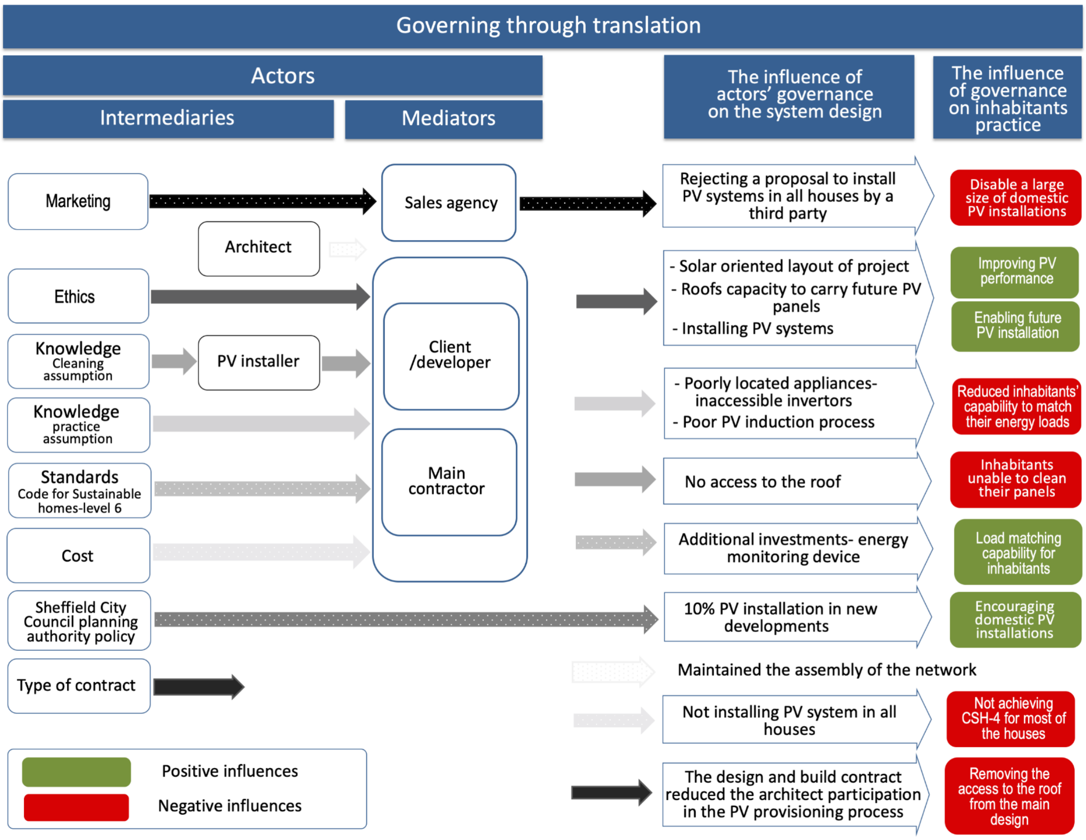


Figure 7.6: Provisioning team governance – Case Study E

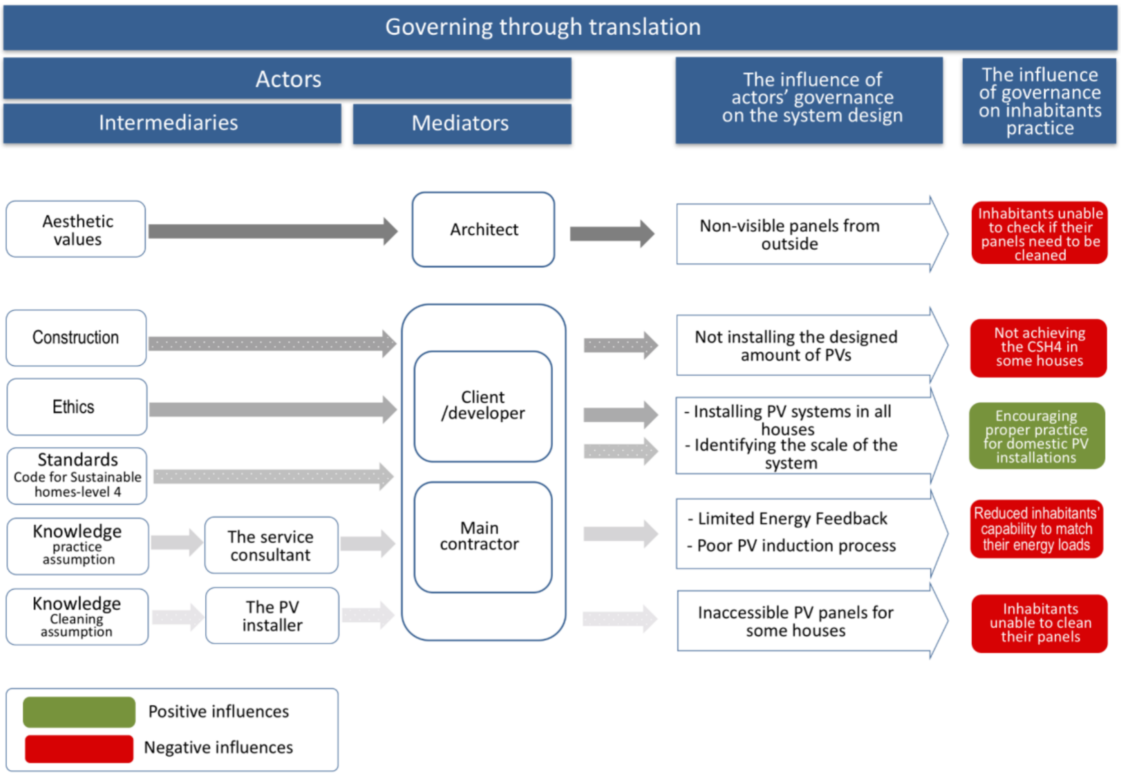


Figure 7.7: Provisioning team governance – Case Study F

7.2.1.3 Predominant intermediaries

Further intermediaries predominated by significantly impacting the provisioning team decisions in *both* the PC and NPC case studies. These were *knowledge, construction, standards and type of contract,* as detailed below.

- *Knowledge.*

Architect's knowledge (D) positively impacted the system performance when he changed the location of chimneys in the main design to avoid overshadowing the PV systems (see 5.3.1.2, context change). Similarly, the high technical knowledge of the PV installer led him to change the specification of the inverters to match the PV panel generation rate (see 5.3.1.2, technical changes), again improving the system performance in terms of energy generation: "the installer changed it to 1100E instead of 1200E … And I think that was because the inverter will work more efficiently" (C1).

By contrast, the assumption made by various professionals and other participated actors that PV panels were self-cleaning (Sarver et al., 2013, Kaldellis et al., 2004) led to insufficient cleaning governance during the provisioning process, resulting in all PV panels being inaccessible and not being cleaned by the inhabitants, except in case study C. This also meant they would not be aware of any problems afforded by a visible inspection process, unless they compared the outcomes of the identical PV systems with each other. One PI and community group even made the decision to remove the roof access to the PV panels from the main design, impacted by the cost and poor knowledge of the main contractor and project manager intermediaries (see 5.3.1.2, context change):

> "We took out the accessibility to the roof from the design for cost issues… the panels were self-cleaning as far as I'm aware, so they would not need regular cleaning" (PI, A3)

By contrast, the PV installer in case study C discussed the PV panels cleaning process with the PI widely by telling him how frequently their PV panels needed to be cleaned and the method to do so. Together with the affordance of the roof-sheltered house design in case study C, which provided the inhabitants with easy access to the roof to clean their PV panels, this enabled the regular cleaning of all the PV panels by the inhabitants responsible for this task (see 6.2.1.2).

Although all inhabitants in case studies A and B argued that their energy generation figures were relatively stable, some inhabitants in case study D claimed that their PV energy generation dropped dramatically after a year, as a result of not being able to clean off sticky deposits from trees on their PV panels, and trees overshadowing the panels (see 6.2.2.3). An inhabitant in case study D illustrated the consequences of this assumption:

> "Sycamore trees … have very sticky deposits that come down from them on the PV panels, which does not get cleaned by rain ... so, we are actually generating a lot less energy from other houses here…I have managed individually to clean about 2—3 of the arrays, the other 4—5 arrays beyond them are just getting dirtier and dirtier and I can't reach those" (D1)

Surprisingly, the PV installation guide documents did not mention any cleaning requirements, merely stating "the cleaning effect from rain, hail etc." (MCS, 2012: 23). However, some PV websites do mention physical panel inspections or checking via a monitoring system (Solar Facts and Advice).

Worryingly, in the NPC case studies, cleaning issues were not mentioned at all because the inhabitants did not know their own PV energy generation, or even if their system was working: "So, I have got the system, but I don't know anything about it … we don't even know if it switched on" (E1). Two other owner inhabitants also did not know whether their panels needed cleaning or not because the developer did not tell them that they need to check and clean their panels if needed: "We were not specifically given that information" (F4). These inhabitants also did not have any feedback to tell them whether their system was generating the expected energy or not.

Similarly, the assumption made by PV provisioning teams that the PV inverter and meter needed no real inhabitant engagement (apart from quarterly meter readings for the FIT) significantly impacted the material script for the system. All design teams focused on the generation side and neglected the specific needs of inhabitants who wanted to manage these energy loads. The notion of practical energy demand management was simply not part of the provisioning agenda:

> "The technology is in the house and just sits there passively doing stuff for them and they don't need to do anything, just need to fill the form to get the FIT and read the meter to claim benefits" (client representative E6)

The main consequences of these governance decisions, which were highlighted by all inhabitants as key engagement problems, were insufficient provisioning of direct monitoring feedback to inhabitants for PV system performance (D, F) and energy performance (all PC and NPC case studies), and lack of Wi-Fi capability in PV appliances for inhabitants to download the PV energy generation data during the day from the inverters or meters (see 6.2.2.2 & 6.3.2.2). As one inhabitant said: "I need to see the patterns of energy generation and consumption during the day. I think this will have an impact on our usage pattern" (Inhabitant C2). All these consequences reduced the capacity of inhabitants to match their energy loads.

The other significant impact of the above 'zero engagement' assumption concerned the material arrangements of the system appliances inside the house. Three video tours revealed that inverters were located in a small dim room and/or in a very low or high position, restricting inhabitants from being able to read the display screen or changing the setting of the information (A and B) (Figures 7.8). The influence of poorly located inverters by the developer was worst in the NPC case study E, as it resulted in inhabitants not understanding that their PV systems had an inverter in the first place. Tellingly, when asked about the inverter, one inhabitant replied, "I don't know, I have never seen it before. I don't know anything about it? What it does look like" (E1). Further impacts concerned the inhabitants' governance of their practice with the inverter which will be discussed later in the next section (PV governance of practice).

Figure 7.8: Inverters' location – Case Study A

- *Construction.*

The PV provisioning team had to reduce the size of the planned PV systems significantly in some houses due to improper governance by the architect in relation to the roof size (case study F) with insufficient prior discussion between the architect and the service consultant for reasons will be discussed in the next chapter in case study F:

> "There were two homes where the roof size was insufficient to accommodate enough PV panels – the size was designed to achieve the A score. So, for those homes we just put PVs on as much as we could" (Client, F7).

Not achieving the CSH level 4 standard in those two houses was the main negative consequence from making this change.

- *Standards.*

The high requirements of the CSH level 6 standard, as an intermediary passing on government environmental policy, positively impacted the developer in case study E, who installed a smart monitoring device, enabling the inhabitants to potentially individually match their energy loads, as discussed in depth in section (9.3). These requirements further impacted the developer positively, who increased the scale of the PV system from 4.0 to 7.8 kW in four houses to achieve the CSH level 6 'zero carbon homes' standard.

In case studies A and F, the CSH level 4 standard (a 44% reduction in dwelling emission rate below building regulation standards) also positively impacted on the energy consultant and the client respectively, who installed PV systems in all houses (see 5.3.1.1 and 5.3.2.1, preparation stage).

- *Type of contract.*

In case studies A and E, the design-and-build contract (DB) (see 8.2), acting as an intermediary by passing on client decisions, impacted the capacity of the architect to actively support the translation process with some critical decisions being made without his consultation, because the contract excluded him from these later design decisions. Examples include removing access to the roof in case study A and installing inverters in an inaccessible place in case study E. The influence of the contract as a non-human intermediary in terms of shifting the agency of the various actors at different building construction stages and on the whole actor-network will be discussed in depth in chapter eight.

7.2.1.4 Governance actors and networks

A clear difference in the actors' agency and associations in the PV governance networks was identified between the two sets of housing provisioning. In the PC case studies, the PIs were the key governance mediators during the provisioning of the PV systems, while the client developers and the main contractors were the key governance mediators in the NPC case studies. However, the agency of the PI in terms of making decisions was undermined in some cases (A, D) due to his insufficient knowledge of PV systems and other reasons discussed in the next chapter. Importantly, the agency of the provisioning actors in governance network were not fixed in form, instead, they were interchangeable across all the PC and NPC case studies. PIs, for example, performed mediator *and* intermediary roles during the PV provisioning process. They made the key decisions during their discussions with other provisioning team (Figures 7.2—7.5), while also acting as intermediaries by passing on decisions to the inhabitants. However, only one-way translation occurred from the provisioning team to the inhabitants through the PI in all PC case studies, as the PI did not take the view of inhabitants back to the design team in relation to the PV system design. This could be attributed to the PIs belief that the design team were the *experts* with better knowledge than the inhabitants, leading all PIs (A, B D) to accept all the suggestions made by the provisioning team without challenging their decisions. Furthermore, the PIs in projects A, B and D were more aligned to the design team than to the inhabitants when discussing the final decisions with inhabitants, moving from a basis of neutrality and changing their PI role as intermediary to mediator, persuading the inhabitants to accept all the design team's decisions, and influencing the PV provisioning networks and outcomes as a result, which will be discussed in the next chapter. The findings also show that the agency of non-human actors (e.g. fixings and market) are also not fixed in form, instead they changed from intermediary to mediators in practice, changing the outcomes as a result, which are factors often overlooked in the discourse and in the industry itself.

In terms of other provisioning team governance, the energy consultant and main contractor performed as mediators in case study A, making key decisions in relation to system design and integration into homes, despite the presence of the PI, while the rest of the provisioning team, particularly the project manager, acted as intermediaries who impacted the final decisions made by the PI. In case studies B—D, the installer became a mediator because the PV system was installed independently from the main building construction. He decided the system design and integration into homes directly with the PIs, in terms of locating the monitoring device (C) and inverter (B) in an invisible place, and not providing accessible PV panels for cleaning purposes (B, D). In case study A, by contrast, the installer had a different role, acting only as an intermediary who maintained the assembly of the actors in the network. The architect acted only once (D) as a mediator during the PV provisioning process due to the PI commissioning him separately from the main building construction process, while he acted only as an intermediary in case study A by linking the PI with the grant body consultant (HCA) in early stage of building construction process. The architect was also relatively powerless in all the other case studies as an intermediary due to reasons will be discussed in the next chapter. The human grant body consultant acted positively as a mediator by determining and agreeing the overall size of the PV systems (D) and making the decision to fund the PV systems in case studies C and D. The non-human grant body policy, by contrast, acted as significant intermediary in case studies C and D by routinely requiring a monitoring system to be installed, and impacting the energy consultant decision (A) in terms of ensuring that the homes were built to Code for Sustainable Homes (CSH) level 4 standard.

The professionals' and PIs' knowledge of PV system and its meaning, and FIT were the key intermediaries in all the PC case studies, which influenced their decisions in relation to the system design and integration into homes, while the CSH standards were only influential in project A, impacting on the decision made by the energy consultant to install PV system. In the other projects, the CSH had no impact on the PV governance.

In the NPC case studies, the client/developer, the sales agency, the main contractor were the mediators who made the key PV decisions in both case studies, impacted on by other intermediaries (Figures 7.6 and 7.7). The architect acted as a mediator only in case study F due to his early participation in the PV governance network with the client and the developer which will be discussed in depth in the next chapter. However, the inhabitants had no agency at all when governing their PV design and remained ignorant of system performance and maintenance, as discussed above. In both NPC case studies, the installer acted as intermediary who only maintained the assembly of the network by installing the specified PV appliances by the main contractor, and impacted the client decision in terms of not providing accessible PV panels so they could be cleaned (E).

In general, *Knowledge* proved to be the most significant non-human intermediary in terms of how often it came up, when coded and mapped in relation to each case study, followed by *standards/polices* and *ethics certificate* (NPC case studies), and *FIT, environmental motivation* and *aesthetic* (PC case studies) (Figure 7.12). The provisioning team *assumptions* about inhabitants' engagement with their PV system clearly impacted the governance of system design and integration into homes, and reduced the inhabitants' capability to engage with these systems effectively. Importantly, where a provisioning team had specific PV technical knowledge, this generally helped them to improve the PV system performance in terms of energy generation (C, D).

No actors in any case study taught inhabitants how to engage effectively with their PV appliances and manage their energy loads when they first moved into their homes. No inhabitants in the NPC case studies knew how to engage their inverters and energy monitoring device: "I don't interact with it because I don't know much about its application" (E1). In the PC case studies, only the PIs and one inhabitant in project A were aware of how to engage their own inverters' display screen, while the other inhabitants were not, because the PI did not *transfer* their knowledge to other inhabitants – a vital omission. Lacking an understanding of their system, therefore, is not simply the 'fault' of the inhabitants as has been highlighted in previous studies (chapter two), but, more significantly, is also the fault of the provisioning actors' decision-making with a lack of prioritization.

7.2.2 Inhabitant governance

Participation played a key relational role in helping inhabitants to govern their PV system design and their subsequent practice, as discussed next.

7.2.2.1 Governance at the preparation stage

Five key non-human intermediaries significantly impacted the decisions made by the PI and community groups, and the PV system design as a result: *Independent PV Agenda*, *FIT*, *environmental motivation*, *social image* and *planning authority policies.* These relationships are analytically mapped out in Figure 7.9.

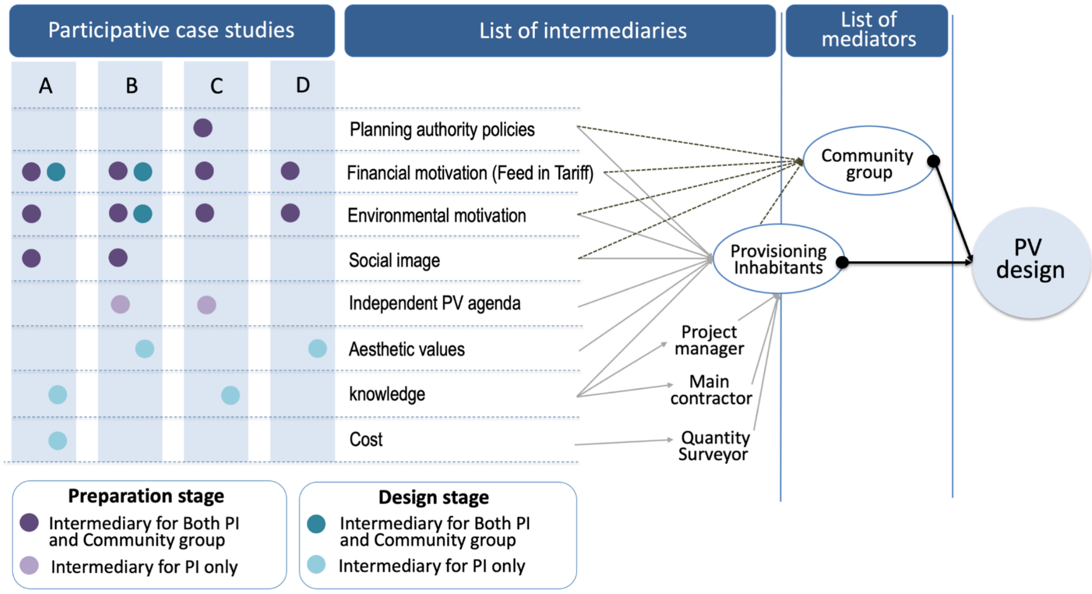


Figure 7.9: Participative inhabitant governance

For all community groups, the FIT, as an intermediary through which government decisions are passed on to clients, and environmental motivation of the inhabitants, were the key intermediaries when making the decision to install PV systems: "as a group we decided to have a very low impact on the environment" (C1). Inhabitants sometimes linked their PV system to an opportunity to demonstrate a visible green agenda '*social image*' highlighting another significant intermediary (A, C):

> "Well, we joined the community, which was going to be ecologically oriented. Therefore, it would be very odd if we did not have solar panels on the roof" (A2)

Figure 7.10 illustrates the degree to which each intermediary impacted on a number of inhabitants in each case study, in terms of these intermediaries being quantitively coded and then mapped.

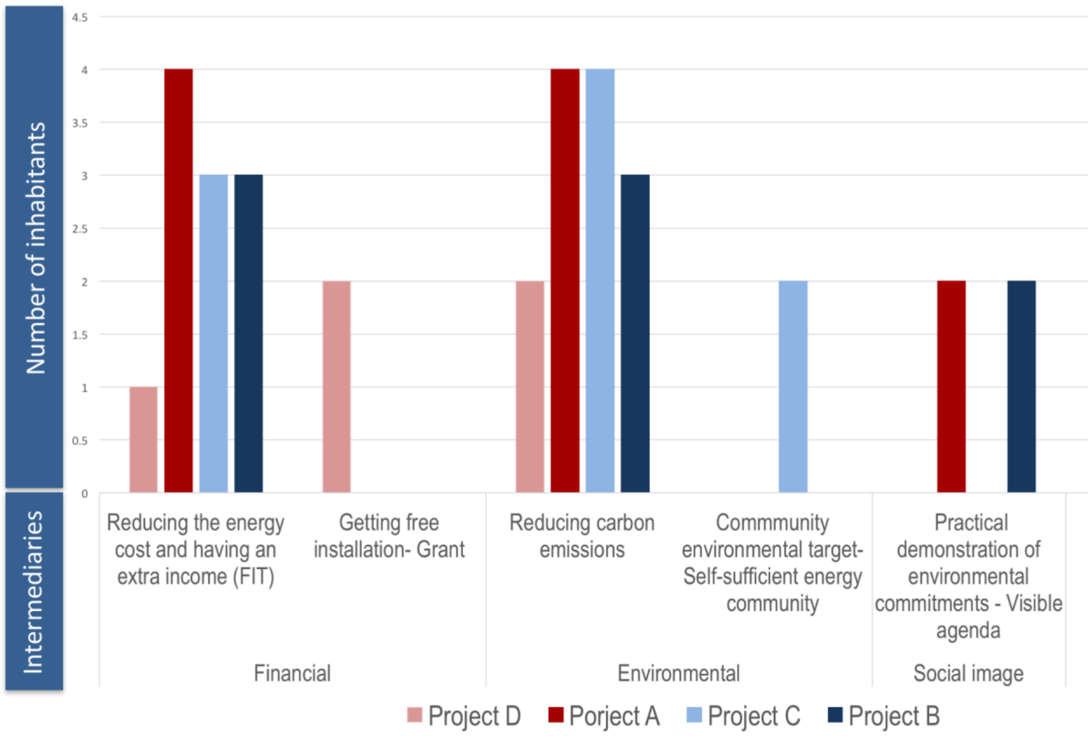


Figure 7.10: PV installation intermediaries

The constant reduction in the FIT tariff impacted the decision by inhabitants to install the PV systems quickly in all PC case studies (see 5.3.1.2, process change). In some case studies, an individual system was installed in each house instead of one big community system (A, B) (see 5.3.1.1.2, system design change). These decisions enabled inhabitants to apply for the FIT, and to individually monitor performance and match their energy loads:

> "We could understand the energy production from PV system for each house…so we could fit our energy consumption with our energy production such as changing the time of using washing machine or the kettle" (Inhabitant, B3)

The main intermediary impacting on the inhabitants' decision to have on-grid instead of off-grid PV systems (C) (with off-grid having more resilience following grid failures) was the *policy* of the planning authority that granted a separate PV permission from the main building construction (see 5.3.1.2, system design change). Crucially, the *independent PV agenda* (B, C), with the PV systems being installed independently from the main construction process, allowed the PI as a mediator to have individual PV meetings and discussions with the installer directly. This was very informative in terms of improving the PI's PV technical knowledge.

7.2.2.2 Governance at the design stage

Five key non-human intermediaries impacted the system design decisions made by inhabitants at the design stage in the provisioning process: FIT and *environmental motivation* (PI and community group), *knowledge, cost* and *aesthetic values* (PI only). The inhabitants at this stage governed the scale and the cost of the systems (A—C), while in the case study D, the grant body consultant governed the scale and cost of the systems. One PI (A) said that the FIT intermediary drove him and his community group to make a decision to *increase* the scale of their individual systems from 0.75 to 1.25kW (see 5.3.1.2, system design change), trading off the extra capital cost against long term savings. In another case study, the inhabitants *decreased* the originally designed scale of the systems in order to leave room for future solar thermal installation: "we made a decision that we wanted to leave a space on the roof for putting solar thermal panels afterwards" (PI- B2). The latter PI also commented:

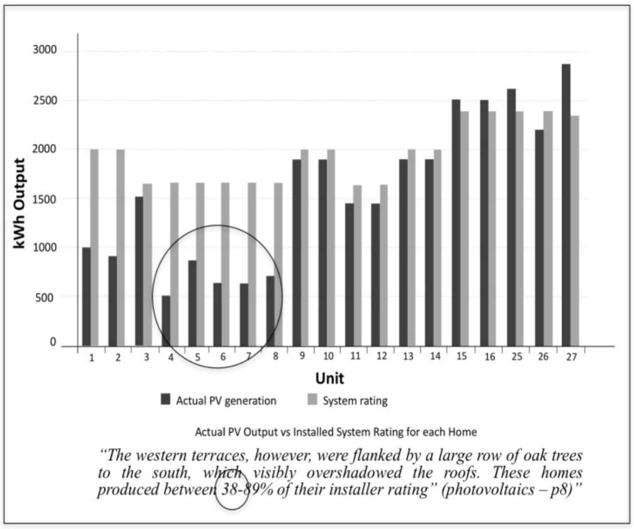
> "The most problematic thing about the whole process is the way that the government policies are operating around the FIT. The first rate of Feed-in-Tariff was too high when we installed the system, which led the industry to become dominated by finance drives much more than people being interested in installing solar panels … the companies were setting up a finance model rather than an industry of installing solar panels. And some people have got out of the business now because the competition has become very hard for people who are more interested in running a business than running a finance model" (PI- B2).

Importantly, this shows that installing PV systems means different things to inhabitants who apparently have a similar commitment in relation to reducing carbon emissions. Some people install PV for immediate financial gain, while others install it for environmental gain. This could be attributed to the different PV meanings that the PIs gained through discussion with other provisioning team and then translated to other inhabitants in relation to the provisioning of their PV system.

Where the PI had technical knowledge (C), discussion occurred concerning the influence of chimney overshadowing on PV system performance and PV panel maintenance, but this did not occur in case study B. This resulted in identical PV systems within case study B performing differently in terms of their energy generation. The PI in case study B said:

> “What we did not discuss… which we only found later…we have different chimneys on the roof and this made each system different through operation in terms of the performance. The shadows of chimneys on the solar panels affect the performance of each system” (Inhabitant B3).

Due to unmitigated *overshading by trees,* the predicted PV system energy generation was significantly lower (60%) in case study D, as calculated by Pasquale et al. (2013) compared with the minimized *overshading by the chimneys* in case study B, resulting in only *a* 5% reduction in predicted energy generation as calculated by the PIs (Figure 7.11).



Fireside pv performance - year 1 Summary				07/08/2011-05/08/2012	
House	Projected		Difference	% error	
55	1634	1710.4	76.4	4.70%	
57	1634	1568.1	-65.9	-4.00%	
59	1634	1647.2	13.2	0.80%	
61	1634	1632.8	-1.2	-0.10%	
Total	**6536**	**6558.5**	**22.5**	**0.30%**	

Fireside pv performance - year 2 Summary				05/08/2012-04/08/2013	
House	Projected		Difference	% error	
55	1634	1734.7	100.7	6.16%	
57	1634	1592.8	-41.2	-2.52%	
59	1634	1656.8	22.8	1.40%	
61	1634	1659.6	25.6	1.57%	
Total	**6536**	**6643.9**	**107.9**	**1.65%**	

Fireside pv performance - year 3 Summary				04/08/2013-03/08/2014	
House	Projected		Difference	% error	
55	1634	1716.6	82.6	5.06%	
57	1634	1583.3	-50.7	-3.10%	
59	1634	1571.8	-62.2	-3.81%	
61	**1634**	**1619.9**	**-14.1**	**-0.86%**	
Total	**6536**	**6491.6**	**-44.4**	**-0.68%**	

Actual PV energy generation vs projected rating for each home in project B

Figure 7.11: Photovoltaic performance gap — Case Studies D and B. Resources: (Fireside, 2014, Pasquale et al., 2013)

Worryingly, no PV provisioning team gave any consideration to tree overshadowing, despite a clear reference to this in the PV panel installation requirements (BRE, 2006), creating a significant performance gap as highlighted above. Either the provisioning teams were not properly trained to understand and apply this requirement or they de-prioritised this requirement in terms of its *meaning* to them – a deeper point which is discussed in the next chapters. In fact, the monitoring representative of the client thought the tree shadow problem in case study D only happened because inhabitants obtained their systems for free and were not concerned with the installation details, as discussed earlier in section (5.3.1.1). Thus, a *PV champion*, as new intermediary, is needed on the provisioning side to ensure that all the PV installation requirements are covered at each stage which will be discussed in deep in the next section. However, this particular problem was not raised at all by the inhabitants in the NPC case studies. This does not necessarily mean that this problem did not exist in the NPC; the inhabitants' lack of understanding of their PV performances was the main reason for inhabitants not indicating this problem in their responses.

Aesthetics had a clear impact on the PIs decision in case study B to locate the PV appliances in the cellar, which reduced inhabitants' motivation to monitor their energy consumption. This monitoring was needed in order to match their energy loads and reduce their carbon emissions by monitoring their energy production and consumption synchronously (B3). The *aesthetic* values also impacted on one PI who chose PV tiles (BIPV system) in preference to PV panels, because "it looks cool … the reflectivity of the material is attractive" (D4) , even though one inhabitant stated that they expected difficulty in replacing the broken PV tiles "because you have to lift all those tiles and retile them, then maybe that has implications for a new structure underneath" (D1). The other PIs in the PC case studies were not concerned about this issue and decided to install the traditional PV panels. This was mainly due to not perceiving PV systems as a true construction material (Ballif et al., 2018).

FIT, environmental motivation, social image and *independent PV agenda* were the most significant non-human intermediaries in all case studies in terms of how often they came up, when coded and mapped in relation to each case study, and the impact this had on the governance of PIs and community groups in the preparation stage. In the design stage, the *FIT* was the key intermediary that had an impact on both the PIs' and community groups' decisions, while *aesthetics* and *knowledge* were the main intermediaries that impacted the PIs decisions only. The overall governance network of both provisioning team and inhabitants is analytically mapped in Figure 7.12, which shows the complete list of intermediaries that impacted the decisions made by the various mediators, and the PV system design as a result. Once again, the green dots illustrate the positive influence of an intermediary and the red dots illustrate the negative influence of an intermediary.

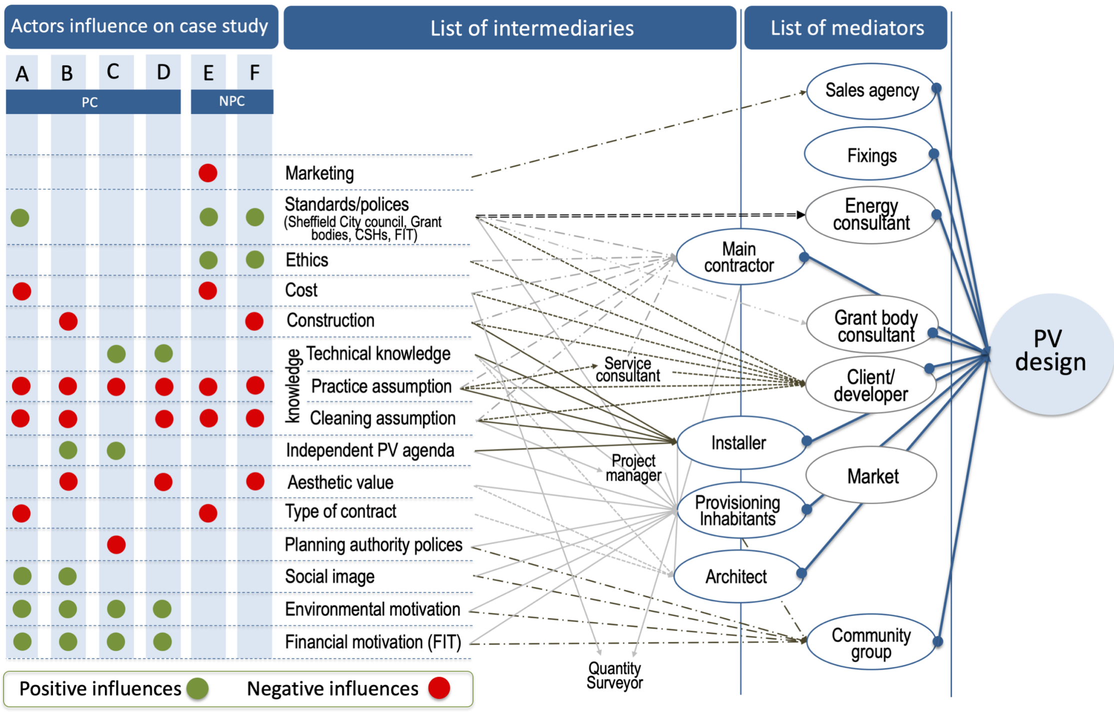


Figure 7.12: Provisioning team and inhabitant governance

There was no effective governance by the PIs in all the PC case studies in relation to the location and position of the PV inverters, meters and monitoring loggers when discussing the PV design:

> "We never talked about the location of the PV parts through the design stage until I saw them… the inverter is hidden and in low position so I can't see the display easily" (PI, A3)

This resulted in hidden and poorly illuminated PV appliances in the homes (inverter, meter, and energy monitoring appliances), and poorly positioned PV appliances on the wall, as will be discussed in detail in the next section. The same PI also suggested having Wi-Fi PV appliances (e.g. inverter, PV meter) to load match their energy more effectively which was not discussed during the PV provisioning process: "… but I think if we bought a meter now, we will decide to have a Wi-Fi enabled one" (PI- A3).

Failure by the PIs to also discuss the PV designed performance in relation to the energy performance targets with inhabitants in all PC case studies also reduced the inhabitants' capability to benchmark their own PV system efficiency by being able to compare the actual performance with the designed performance. They did not know what the design performance target figure was.

The overall governance limitations during the preparation and design stages of the provisioning process (PC), and their negative consequences on inhabitant practice with PV appliances, is mapped out in Figure 7.13.

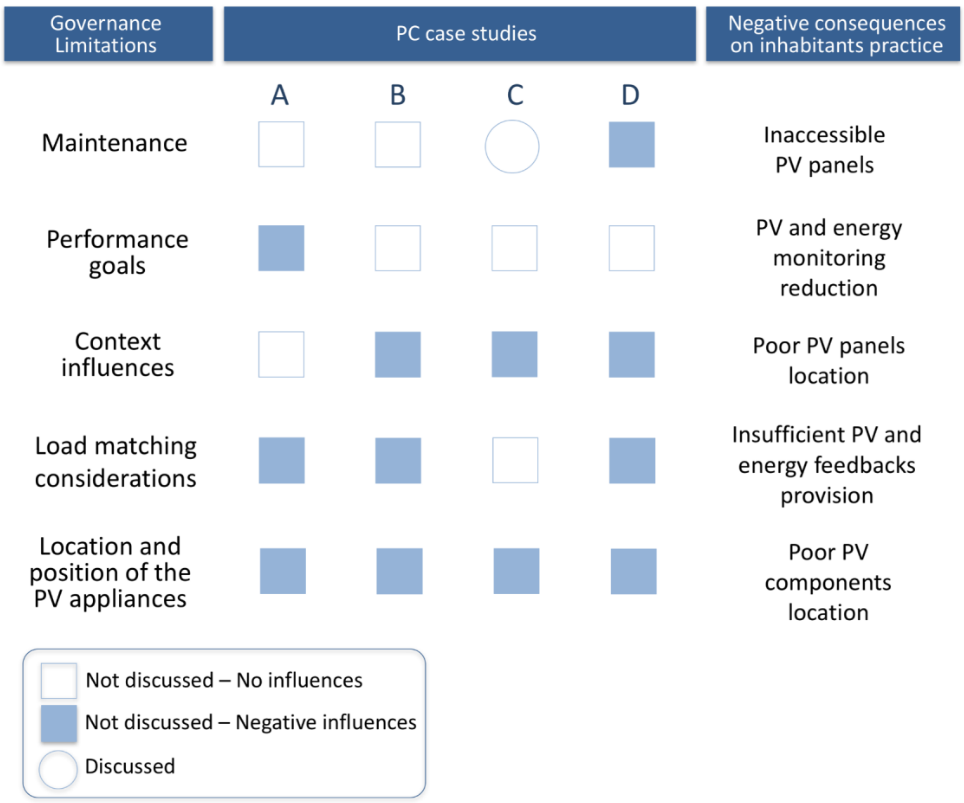


Figure 7.13: Inhabitant governance limitations

It is clear from Figure 7.13 (above) that lack of discussion of the location and position of the PV components in the house was the single most significant limitation in terms of its *frequency* of occurrence across all the case studies and the *criticality* of its consequences. Although some appliances provided affordances for user understanding, such as the inverter in the case studies A and B, and PV performance analogue meter in the case study C, many inhabitants did not use them because of the relative 'invisibility' of this equipment in terms of its location.

7.3 PV governance of practice

This section discusses the individual and collective governance of inhabitants' practice of their PV system during the operation stage. This is to identify and describe the role of the various actors (both mediators and intermediaries) that enrolled in the network and influenced and outlined inhabitants' practice with their system appliances during occupancy. The section is divided into two key sub-sections: practice mediators and practice intermediaries.

7.3.1 Practice mediators

Provisioning Inhabitants (PIs) were the only human mediators, identified through the coding process, that influenced inhabitants' practice with their appliances as discussed below.

The PI acted as a mediator in case study A when he asked the other community members not to engage with their PV controls other than to take meter readings every three months in order to claim the FIT, assuming that: "people in this project are already low consumers" (A3). He supposed that all the measures to be a low carbon community were considered during the provisioning stage. He claimed that he was aware that "there might be some interesting information about the generated electricity at a specific moment", but he soon gave up on this aspect. As a result, the load matching potential was never examined and discussed between him and the other inhabitants. Contradicting himself, he later ascribed the lack of inhabitants' engagement with their inverters to:

> "… quite a small display screen, and they have put it in a hidden location, in the storage room for the houses and outside the flats, for the flats, so people do not interact with it" (PI, A3)

By contrast, the PI in case study C asked inhabitants to continuously monitor their energy generation and consumption patterns in order to match their energy loads, even though this was not considered during the provisioning process. This activity was discussed when inhabitants had regular energy discussion meetings to collectively govern their energy efficiency during occupation. The PI also produced a timetable for inhabitants explaining when to use their washing machines. In this load matching timetable: "he assigned each of the houses a time slot of night. So rather than having all those appliances on at the same time, we staged it. For example, housing no (1) ran their appliance from 12:00-2:00am" (Inhabitant, C4). This was to achieve the best use of energy generated from their second renewable energy technology (wind turbine) at night, rather than exporting it to the main grid.

7.3.2 Practice intermediaries

7.3.2.1 Non-human intermediaries

10 non-human intermediaries were identified in all case studies: Six existing ones from the provisioning stage (*grant body policies/rules, location*, cost, *aesthetic value*, *ethics*, and *FIT*) and four new ones in relation to the occupancy stage (*digital forums*, *skill*, *graphs* and *social arrangement*) (Figure 7.14).

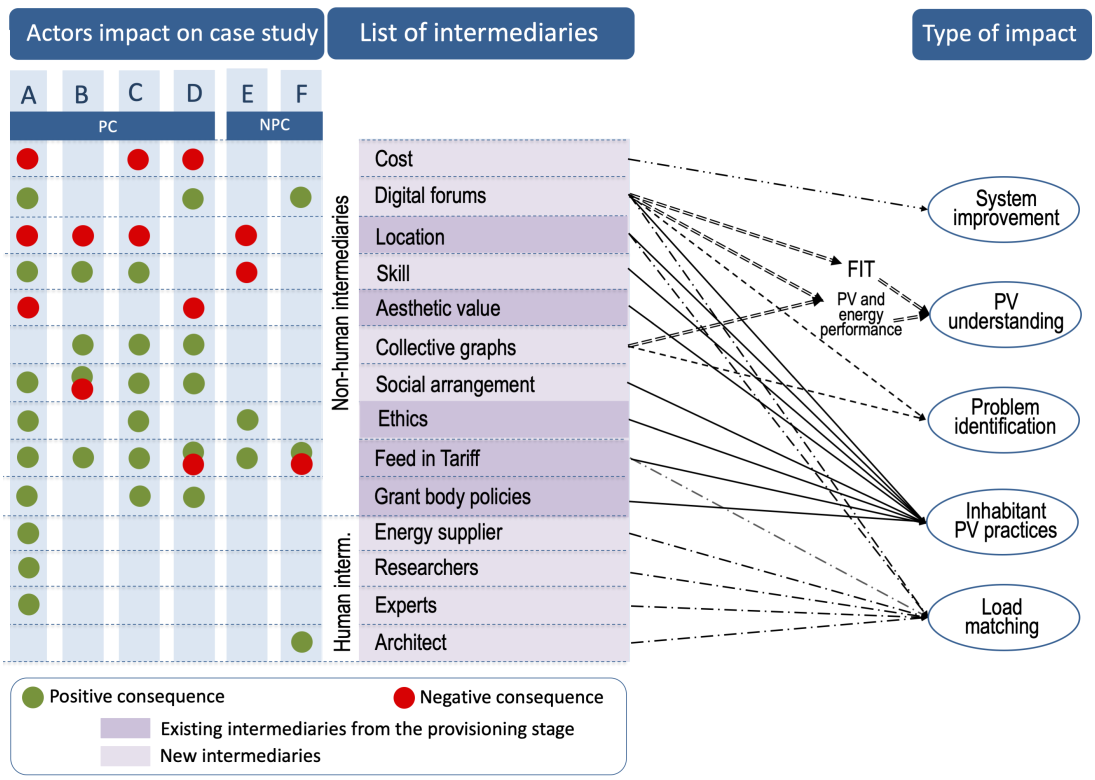


Figure 7.14: Intermediaries impacts on inhabitants during practice in the occupancy stage

- *Grant body policies/rules*

The continuing intermediary grant body policies in case studies A, C and D obliged inhabitants to regularly monitor their energy generation and consumption and produce collective energy graphs for two years after initial occupation. Inhabitants consequently were reading their meters monthly (A, C, D), monitoring loggers (C, D) and the energy export meter (D). One inhabitant stated: “We have got a grant, which says you must monitor your energy” (A1). Accordingly, all inhabitants in the case study A bought a smart energy monitor to monitor their energy efficiency. Again, the assumption made by the PI in this case study that they were low consumer inhabitants, led all inhabitants to disconnect their smart energy monitors when they first had problems connecting them with the PV system, according to a suggestion made by the PI saying: “I think the energy monitor is interesting, but it does not really fundamentally change your behaviour”. In the same interview, he contradicted himself by saying: “It is still quite interesting to make some observations of using energy, such as how much do you use energy to boil a kettle” (PI, A3).

By contrast, the environmental manager of the client ‘The Great Places Housing Group’ in case study E stated that due to a rule in their contract with the grant “The FIT tariff cannot be claimed at these properties as the PVs were purchased and installed via grant funding from the HCA. To claim FIT as well would result in double subsidy being claimed” (E5). As a consequence, the majority of inhabitants in these homes did not visit the PV meter and did not even know if the PV system was working or not.

- *Feed in Tariff (FIT)*

FIT was the key continuing intermediary in terms of inhabitant’s practice with their PV meters in all the case studies with rules stating that inhabitants had to send their meter reading every three months to their energy supplier company to claim the financial payback from their system. As one inhabitant said: “Taking meter reading when the main electricity supplier ‘EDF’ ask me to do that for the FIT” (D1). Because two tenant inhabitants were unable to claim the FIT in the case study E, they had no engagement with the meter and did not know if the system was working or not. By contrast, the high rate of the FIT stopped three inhabitants (D, F) from managing their energy loads appropriately:

> “The issue of whether we use energy during the day or not was not so important because the attraction was the FIT. The FIT was very high” (F4)

- *Social arrangement.*

Allocating responsibilities for PV monitoring and cleaning the PV panels to a community member, or to an ‘ad hoc’ team, ensured inhabitants continuous record of their energy generation and consumption through the reading of PV meters in all the PC case studies, reading the monitoring loggers (C, D), cleaning all the PV panels (C) and observing all the PV inverters (B). By contrast, this stopped the other inhabitants from individually monitoring and understanding their own PV system performance (A) or even engaging with their PV appliances by taking meter readings for energy generation and consumption and observing their inverter (B). as one inhabitant commented:

> "I'm not interested enough to find out, and also X (author: PI, B1- the name is anonymised) is taking this responsibility and we are happy to do that … such as reading the meters for the FIT and other type of monitoring" (B3)

This is because the responsible person (B) and the maintenance team (A) did the meter readings rather than individual. This point will be further discussed in section 9.4. The collective approach to maintenance in case study A and making physical changes to improve their individual system was viewed negatively by inhabitants A1 and A4 (see 6.2.2.3, context problems):

> "It is not just that I'm not allowed, I suppose if I put the ladder there to have a look, somebody might think… 'oh, what are you doing', and if I then got on the roof and start doing the cleaning, somebody may say… 'are you sure that is the best thing to do', so that is why we have a maintenance team who are a part of LILAC and they will be the people who make the decision" (A1)

> "I am not allowed to change the location of the inverter individually. I have to go back to the group. I think for both the inverter and the meter, the cost and the implication to the society is the main reason for not making any change" (A4)

Although the same collective monitoring process was conducted in case studies A, C and D, the inhabitants were individually responsible for reading their PV meters and observing their inverters. However, the inhabitants in the case study A did not analyse and compare their energy generation and use date to improve their energy efficiency. Curiously, this might be the downside of PC case studies actually having a maintenance team, because it encourages inhabitants to give up responsibility for understanding and engaging with their equipment, as will be discussed in depth in section 9.4 as a key practice element (explicit rules) in relation to other elements.

Allocating individual responsibility for inhabitants to maintain their house, alongside the problem of inaccessible PV panels, disabled three inhabitants in case study D from cleaning their dirty PV panels, or even having them cleaned by external cleaners, despite the high reduction in the energy production that occurred due to the panels being dirty. This is because they could not afford the cost of the cleaning. As one inhabitant stated:

> "There is no community responsibility to clean them (D2) … ('interviewer': have you cleaned your dirty panels?) … not without getting a special scaffold, which we can't afford" (D1)

- *Location*.

The hidden location of the PV inverter (A- located in the storage room, B- located in the cellar) and the energy generation monitor (C- located in the porch), and poor positioning of PV meters and inverters (A, C, D), and of the monitoring loggers in the case study C significantly discouraged the inhabitants from engaging with these hidden appliances in order to match their energy load and to reduce the energy imported from the main grid. Poor positioning refers to either appliances that are located 'very high' on the wall (D, C) or 'very low' (A), which makes it very difficult for inhabitants to engage with them. One inhabitant ascribed not observing the energy generation monitor because:

> "… it is in the porch, so we need to put something (authors comment: monitoring device) on the dining room table. This will help you to better manage your energy use during the day" (C1)

Not surprisingly, a study interested in measuring the usability of PV controls in case study A showed that only 7% of the inhabitants knew the purpose of the inverter and how to engage with it in their home, which was the worst percentage among all the PV appliances (Baborska-Narozny et al., 2016). The study referred to the inconvenient location as a main reason that made attempts of engagement with the inverter difficult due to it being in a dim space and at low level.

The manufacturer claims that the PV inverter (Mastervolt, Sun-master XS series) features "accessible monitoring functions that offer a complete overview of performance … with LCD read-out that further optimises the user-friendliness" (Mastervolt, 2008: 7). However, these features were impeded by an inaccessible location. The negative influence of locating the inverter in a hidden place was worst in NPC-case study E, where three inhabitants were completely unaware that their PV system had an inverter as they were not told about it by the house demonstrator. This key intermediary will be discussed in depth in chapter 9.2, and in relation to other practice elements.

- *Skill*

Inhabitants practice with the appliances that require some know-how to engage with them (e.g. observing the display screen of the inverter (A, B), and downloading the data from the monitoring loggers (C)) worked because they had the skill in the first place. However, this was limited to just some inhabitants. By contrast, inhabitants' limited understanding of using their energy monitoring device (only installed in the CSH-6 houses in the case study E), led to them ignoring it despite its high cost and load matching potential, as will be discussed in detail in chapter 9.3. Interestingly, one inhabitant ascribed her engagement with the MHVR system rather than PV system because "I had some previous information and skill about it" (A4).

- *Collective graphs.*

The collective learning processes offered by the community context, and the publishing of collective PV and energy performance graphs as a new intermediary in the PC case studies, enabled inhabitants to understand the relative performance by comparing their energy results with the results from neighbouring houses:

> "What (author: PI-B1) did is just published the outputs - 'the figures' - for the all community by putting them on the email and website. So, individually we looked at the figures and compare the results…we have detected the problem of the underperformance of our PV system and asked for suggestions" (D1)

Knowledge of their PV energy performance helped inhabitants to manage their energy loads more efficiently. Although inhabitants' understanding of their individual PV and actual energy performance was cited highly across all PC case studies (10 inhabitants out of 14), an uneven rate of understanding across all the case studies was identified through the coding (Figure 7.15).

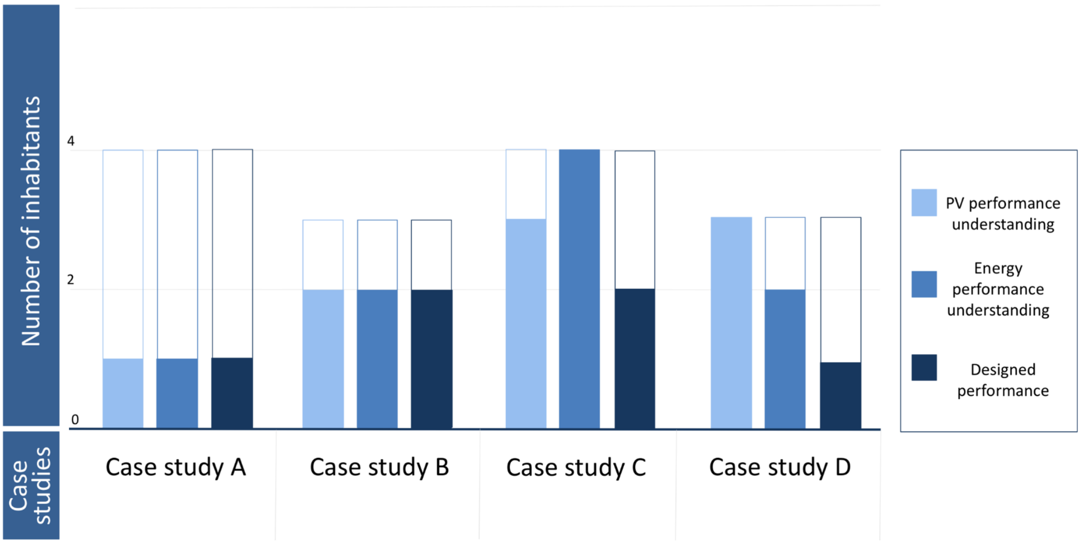


Figure 7.15: PV and energy performance understanding in the PC Case Studies

The failure to publicise the energy performance graphs to all the community members in case study A resulted in a surprisingly low level of PV and energy performance understanding, creating a collective case of ‘unknown-unknowns’[25] despite carbon reduction being a significant aim of the case study. The collective PV and energy monitoring approach was very influential in case studies B, C and D in motivating inhabitants to reduce their energy consumption. One inhabitant commented:

> “So, it keeps a continuous pressure on you to reduce your energy use because we are comparing the data all the time … I would say, seeing our production and consumption in comparison to our neighbours has more effect” (C2)

This collective monitoring process, accordingly, is a significant intermediary that needs to be better understood in relation to governing PV systems effectively, in terms of potential barriers as well as opportunities.

- *Aesthetic values*

A conflict in the inhabitants’ motivations was identified in relation to the visibility of the PV meter and inverter inside the house. Some inhabitants wanted to have visible

[25] Three terms were introduced by Donald Rumsfeld in Feb. 2002. The first is ‘known-known’ which means that there are things we know that we know. The second term is, ‘known-unknown’, which means that there are things that we now know we don’t know. The third term is ‘unknown-unknowns’ which means that there are things we don’t know we don’t know.

appliances, particularly where the appliances had a display screen. By contrast, inhabitants' aesthetic values overruled energy efficiency when they decided to hide their PV meter (A) and inverter (D) using different methods, and reduced their engagement as a result:

> "The meter was in the hallway, in not a very good place, just because it could not be put somewhere more aesthetically pleasing and out of the way… It would be much better if they had put it in the storage room (A3) … lots of people have covered their meters with a blanket, put bookcases in front and around it... So, it is just ugly, not only for me" (A4)

- *Cost*.

The high cost of changing a PV meter or an inverter was the main intermediary obstacle for some inhabitants in the case studies A, C and D deciding not to change their old inverter/meter (despite their dissatisfaction in terms of the affordances offered) to a new model supported with Wi-Fi capability. This change, if implemented, would have helped inhabitants to improve their system affordance in terms of downloading the PV energy generation data for a specific time (day, month, etc.), and thus, improved their capability to match their energy loads: "I did not make any changes…I could buy a wireless smart meter or inverter, but the cost will be prohibitive for me" (A3).

No changes were made by inhabitants in either type of community to improve the affordance of their PV appliances. This is because, the PV appliances did not enable their users to upgrade the specifications; inhabitants had to change the appliances completely if they wanted to upgrade their specifications and the cost stopped them from doing so in the PC - a significant point that needs to be considered by the provisioning team when choosing the PV appliances. Cost also restricted the inhabitants in the case study A from hiring a technician to add a new appliance to their PV systems to enable an individual inhabitant to use the surplus energy generation from all the PV systems communally. This would have helped with load matching as one occupant said: "The expert might for example say, it would be easy, but because of the construction of these houses, it will cost you £7000 to install it, which might be not feasible" (A2).

In case study D, cost also crucially prevented one inhabitant from hiring a professional to clean his PV tiles, which restricted their energy efficiency, and cost also stopped all inhabitants from improving their systems by attaching micro-inverters to each panel, to avoid a big reduction in energy generation which resulted from the overshadowing of the PV panels by trees. The micro-inverters, if implemented, would have helped each panel in the system to act independently even if some panels were in the shaded area. This point is illustrated in the PV literature:

> "With a traditional inverter, all modules in a string operate at the same current. This means that the entire array will work only up to the peak output of the worst performing panel. Indirect lighting, shade, clouds, dirt or even a manufacturing defect on any one panel, will lower the performance of the entire array dramatically if using a string inverter" (SolarEdge Retrofit)

Other benefits from installing micro-inverters according to the Energy Saving Trust (2014b) are:

a) Monitoring the performance of each individual panel separately.

b) Enabling users to increase the system size by adding new panels.

- *Digital Forums*.

Group discussion forums (e.g. email, Google) as new intermediary, enabled inhabitants to discuss the possible methods to clean their inaccessible PV panels in the case study D, and to identify collective inhabitants' misunderstandings in relation to the FIT registration process and responsibilities in case study F. As one inhabitant said:

> "Sometimes there was an email discussion … I put a message saying, we have a problem of dirtiness building up, has anybody got any suggestions. So, people came out with suggestions" (D1)

The internal email discussion in case study A also enabled inhabitants to argue about how to achieve the optimum use of the total PV energy that was generated from the whole community system, which was identified by inhabitant (A2) as a key PV affordance problem (6.2.2.2), and to identify a collective problem associated with the use of energy monitoring device. However, these discussions did not help the inhabitants to solve the problems due to the high *cost* of improving the system affordance as a key intermediary, and also due to the influence of the PI when acting as a mediator (7.3.1).

- *Ethics*.

Inhabitants' environmental ethics encouraged them in case study C to regularly meet and discuss their PV and energy performance which had an impact on managing their energy loads, and motivated them to suggest technical solutions to so improve their energy consumption. Ethics also motivated some inhabitants to individually monitor their energy efficiency and to strictly manage their energy loads (A, C, E). By contrast, some inhabitants did not have these ethics which stopped all the community members in the case study B from collectively discussing their energy performance as: "it generated a tension between people who really want to reduce their carbon footprint and people who do not give very much consideration to that" (B1).

7.3.2.2 Human intermediaries

One existing human intermediaries from the provisioning stage (*architect*) and three new ones for the occupancy stage (*energy supplier*, *academic researchers*, and *experts*) were identified in all the case studies presented in this thesis.

- *Architect*.

The architect in case study F, as a continuing intermediary actor between academic research (the Nottingham University climate and environment research team), and local energy efficiency practices, led to install individual batteries in some houses and a big community battery. His extended 'middling out' role by enabling wider network of practice based research will be discussed in chapter 8.6.2.

- *An external expert.*

An external expert, who was employed to investigate the possibility of installing a car charging point in the case study A, acted as a significant intermediary when he passed on PV knowledge to inhabitant in terms of how the PV energy flowed in the house. One inhabitant (A2) claimed that he did not know that the energy system in the house was designed to take electricity from the PV panels, at the time of generation, rather than from the grid. This was before he was told by the external expert a long time afterwards, when normally this would be explained by the PV installer *before* the inhabitant moves into the home. As a result, a misunderstanding occurred because: "the FIT went to LILAC, only LILAC could gain from the actual use of electricity" (A2). In effect, the inhabitant thought that all the PV electricity was for communal use and not for his individual house. If this inhabitant had had the knowledge that the PV energy was going straight through the house, this would have encouraged him to use electricity during sunshine hours to gain the 'free' energy benefit. It thus is vital for all inhabitants to be appropriately informed in terms of how to engage with the affordances offered in their home technologies as intended during the first year of their occupation. Inhabitants can be uncertain and look for guidance before taking any action (see 9.5.3).

- *An academic researcher*.

Another academic researcher, carrying out a different research case study at the same time as the author (Baborska-Narozny et al., 2016), acted as key intermediary in case study A in terms of passing on educational advice to the inhabitants about how to use their energy efficiently in their homes by matching their energy loads and reduce the imported energy from the main grid: "If I used my things during the day, I actually then keep my bill low. (interviewer: Did the guidance tell you that?) No. X (author: name is anonymised) did" (A4).

In the same case study, the academic researcher also passed on information to some inhabitants about how to improve their PV performance in terms of energy generation by keeping the inverter well ventilated as will be discussed in deep in chapter 9.4. All this know-how was supposed to be passed on by the PV installer or by the PI as an intermediary *before* people moved into their homes.

- *An energy supplier.*

The energy supplier in case study A acted as a key intermediary by maintaining the network and passing on the governance of other bodies, continuously encouraged the inhabitants to reduce their energy consumption and energy bills. Accordingly, inhabitant A4 claimed:

> "I have started paying around £23/month, and after six months, it has been reduced to £12/month. The electricity company at that time (when I was paying £23) asked me to reduce my bill. The electricity company is also asking me now to reduce it further to £8/month" (A4)

The key impact of this positive pressure on the inhabitant was that she started using electrical kettle to boil water during the daytime instead of using gas, and even thought to buy a big thermos to save hot water.

7.4 Sub-conclusion

This chapter has identified and investigated the emergence and function of various mediators and intermediaries in different PV governance networks, to shift the focus away from fixed action of actors towards an explanation of the relational roles and practices of the provisioning actors by which PV provisioning and inhabitant practices are specified and governed. By adopting the ANT principle of generalised symmetry (see 2.2.2.2), this chapter has also explored the significant role of non-humans acting as intermediaries for shifting the governance of the PV systems, whereas previous sociotechnical studies concerning these technologies have been highly focused on human actor practices alone to understand the governance issues.

The first section of this chapter creatively explored, through an innovative mapping of the coding, how various provisioning actors (both human and non-human), acting as *mediators*, govern the provisioning of PV systems and the impact of various *intermediaries*, mainly the non-humans, on their governance. These findings represent a significant contribution to an area that has been underdeveloped in previous PV research studies. This chapter has also demonstrated that that the agency, associations and action of actors, and the PV governance networks as a result, are not fixed, Instead, they are a result of the negotiation of conflicting priorities and visions embodied in a variety of actors who are enrolled in a specific governance network. The different role that PV installers, architects, main contractor and PI play during the PV provisioning stage means that PV provisioning actors can act both as mediator or intermediary role according to their position in terms of making decisions and the role they take in relation to a specific relationship with other actors in the governance network (Figure 7.12).

The findings also show that the PV governance network was highly differentiated between the two types of housing provision: PC and NPC case studies. This is due to the PC PIs having an active agency when governing the system design in the PV provisioning stage, thus, changing the governance network and decision making process as a result. Given the role of the PIs, the number of changes made in the system design in the PC case studies during the provisioning stage was much higher than the number of changes that were made in the NPC case studies, showing a high degree of flexibility. The majority of these changes were made by the PIs to ensure that their own/community group visions and interests, mainly financial, were aligned with those of the provisioning team. In some cases, however, the PIs overly aligned themselves with the provisioning team visions, particularly in relation to the technical aspects of the system, reducing the power of inhabitants in terms of governing their system design and affordance in the governance network, as a result. In the NPC case studies, the governance network were more like a fixed model of production, with only a small change in the system design during the provisioning period, mainly in case study E, in order to comply with the required CSH standards. This was because of the fixed interest and vision of the main contractor in relation to the system design and integration into homes, which overrode other actors.

Significantly, some PIs played a key role as a mediator, by making key decisions, when they had *knowledge* about the technology and were able to have an *independent PV agenda* and discussion with the PV installer. *Knowledge* and an *independent PV agenda* are two positively effective intermediaries that could empower the role of all PIs in terms of making decisions based on personal knowledge rather than relying on the knowledge of other provisioning actors. The PI roles were completely absent in NPC case studies, where the client and main contractor are generally the key mediators. This resulted in inhabitants remaining ignorant about their PV system – a major concern, as NPC case studies make up the majority of housing in the UK.

The findings also show that the non-human *FIT* intermediary had the biggest impact on PV outcomes in the PC case studies in terms of scale, system design and installation time frame – all designed to improve the energy generation from the supply side and to increase the financial benefits. By contrast, the *FIT* had no impact on the system design in the NPC case studies; instead, the *energy standard* and developer *ethics* usefully impacted as intermediaries on developer decisions to install PV systems in the first place, and greatly impacted on the scale of the systems alongside other intermediaries, such as *roof size* and cost.

Provisioning team governance limitations were also revealed in this chapter which if addressed, could help improve the effectiveness of future housing developments which include PV systems. The most critical limitation concerns the poor decision making around the location of the PV appliances inside the home, especially in NPC case studies, followed by the insufficient governance of provisioning team in terms of providing inhabitants with opportunities to match their energy loads, and the poor positioning of PV panels on the roofs.

The second section of this chapter discussed the role of new and continuing mediators and intermediaries in influencing/impacting the inhabitants' practices of their PV system and overall energy consumption during occupation. *Grant body* policies, *FIT*, *location, cost, ethics* and *aesthetic values* were the key continuing non-human intermediaries from the provisioning stage, while *digital forums*, *skill*, *graphs* and *social arrangement* were new intermediaries that shaped the type and degree of inhabitants' engagement with their system appliances. Collective graphs and digital forums, offered by community housing context, are very powerful intermediaries, which enable inhabitants to understand and compare their PV and energy performances and identify underperformance problems. These intermediaries are probably missing in NPC case studies generally which is a major concern. In general, the human intermediaries helped inhabitants to improve their knowledge in terms of how to efficiently use their PV energy and to reduce the imported energy from the grid by matching their energy loads, while the non-human intermediaries encouraged inhabitants to engage with their PV appliances, to identify underperformance problems, and to increase their PV and energy understanding. Surprisingly, none of inhabitant in all case studies referred to *Home User Guide (HUG)* as an intermediary that had an impact on their system practices, due to the limited PV information and provisioning by the installers which was identified as a key source of inhabitants' understanding and practice problems.

The ANT analysis in this chapter showed that PV provisioning practices are perceived by building professionals and other participating actors as a 'Black Box' approach (Latour, 1987), where the outputs can simply be understood in terms of the inputs. This perception has clearly underestimated how actors' networks and arrangements, including wider and extended actors and networks, can change the agency, power, practices and outputs of PV provisioning actors in a local building contract network, even when the inputs are similar. Opening this Black Box therefore, is vital to further investigate the specific aspects of these wider networks and arrangements (see footnote 23) that influence PV provisioning practices as a means of critically interrogating the effectiveness of different building contracts.

This chapter also described the interchangeable role and agency of the various PV provisioning actors when governing the system design and integration into homes, which resulted in different governance networks and arrangements in the case studies. However, the deeper question of *why* these shifts in the actors' agencies, and networks took place has not been yet investigated. The next chapter addresses all the aspects described above using fragmentation analysis.

CHAPTER EIGHT: FRAGMENTATION IN CONTRACT NETWORKS

8.1 Introduction

The shift towards sustainability in the built environment requires a high level of collaborative engagements across various professional domains in the industry to develop more holistic solutions, (Hughes and Hughes, 2013). However, the findings in this thesis so far show that PV governance rely mainly on the *individual* engagement of professionals in the various PV domains and stages, rather than a truly collaborative engagement. This has resulted in highly fragmented PV provisioning networks and practices – a critical point that needs to be further discussed and analysed.

Chapter seven also showed that PV provisioning practices are understood by policy makers and professionals as a 'Black Box' with PV provisioning networks and practices taken for granted and never questioned (Lowe et al., 2017). Therefore, the key purpose of this chapter is to critically *question* the PV provisioning actors' networks and arrangements in relation to different building contracts, and to extend this examination beyond the boundary of the local contract and building professionals.

Moving beyond the issue of professionals and inhabitants' governance highlighted in chapter seven, this chapter discusses *how* and *why* the disintegration between PV provisioning actors took place within the entire contractual process across the case studies presented in this thesis, which is underexplored in the literature on PV systems, performance and provisioning. To open up this black box, fragmentation analysis (Alashwal and Fong, 2015) is employed in this chapter to further understand particular situations within the specific contractual networks. Fragmentation analysis reveals *why* a disconnection happens between actors within the different PV provisioning contracts and networks, and the influence of this disconnection on the agency and action of the human and non-human actors in the network. This chapter, thus, starts by further analysing actors' arrangements and networks during the different contract stages in each case study and then providing an overview by cross relating the findings of the six case studies to understand the differences in PV provisioning contract networks and the reasons for that. In this chapter, new actors and associations in the different building construction stages are suggested to form a more effective networks and arrangements for governing PV systems.

8.2 Construction fragmentation

In the construction sector, fragmentation simply refers to *disintegration* in stakeholders' roles and responsibilities (Mohsini and Davidson, 1992, Crotty, 2012) and is understood as one of the key reasons that contribute to lost efficiency due to a lack of collaboration, sharing knowledge and expertise between the different participants (Ofori, 2012). It has been reported that 50% of construction projects in the UK suffers both cost and time overrun due to the fragmented construction process (Crotty, 2012). The discussion drawn here uses the key types of fragmentation that have been classified in the building construction literature. This is to provide an initial framework to re-appraise and advance the different types of fragmentation that have occurred in the network presented case studies in this thesis in relation to the PV provisioning practices and actor – networks identified previously.

In general, fragmentation in building construction takes place along two key dimensions: *Horizontal* and *Vertical* (Egan, 1998, Higging and Jessop, 1965, Fellows and Liu, 2012, Alashwal and Fong, 2015). *Horizontal* fragmentation refers to the multiplicity of *entities* (e.g. individuals, business units and organisations) which execute functions at a given stage, while the *Vertical* fragmentation concerns the splitting up of a total *process* into stages which are executed by separated functional actors (Fellows and Liu, 2012: 655). The fragmentation analysis, thus, involves two key dimensions: *Entities* and *Processes* (Alashwal and Fong, 2015). *Entities* involve the disintegration of various provisioning team and their ability to work together efficiently, while *Processes* involves the vast division of labour between the various construction stages (ibid). This classification of fragmentation (Entities and Processes) is adopted in this section for its flexibility in examining the entire process of PV provisioning over the complete contract time, while at the same time examining the entities and activities that were involved at a certain stage of PV provisioning.

Prior to any identification and discussion of the two key types of fragmentation (Entities and Processes) across all the PC and NPC case studies, it is vital to illustrate the types of building construction contract that were used to deliver the thesis case studies. Two types of building construction contracts were identified: Standard Building contract (SBC), also known as the traditional system of procurement, and Design and Build (DB) contracts (JCT, 2016, RIBA, 2014, Chappell, 2018) (Figure 8.1).

Housing provision types	Case studies	Standard Building Contract (SBC)	Design & Build (DB) contract
Participative Community (PC) case studies	LILAC (A)		●
	Fireside (B)	●	
	Hockerton (C)	●	
	Springhill (D)	●	
Non-Participative Community (NPC) case studies	Brearley Forge (E)		●
	Green Street (F)		●

Figure 8.1: Contract types across Case Studies

In the SBC contract, the client contracts an architect and a contractor separately to design and construct the projects (Mohsini and Davidson, 1992), while in the DB contract, the client deals with a single contractor (design-builder) to design and construct the project. The NPC case studies only used the DB contract, while the PC case studies used both, depending on the individual case study.

8.3 Fragmentation in the PC case studies

8.3.1 Case study A

The Design and Build contract process in case study A resulted in clearly the most fragmented PV provisioning process across all the PC case studies. The PV works were completed by different actors during the different stages of building construction process (preparation, design, construction and induction), and without there being any real integration between these actors across the stages. More critically, the inhabitants were completely disintegrated from the other PV actors. This was due to the key PI changing his normal *role* as an intermediary between the inhabitants and PV actors in the network to a more governing role, by acting as a mediator when enacting a real practice (see 7.2.1.4). The fragmentation was also due to the incomplete participation of the PIs in the PV design stage for reasons that will be discussed later (see 8.6.2). In this case study, both types of fragmentation were identified through a careful mapping process related to the coding of human intermediaries/ mediators: *Entities* and *Process* (Figure 8.2).

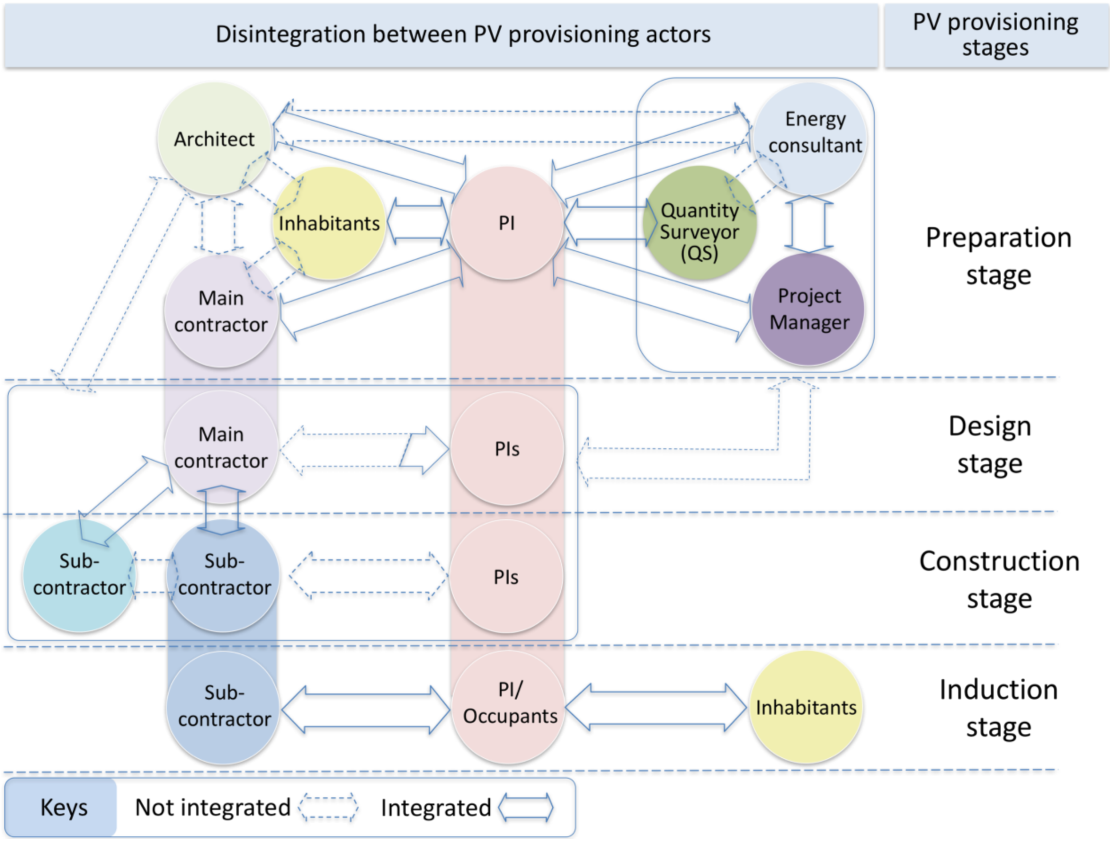


Figure 8.2: PV provisioning fragmentation – Case Study A

In the preparation stage, a disintegration between the energy consultant (who decided to install PV systems in all houses) and the architect occurred (fragmentation in the *Entities)* due to the PI (the key agency in this case study in terms of liaising with all PV actors in the network) disabling the connections between the architect and energy consultant by meeting them both separately. Such disintegration discouraged the architect from actively participating in the later discussions concerning the PV provisioning process during the design stage, despite being "… knowledgeable and passionate about how to build low carbon housing and … refreshingly knowledgeable about cohousing" (Chatterton, 2015: 51) - a major exclusion. More specifically, when the main contractor and the PI removed the roof garden strategy from the main design in order to reduce the total cost of the case study, this led the PI to also unilaterally remove all the access to the roofs from the original design, based on advice from the main contractor, without consulting the architect (see 5.3.1.2). This significantly influenced the PV maintenance process in a negative way as a result. In fact, no specific budget was assigned for PV installations by the Quantity Surveyor (QS) in this case study as a part of the contract. The PV costs were simply included in the total budget of the mechanical works as a stated by the PI, A3:

> "… the total available budget for mechanical services in the project was just over £100,000. This figure included an allowance for renewables as well as the conventional equipment …" (Chatterton, 2015: 123)

This pushed the main contractor and the subcontractor in the PV design stage to choose PV appliances (e.g. meter, inverter) with the least affordances without taking the view of the other participating actors in the network (PI, architect, project manager) into account. This was in order to stay within the total budget of the mechanical works, which was at the minimum level. Surprisingly, the project manager in this case study (an actor to manage building construction projects), was also not actively involved in the PV provisioning process, including the detailed aspects of the systems design and installation. This means that there was no liaison actor, as an expert in energy efficient technologies, with a role to connect the construction team together at the different stages of the provisioning process to ensure the proper design and functioning of the PV system, resulting in a clear fragmentation in *Entities*. This resulted in a disintegration between the architect, the energy consultant and the contractor in relation to PV provisioning process, negatively influencing the entire governance network and arrangements in case study A. The project manager said:

> "My specific responsibility with the PV installation was to ensure that the project met specific sustainability target brief which was CSH- level 4 … Other than that, I did not have a specific role in PV procurement process" (A5)

The key PI at the design stage also disconnected himself from the discussions with the main contractor and sub-contractors when they were making decisions concerning the PV system design and integration into homes, negatively shifting the power to the main contractor, who was a non-expert actor in terms of how to achieve greater energy efficiency. This consequently meant that the main contractor vitally missed connecting with the inhabitants when deciding the affordances offered in the system appliances and their location in the homes, which were evidenced to be problematic by inhabitants when interviewing them (see 7.3.2.1). The key PI stated: "I would also have chosen an inverter and meter with Wi-Fi capability. So, we could download the data somewhere by using 3G connectivity" (PI, A3) but he did not communicate this vital idea to the contractor.

The PV design and installation works were not completed by a certified PV installer. Instead, the main contractor commissioned the job to two sub-contractors: the PV panels were installed by a roofing subcontractor and all the PV controls (e.g. meter, inverter, isolating switches and wiring) were separately specified and installed by Mechanical and Electrical (M&E) engineers as stated by the PI:

> "X (authors comment: this was the roofing subcontractor) put the solar PV on the roof, and then Y (author comment: this was the M&E subcontractor) did all the inverters, meters and all the wiring system" (A3)

In this case study, this level of contractual fragmentation hides the complete picture of the PV work from the PI who had no direct connection with these two subcontractors. Inhabitants could have learnt how to use and maintain their technologies directly from the installers when integrating with them during the design and installation process (Gram-Hanssen et al., 2017), but this was a missed opportunity in PC case study A. Unexpectedly, the inhabitants in this case study were, to different degree, unaware of their PV system due to their disintegration from the PV provisioning actors, despite their theoretical participation in the construction of their houses.

During the PV induction stage, as examined in another study (Baborska-Narozny et al., 2016), the PV systems in case study A were handed over by the M&E subcontractor (who only installed the internal appliances of the PV systems) who demonstrated the home technologies to just three representative inhabitants out of twenty households, including the PV systems with which the subcontractor himself was not at all familiar. The demonstration process was very general and confined to showing them only the location of the appliances without going into details. When an inhabitant asked how he could check if the system was generating power in a separate study from this thesis, the subcontractor replied: "… you just press the button on the equipment under your stairs" (Baborska-Narozny et al., 2016: 31), without any demonstration of how to actually do it. Crucially, the demonstrator did not explain why PV energy generation figures are important in terms of FIT and energy load matching, which discouraged the inhabitants from making this connection. Another fragmentation in the home induction process also happened when the demonstration responsibility was given later on to the three representative inhabitants (who participated in the home induction process explained by the subcontractor), to provide a home demonstration tour for the other community members. In reality, another study revealed that this further demonstration was only given to seven members out of 20 and was also very poor in relation to the PV system. Half the resident members thus remained completely uninformed about how to use their PV systems as installed (Baborska-Narozny et al., 2016).

8.3.2 Case study B

The PV provisioning process in this Standard Building Contract case study was based on the participation of only two actors: the PI and the PV installer. In this case study, the main contractor and the architect were completely disintegrated from the PV discussions with the other actors during all the PV provisioning stages due to the PV works being commissioned independently from the other construction works when retrofitting the houses. Interestingly, this contractual fragmentation greatly enabled an independent PV agenda and budget for PV works, which positively empowered the client, through the PI, to largely participate in all the discussions about the system design and integration into homes directly with the PV installer (Figure 8.3).

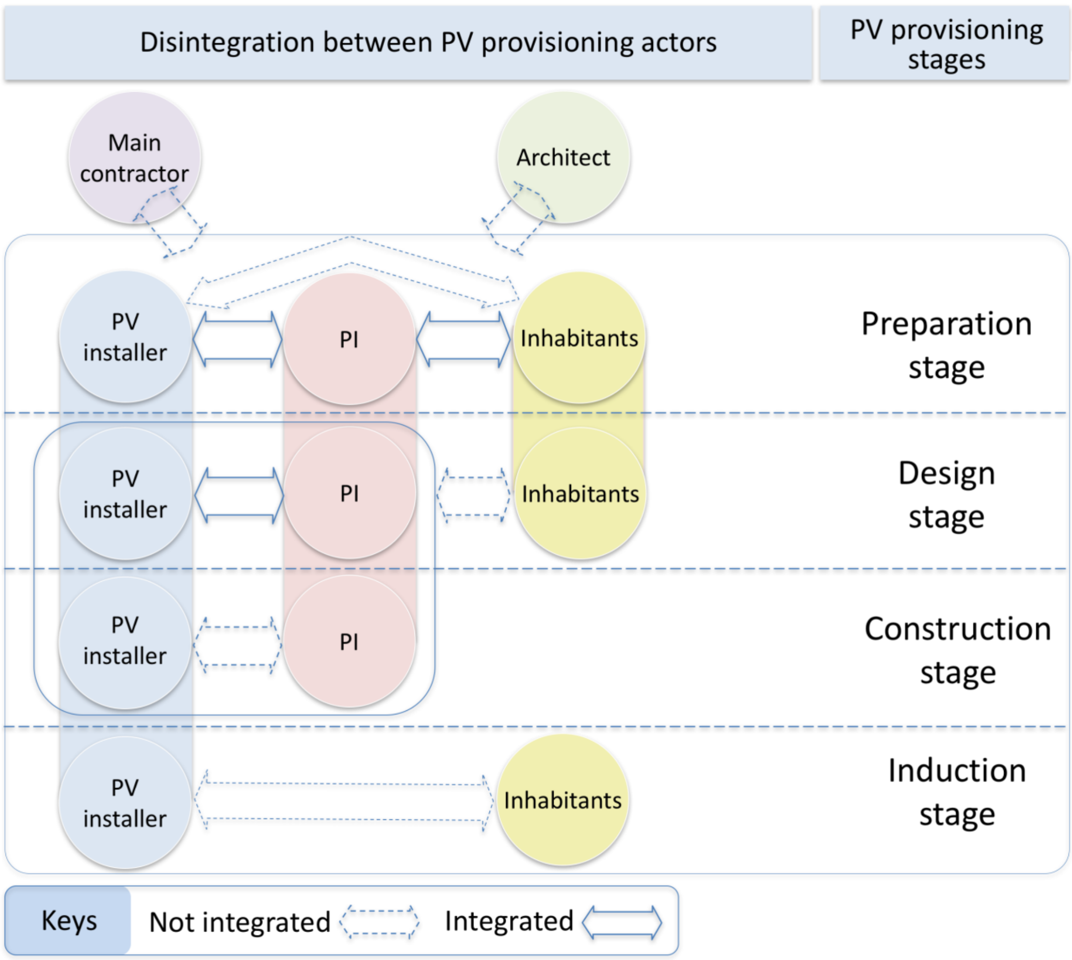


Figure 8.3: PV provisioning fragmentation – Case Study B

When all the installations works were finished, the installer demonstrated the PV systems only to the PIs, but without going in details in terms of how to strictly manage their energy consumption efficiently, resulting in inhabitants overlooking this significant practice (load matching) during occupation. Another critical disconnection took place between the inhabitants and the PV installer, due to the PI changing role from an intermediary to acting as an independent mediator by making all the decisions with the installer without taking into account the view of the inhabitants. This form of contractual governance network (Inhabitants – PI – Installer) in the PC case studies, despite its potential to empower inhabitants to govern their environment, clearly reduced the agency of inhabitants in terms of discussing and choosing the PV affordances during the design stage with the architect, installer, and contractor, which could have improved their know-how of the system. This shows how the change in overall actors' arrangements and networks can change actors' associations and the potential outcome as a result. The new role of the PI shifted the power from inhabitants to the PI, who the later made all the PV decisions with the installer (see 5.3.1.1). When he was asked about whether the inhabitants had enough information in relation to each part of their PV system and how to engage with it, the PI replied: "No. I think just X (author: another PI) and me" (the name is anonymised) (PI, B2).

8.3.3 Case study C

The PI in Standard Building Contract case study C had significant experience in PV systems, and this empowered him to provide a strong integration with the other inhabitants in the community during the preparation stage of the PV provisioning process and after all the houses had been constructed and occupied (see 5.3.1.1). By contrast, there was a clear disintegration between the grant body consultant and the PV installer during this stage (fragmentation in Entities). This was due to the PI having the agency to prepare an initial design for all the PV systems and to build a powerful connection with the grant body consultant to fund the PV systems and the monitoring equipment *prior* to contacting the PV installer. Thus, the PV installer was not involved in the initial design decisions at this stage. However, this disintegration had no negative consequences on the funding process. Figure 8.4 illustrates the participation of the various actors in the PV provisioning stages rather than the building construction stages because the PV systems were retrofitted after all the construction works were completed and all the inhabitants had already moved into their homes.

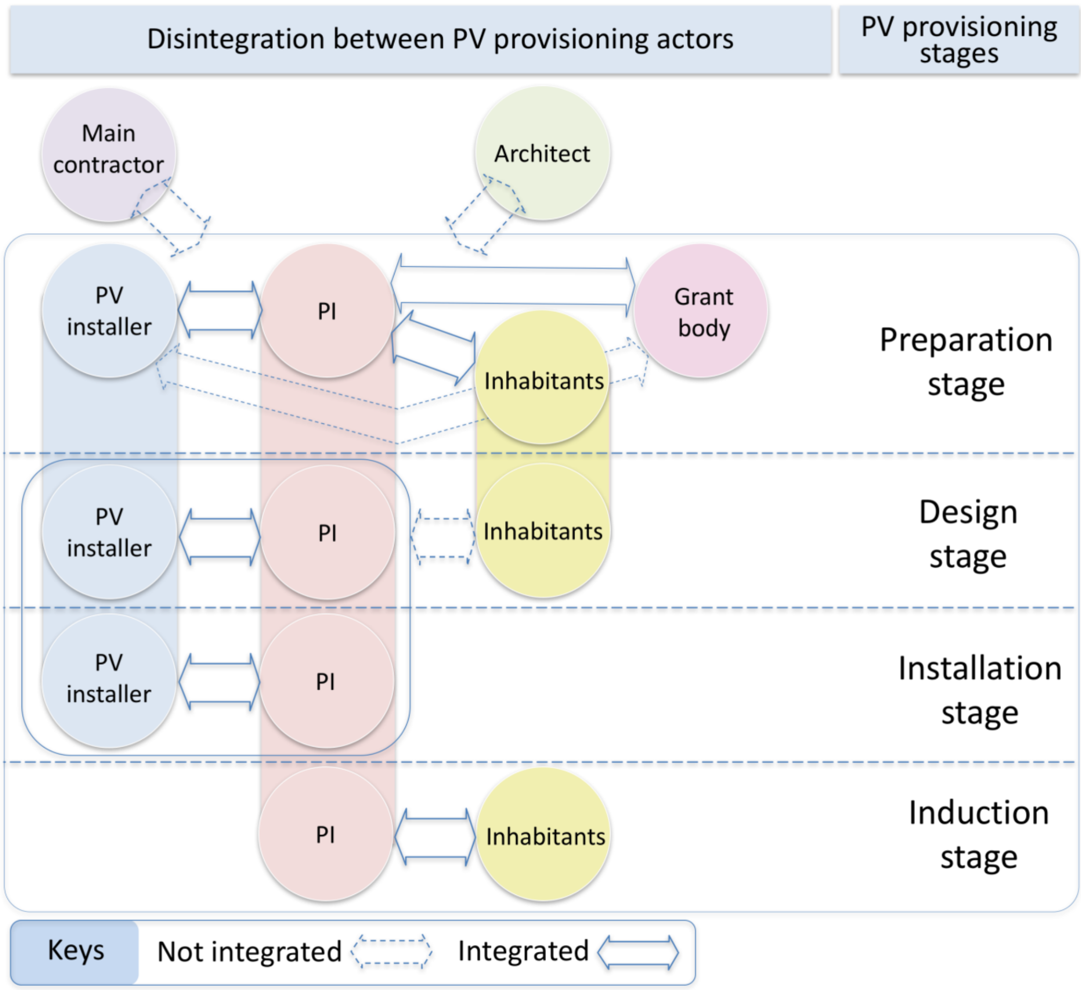


Figure 8.4: PV provisioning fragmentation – Case Study C

In fact, without the PI having this agency, the PV systems might not have been funded and installed at all, as inhabitants were not able to afford the high cost of the PV systems at that time. The participation of a powerful PI also enabled him to actively participate in the design and installation stages of the system and to have a powerful integration with the installer to collectively make positive decisions in terms of the arrangements of the PV panels on the roofs and the size of the inverters (see 5.3.1.1). The PI also acquired practical knowledge in relation to PV maintenance and monitoring, which was translated later to the other inhabitants. However, fragmentation in this case study concerned the involvement of some actors (e.g. the grant body consultant) only in one stage of PV provisioning process, but not in the other stages (fragmentation in the *Process*) (Figure 8.4), which proved to be problematic in case study D due to poor PV performance, but not in this case study (C).

Unlike case study A, the PI in case study C built a strong connection with the other community members to demonstrate the PV systems to all of them and to collectively govern their energy efficiency during occupation. In case study A, the PI was completely disintegrated from the other inhabitants in this stage. This was due to the discrepancy between the meanings (a key practice element) of the PV systems for the PIs in these two case studies, which will be discussed deeply in chapter 9.5.3. The PI in case study A understood the system as simply generating free energy, while the PI in case study C understood it as a technology that has the potential to impact on energy consumption practices. This means that PV outcomes can be varied even when case studies have similar governance networks and arrangements, if the elements that hold practices together (e.g. PV meaning for the PIs) are different, affecting the overall governance network during occupancy as a result.

8.3.4 Case study D

The key fragmentation that took place in this Standard Building Contract case study concerned the disintegration between the architect and the PV installer prior to the design stage of the housing construction process. This resulted in all the chimneys for the houses being wrongly located by the architect on the roofs (which could produce excessive shading on the PV panels). This happened due to the late enrolment of the PV installer in the housing construction process (fragmentation in the *Process*), after all the houses and site had already been designed and approved. This late enrolment was due to the late decision of the client (the PI) to install PV systems. The architect replied to the author's interview prompt concerning whether or not the PV installer has participated in the preparation stage of the houses, by stating:

> "Not really ... We design the houses and then the client decided that he wants a PV; they applied (author: the PI and the installer) for a grant, they have got the grant and then they installed it" (D5)

On a more positive note, the architect's knowledge of PV systems helped him to detect this potential problem and to change the location of chimneys (see 5.3.1.1.2), but this still caused a long delay in delivering the housing project on time. In addition, the PI hired a PV installer to design the PV systems in order to apply for a fund from the DTI (The grant body). After the fund was approved, he then changed the PV installer because of obtaining a cheaper price from another PV installer (see 5.3.1.2). The new installer then redesigned and installed all the PV systems, but without any clear participation of the PI during this stage. This fragmented process in PV design and installation process reduced the agency of the architect and the PI to be involved in all the stages of PV provisioning process (Figure 8.5).

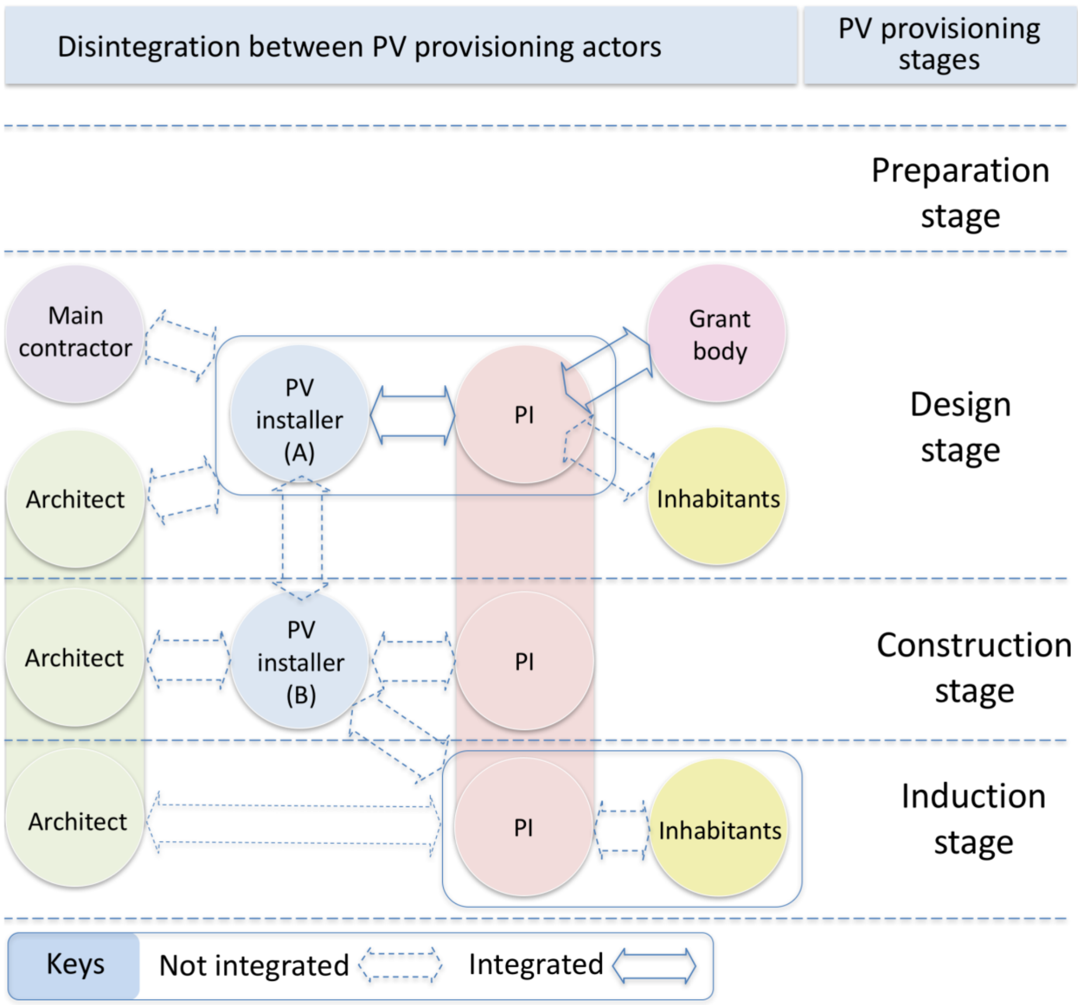


Figure 8.5: PV provisioning fragmentation – Case Study D

Importantly, one inhabitant pointed out that due to the overlap in the construction management role between the architect and the PI, the latter was unclear about who was responsible for demonstrating the homes, or even for providing a Home Use Guide (HUG) to inhabitants. As a result, the homes were not demonstrated at all to their inhabitants and as the PI stated:

> "I was bullying the architect to produce one (author: HUG) after we all moved in and nothing ever happened, and I just kept on and on and he (author comment: the architect) finally produced something just fairly flimsy" (D1)

The PI thought that the architect was responsible to provide the HUG due to the latter having responsibility to manage the whole construction process, rather than the main contractor. This resulted in the main contractor being completely disconnected from the other PV provisioning actors in the different stages. This confusing overlap in roles also led to all the interviewed inhabitants feeling that they did not have a proper leader to represent their interests during the building construction process. Therefore, it is vital that all the home technologies are handed over by the people who install them, to ensure that these technologies are introduced properly to inhabitants. As with case studies A and B, the inhabitants in the case study D were once again completely disintegrated from key PV provisioning actors (PI, PV installer and the grant body consultant) due to the PI critically changing his role from intermediary to mediator at a key point in the provisioning process in terms of making decisions.

Similar to the case study C, the grant body consultant in this case study only participated in the preparation stage of PV provisioning process, while his participation in the other stages was more passive, and confined only to receiving written reports and pictures from the PI in relation to the different stages of PV provisioning (Figure 8.5). As the PI said:

> "Payments (author: from the grant body) were made in 4 stages, Design, Procurement, Installation and Monitoring over a further 2 years … I was responsible for photographing stages and submitting stage reports to DTI and getting the funding paid" (D4, PI)

The disintegration between these key actors in PV Process, among others, resulted in some poor decisions made by PV installer in relation to the location of the PV panels on the roofs of some houses (see 7.2.2.2), without any inspection from the grant body consultant to ensure the designed performance of the systems.

By cross relating the fragmentation analysis from the four PC case studies, the findings show that the PC construction team actors were highly disconnected in several case studies (A, B, D), irrespective of the contract type, particularly in the early stage of the building construction process, due to failure of the PIs, who performed as a key liaison actor, in bridging all the key construction actors together to collectively govern the PV systems within the whole building construction process. This was because the PIs were not at all familiar with performing this controlling and management role – highlighting a significant need for the controlling actor to have an appropriate knowledge in managing the construction of low carbon housing projects that include PV systems from the earliest stage, even when choosing the project site. Training actors, within a wider network is, thus important for achieving effective governance during the different building construction stages. The key fragmentation in the PV *Process* in all of the PC case studies concerned the architects' disintegration from the PV network discussions in the preparation and design stages of the building construction process in the main contract. This because architects are not always trained to consider as part of their design work all the detailed aspects that make PV installations more successful (e.g. orientation of the houses, chimneys locations of the roofs, access for maintenance etc.). If architects were trained to consider 'future proofing' at the outset of any design in their education, then many of the governance and fragmentation problems that were uncovered in this thesis would not occur, because then the architect would automatically consider at the briefing stage the need to interact with other key actors (e.g. installers, contractors etc.). At the moment, architectural education within the wider governance network does not encourage this kind of thinking. Instead, students are trained to think that briefing and design come before the construction, when in fact they all have to be considered together. These wider network issues create a challenging situation, that needs to be carefully considered by the architectural profession.

Another critical fragmentation in the PV Process concerned the inhabitants' failure (the Clients) to actively participate in the PV provisioning process in three case studies out of four (A, B, D) due to the PI changing his normal role from intermediary to mediator in terms of making decisions, thus again impeding any connection between the inhabitants and the other PV actors and changing the whole governance network as a result. New polices need to be formulated by the wider community housing network, in terms of defining the detailed role for the PIs, which remains unclear. This is to positively influence the actors' arrangements in this type of housing provisioning network and for them to play an active part in the wider network. This is to ensure that a PI does not exceed his or her remit in relation to representing the inhabitants of the community during the provisioning stage of any contract. PIs need to be informed about their role, particularly their place in the provisioning team, through training as suggested earlier in this section. Further disintegration in PV Process concerned the insufficient participation of the grant body consultants in the system design and installation stages (C, D), due to their aim of simply encouraging PV installations in new housing projects, rather than improving the provisioning and occupancy practices. The policy of Grant making bodies thus need to be re-defined at the national and local levels and to be considered as a significant actor in the wider governance network influencing the contractual actor-network to achieve their goals of installing PV systems.

All these fragmentations in the PC case studies during PV *Process* led to critical fragmentations in *Entities* as shown above. In the preparation stage, the most critical fragmentation in Entities occurred between the architect and the PV installer in the A and D PC case studies, while in the design stage it took place between the PI and the PV installer (A, D). The PIs in the PC case studies (A, B, D) changed their role from an intermediary role enabling the integration between the inhabitants and the other key provisioning actors, to a more governing role (mediator) also resulted in further key fragmentation in *Entities* between the inhabitants and other PV provisioning team in both the preparation and design stages.

8.4 Fragmentation in the NPC case studies

8.4.1 Case study E

The early and unusually foresighted decision of the client in this Design and Build contract, to make all of the roofs of the new houses face south to maximise the solar benefit (in case a potential inhabitant should decide to install a PV system in the future), encouraged the early participation and integration of the architect in the PV discussions with the client representative and the main contractor (Figure 8.6). The client of the case study said:

> "So, we might not put PV on the roofs, but if somebody (authors: inhabitants) wants to do it in the future, the homes are oriented to make a maximum benefit of solar" (E6)

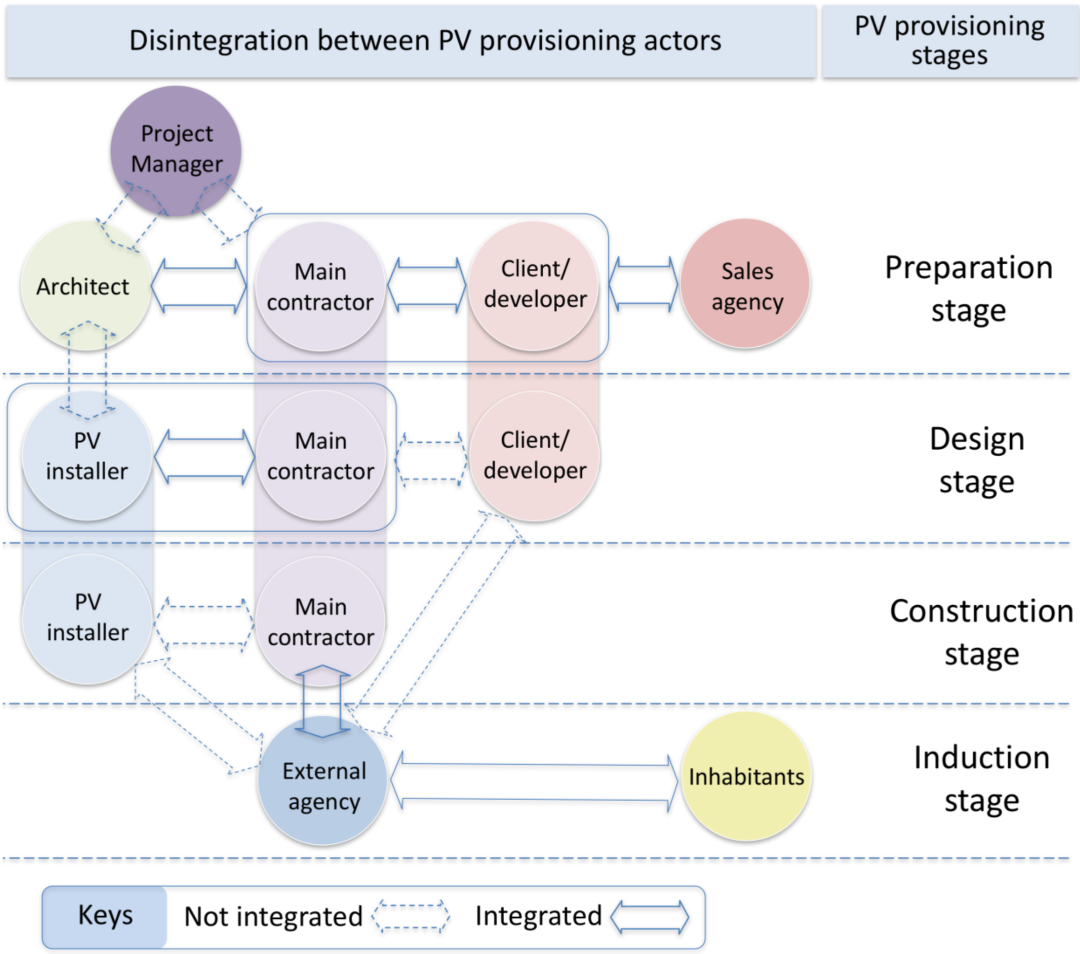


Figure 8.6: PV provisioning fragmentation – Case Study E

This significant future proofing design strategy, resulting in the early integration between the architect and the client in a contractual PV provisioning network, is good practice that also needs to be perceived as crucial by the wider governance network that influences PV provisioning network in all new housing projects in order to achieve the best outcome from the system. Solar-oriented future proofing is a very critical design issue that need to be considered from the outset in projects that aim to future proof energy supplies by enabling positive renewable energy production on site in the future.

By contrast, the architect was completely absent from the contractual PV network in the later PV provisioning stages: design and installation (Fragmentation in *Process*), due to the selected Design and Build contract used by the client to deliver the case study, which will be discussed more deeply in the next section. This disintegration of the architect with the main contractor and the PV installer in the design stage (fragmentation in *Entities*) resulted in the inverters being installed in an inaccessible place (in the attic) without consulting the architect, which was evidenced by inhabitants to be problematic (see 6.3.2.3). Architects, thus, need to be kept integrated beyond the preparation stage of PV provisioning process, and involved in the design and installation stage to avoid such fragmentation effects. This can help to ensure that PV installers and the main contractors do not make mistakes during these stages, which work against the design intention of the project. More critically, the participating project manager, did not perform his normal intermediary role which should have been to integrate the PV provisioning actors during the different construction stages. The client developer (E6) claimed that the project manager was not involved in the PV provisioning stages as a co-ordinator between the key PV actors, instead, he only monitored whether the PV systems were installed in the dedicated houses within the suggested time frame. This co-ordination is a significant missing role in relation to the contractual PV provisioning process, which requires new actors (e.g. training personal, new polices).

Another fragmentation in this Design and Build case study concerned the incomplete enrolment of the PV installer in the PV provisioning process. This was because his participation was confined to the contractual PV design and installation stages only and not in the preparation and induction stages (fragmentation in the *Process*) due to the contract conditions – a wider network issue that need to be addressed national by the people who define the detailed aspects of the contracts in the UK. This incomplete contractual PV network was due to the main contractor, the key agency with a leading role in this particular type of contract, and less knowledgeable PV actor in the network, critically commissioning the PV installer only *after* all the buildings construction were finished, and assigning the home induction process to an external agency rather than to the PV installer, in order to reduce the home induction cost. This incomplete enrolment of the PV installers may be more critical in the Standard Building Construction (SBC) contracts due to these sub-contractors not being appointed at an early stage. The SBC contract, as a key non-human intermediary passing on the governance of people who inscribed the contract, clearly influenced actors' associations and the overall PV network, and the outcomes as a result. Moreover, the main contractor did not enable any integration between the PV installer and the home demonstrator in the PV network prior to starting the home induction process, resulting in the latter not being at all familiar with the PV system (fragmentation in the Entities). This resulted in a poor PV demonstration process, as stated in section 6.3.2.1.

This latter fragmentation was due to the main contractor being unaware of the PV systems and their active meaning (PV meaning= impact on energy consumption practices, see 9.5). The wider network of policy making, thus, need to be challenged to deal with the fragmentation discussed above by developing new rules in the contract which insist that the contractor consults effectively with the energy Experts during *all* the construction stages, influencing the actor-network positively by avoiding any fragmentation between parties as it currently influence the process in a negative way by leaving this as a gap.

The client representative replied to the question about his involvement in the PV provisioning process saying that his contractual involvement was:

> "Very early in the conceptual discussion around the layout and the orientation of the houses … Not the design of PV itself. So, we stipulate a brief to X (author: the main contractor, name is anonymised) and say we want to build these properties in according with the specifications - this number of properties should have PV on it. But where they would put it was not our decision" (E6)

The above quote shows that the client representative in this case study only participated in the preparation stage of the PV provisioning process which undermined his agency to challenge key PV decisions that were made by the main contractor later on, which were not always appropriate. This significant disintegration of the client representative needs to be avoided in the future design and build housing projects, in order that the key decisions are not dominated by any single actor in homes technologies. New polices in the wider networks need to be developed to improve the PV provisioning actor-network by ensuring that clients cannot disconnect themselves from any stage of the contract process.

Confrontation and conflict between different agencies (client and main contractor) with different expectations, goals and priorities when enrolling into a single unit of discussion in an actor-network also increase the effects of fragmentation. This was evidenced in the case study E, when the sales agency of the main contractor (the latter also owned 45% of the Sheffield Housing Company (SHC) – the client) rejected the suggestion made by the client's representative to fund the PV systems in all houses by a third party in order to achieve their initial goal of CSH level (see 7.2.1.2). Despite SHC existing "not to make profit" (E6, the client representative), the contractor actors, in practice, started prioritising their own economic interests from the outset. They thought that having a lot of PVs on the roofs could hinder the sale of the houses (see 7.2.1.2), thus, moving away from their first goal which was to build new low carbon homes, highlighting another issue in the wider networks that can influence the contractual PV provisioning process. Project goals and priorities, thus, need to be clearly defined and literally written into the contract documentation, and adequately discussed between all the PV provisioning actors from the outset, to avoid conflicts and fragmentation. It is also important to mention in the contract that these goals should be strictly adhered to by all the members in the contractual network when making critical decisions at key stages in order to achieve energy efficient houses and a powerful low carbon transition in the housing sector. This is particularly significant, if the main contractor is also the client, as is the case in increasingly popular Design and Build Contracts for housing. More significantly, PV installation should be advertised and promoted by developers as something that attracts people to buy a house, rather than perceiving it as something that hinder the sale, as happened in this case study. This is another wider network issue that need to be addressed by the various institutions (both governmental and non-governmental).

8.4.2 Case study F

All the PV systems in this Design and Build Contract case study were again approved, designed, installed and demonstrated by different agents in the different stages of PV provisioning process, highlighting a key fragmentation in the *Process* related to this type of contract. They were decided collectively by the architect, main contractor and the client during the preparation stage, designed by the Service Consultant (SC) of the main contractor, installed by a PV installer, and demonstrated by an external agent. All the design and construction works were then organised and controlled by the main contractor who integrated with the PV actors directly, but without enabling any integration between the other professional actors in the PV network, resulting in critical fragmentations in *Entities*. As in case studies A and E, the project manager did not perform an expected intermediary role to bring the team together. The latter actor answered the authors' question in relation to his involvement in the PV provisioning process for this case study: "No (author: not participated) – The client dictated that PV's were required and it was then left to the main contractor to procure them" (F6).

The project manager (as an existing actor), thus, needs to be actively involved in co-ordinating the provisioning of home technologies and enabling the integration between the key PV actors in the different stages, rather than just checking whether the technologies were installed on time. Again, this significant role of integrating PV provisional needs to be clearly worded in the contract in order for a contractual network to function properly. The PV installer was completely disintegrated from the architect, and there was a poor integration between the architect and the service consultant, which occurred only during the design stage in order to simply decide the location of the PV panels on the pre-design roofs which had taken no account of the PV requirements. This disintegration between the architect and the other provisioning actors is attributed to the selected Design and Build contract as a crucial non-human intermediary used to deliver this case study, which will be discussed in the next section (Figure 8.7).

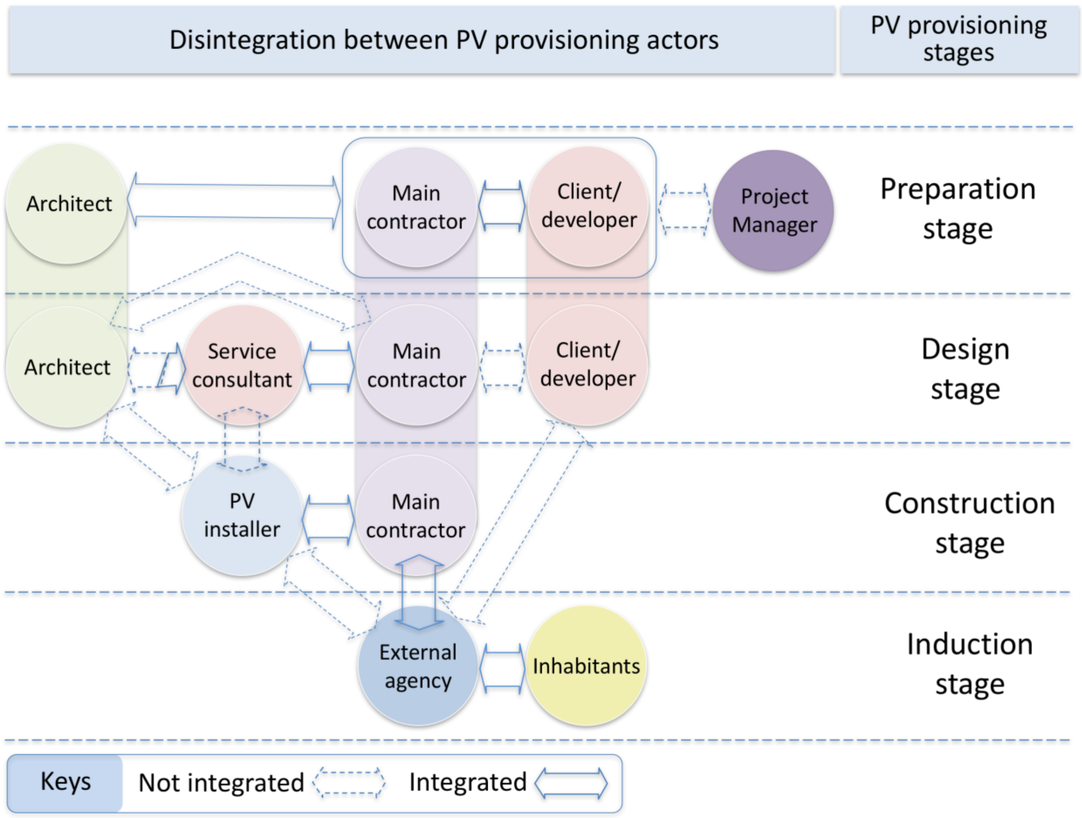


Figure 8.7: PV provisioning fragmentation – Case Study F

The disintegration between the architect and the service consultant during the design stage of this case study, resulted in a lack of governance by the architect in relation to the roof size of some houses and the negative consequence in terms of not achieving the CSH-4 for those houses due to under sizing the roof area in relation to PV panel provisioning (see 7.2.1.3). During the interview, the architect was confident that he "had a lot of experience with PV system" (F5), and that enabled him to make positive decisions concerning the design related to the system. However, his experience was clearly not enough to avoid this serious problem, as he was not aware of the size of the PV system as designed by the installer later on. As with the case study E, the same disintegration between the PV installer and the home demonstration actor resulted in the latter being completely unaware of the PV system (fragmentation in *Entities*). One inhabitant even stated that the home demonstration "was rubbish. It was very inefficient … it just last for 5 minutes – she just gave me a gift pack of documents and information" (F1).

In comparison to the counterpart role of the PI in the PC case studies, the main contractors in the NPC case studies were more successful in terms of enabling an early detailed dialogue between all actors (mainly with the architects at the preparation stage) to encourage true integration between all construction parties in the contractual network. This can be attributed to the main contractors' experience in leading housing construction projects, in which a network of actors is already formed. However, as with the PC case studies, the architects and the clients in the both NPC cases studies were critically absent from the design and installation stages of PV provisioning process, which is identified as a key fragmentation in the *Process*. This was due to their insufficient participation in the construction stage of the building, which they believed they were not needed for. However, the thesis has shown that they are. The most critical disintegration in the *Entities* (NPC case studies) took place between the architects and the people who designed and installed the systems (e.g. service consultant in the case study F, and PV installer in the case study E).

In many UK Design and Build contracts, the architect's involvement ceases after the Construction Drawings stage are completed, and the clients disconnect themselves after approving all the requirements with the contractor – they are not involved on site during the Construction phase itself, creating pure fragmentation. Again, this is a wider issue of networks and arrangements, related to the design of contracts that impacts on the housing case study actor-network, which need to be redefined at the national level. The Design and Build contracts need to be reworded to include the architect and the client participation beyond the design stage, and for them to be kept advised of what is happening and consulted for their views at relevant points in order to achieve the design intention of the project and give PV installation the best chance to succeed and achieve the designed energy saving targets.

In both the PC (A) and NPC (E, F) case studies, the project manager failed to perform an intermediary role as a coordinator between the key actors in relation to PV provisioning process. This is part of a wider network issue related to construction training in the UK. To enable a powerful engagement of a project manager in the provisioning of home technologies, an appropriate training in energy-efficient technologies (e.g. PV systems) and load matching practices should be provided to the project manager in the first place, and the project manager should have a specified co-ordination role in relation to home technologies, set out in the contract by the client.

The critical disconnection between the PV installers/SC and the home demonstrators in both the NPC case studies (fragmentation in *Entities*) resulted in the latter actors being unaware of the properties of PV system including the affordances offered. This is another issue of wider networks and practices related to the lack of training of home demonstrators and assumption that inhabitants can learn things for themselves with a manual (Carmona-Andreu et al., 2012). Home demonstrators should adequately discuss all the PV aspects with PV installers prior to meeting the inhabitants in their homes and should be appropriately trained to explain the PV controls and maintenance, and load matching potentials to all inhabitants.

Although the identification of the critical disintegration between the various contractual actors who participate in the PV provisioning stages can help to improve the contractual network and practices of PV systems, without an examination of the overall actor-network patterns in terms of how power exists and is transformed between actors through diverse relationships (Watson, 2017), any deeper understanding of the PV networks, in terms of actors' effective integration and arrangements in the wider network, is difficult. This is tackled next.

8.5 Power transformations in actor-networks

In this section, the previous PV provisioning fragmentation graphs are now cross-related across both the PC and NPC case studies in order to inductively identify the differences in the various identified PV actor-network patterns (see 8.8 & 8.10) in relation to the deeper power origination and transformations between the key actors during each different PV stage. This is to identify the networks which work best for different approaches of housing provisioning in terms of ensuring the optimum integration of the different actors in the wider network.

8.5.1 Power transformations

In terms of actors' agency and power to make appropriate connections with and between other participating actors, three new types of deeper contractual PV actor-network patterns were identified among the PC and NPC case studies discussed in this thesis through further specific mapping of power relations and transformations between PV provisioning actors during the different building construction stages operating during the two different types of contract used.

1- *Type 1*: Inhabitant client to PI.

In the PC case studies B, C, and D, the power starts with the client (the inhabitants) who quickly passes it to the PI in the preparation stage, without making any connections to other actors. The PI, having the agency, starts to mediate within the existing actor-network by making connections with the grant body consultant (C), the PV installers (B, C) and the architect and the main contractor (D) in the preparation stage, and with the PV installer and the grant body consultant (D) in the design stage. The PI continues keeping his agency by mediating and controlling the network in the design and installation/construction stages. Only in case study C, does the PI maintain the connection between the inhabitants and the provisioning team by performing an intermediary role, maintaining thus the inhabitants' power and the whole actor-network. The other PIs (B, D) disabled the power of the inhabitants, due to changing their agency and role (Figure 8.8).

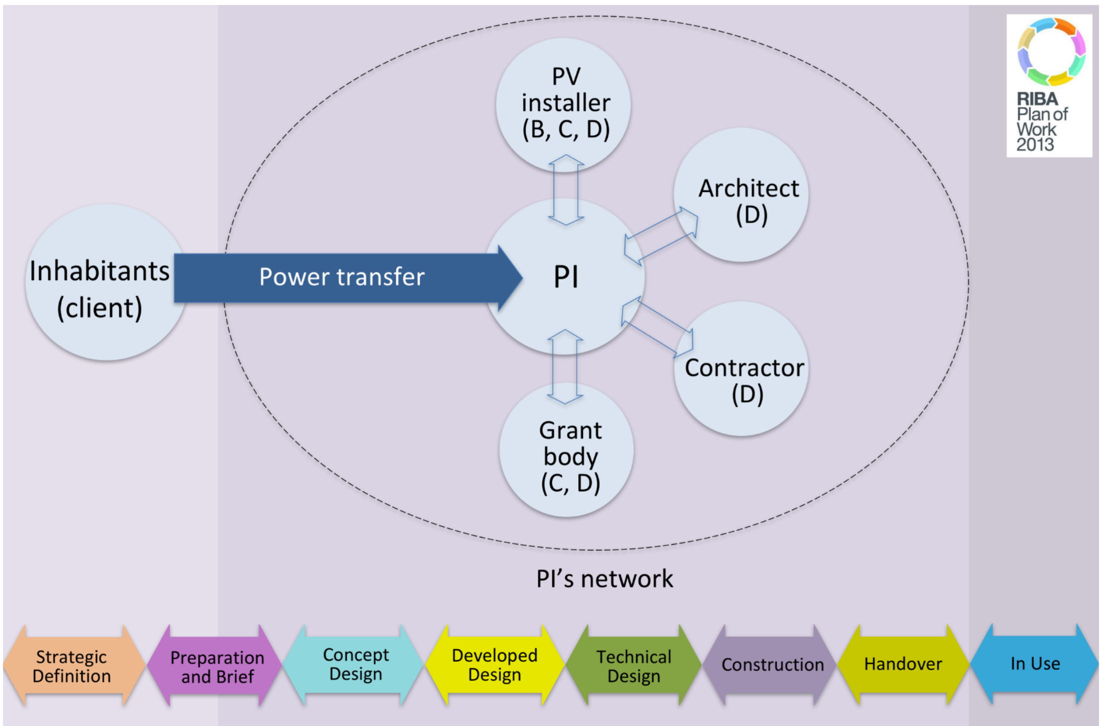


Figure 8.8: PV actor-network formation and power transformations – Type 1

2- *Type 2*: Developer Client to Contractor

The power in these case studies (E, F – NPC case studies) starts with the developer client who form an actor-network by making connections and mediating with various actors, including the architect, the project manager and the main contractor (E, F), and sales agency (E) in the preparation stage and before passing this power to the main contractor in the same stage. The main contractor later starts to form a new network and makes new connections with new actors including the PV installer and home demonstrator (E, F), and the service consultant (F) (Figure 8.9).

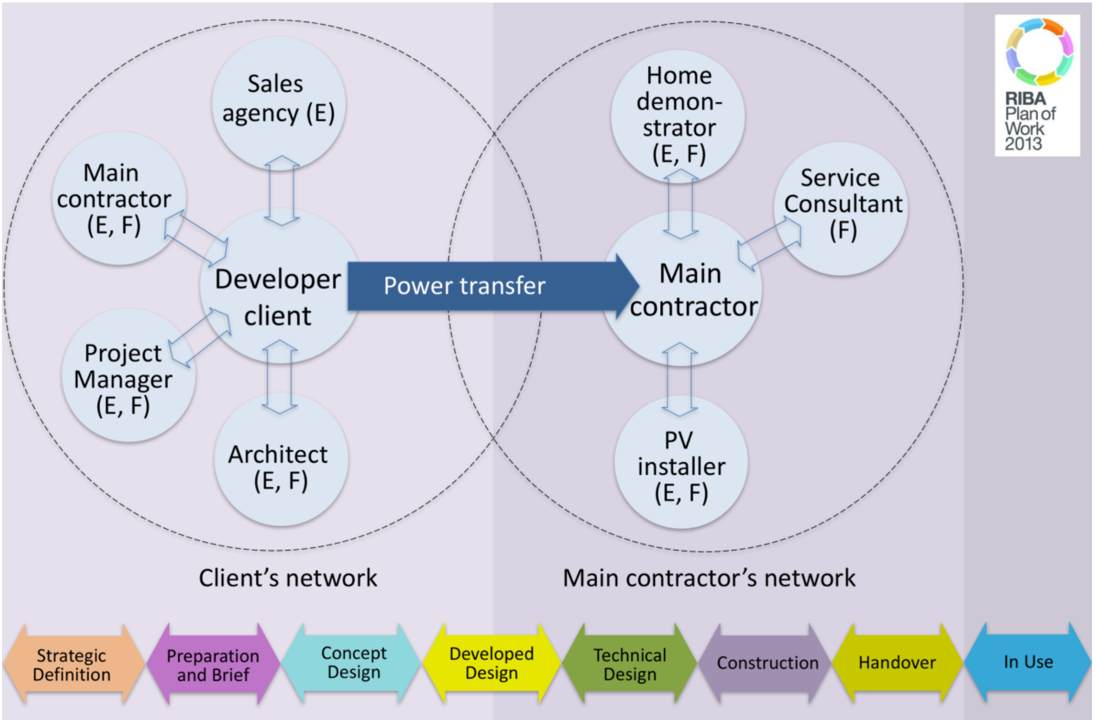


Figure 8.9: PV actor-network formation and power transformations – Type 2

3- *Type 3*: Inhabitant client to Contractor

In case study A, the power starts with the client (the inhabitants including the PI), and then quickly shifts to the PI in the preparation stage who starts to make connections with the architect, the project manager, the energy consultant and the main contractor, and to form the first PV network and mediate between the actors. The PI later dispatches this power to the main contractor in the design stage in which the latter actor makes new connections with new actors (PV installers, home demonstrator and QS), and establishes a new network (Figure 8.10).

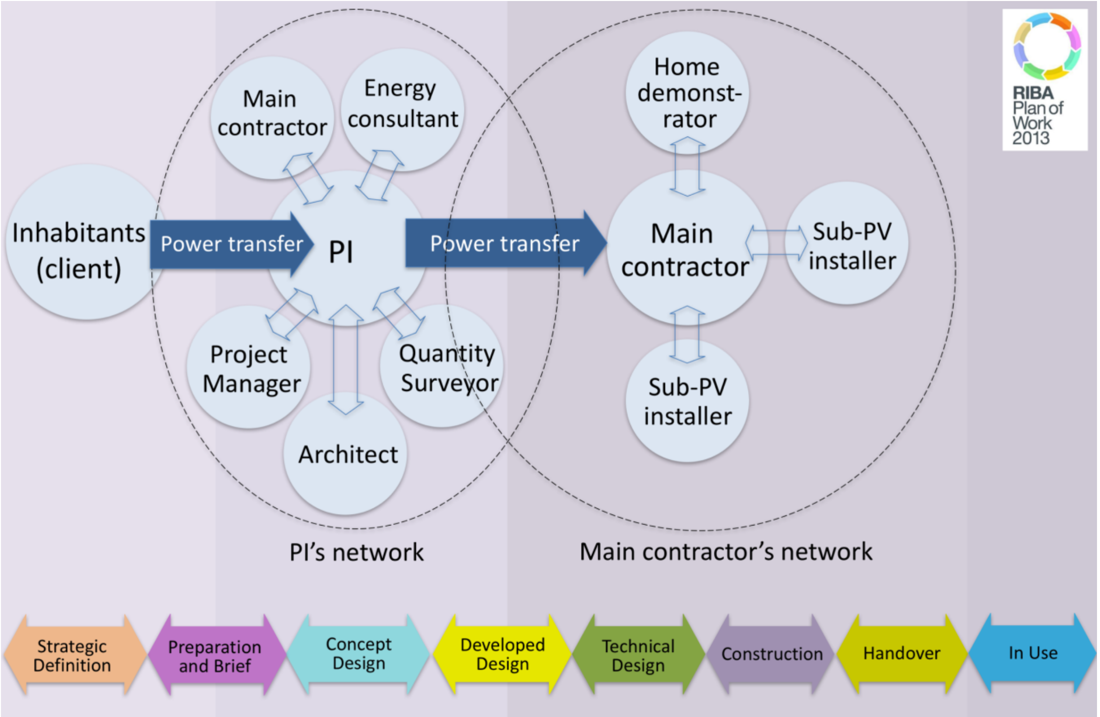


Figure 8.10: PV actor-networks formation and power transformations – Type 3

To enable a powerful comparison between these PV actor-network patterns, the actors' agency and power to form a network is discussed next in relation to the actual contract processes. This reveals how well the power distribution aligns with the contract process itself, and whether or not, the agency of an actor changes with a change in the contract type.

8.5.2 Power versus Contract

The key difference between the two types of contracts involved (Standard Building Contract (SBC) and Design & Build contract (DB)) in the six case studies (Figure 8.1), in terms of *Fragmentation*, concerns the integration between the architect and the client/PI. In the SBC, the architect is specified and contacted directly by the client to design the project before employing a contractor to construct the project. By contrast, in the DB contract, the architect is considered as a part of the contractor's team, which means that there is no integration between a client and an architect prior to commissioning the design and construction works to a contractor.

The main difference in the PV networks between the deeper Actor Networks pattern Types 1 & 3 in the PC case studies, is that the client inhabitant and the PI in the Type 3 DB case study had no agency to form a network and connections with PV specialists (e.g. PV installers, service consultant) in the design and construction stages, given that the DB contract, has already disabled the PV installer from participating in the preparation stage, resulting in a complete disintegration between the client inhabitants/PI and the PV installer. This disintegration had a clear influence on the PV provisioning process and inhabitants' understanding of the appropriate PV practices as a result (see 6.2.2.1) leading to less efficient PV practices and an energy performance gap. By contrast, the client inhabitants in Type 1 SBC case studies had the agency to do so. This means that the adopted DB contract to deliver the Type 3 case study reduces *the inhabitants/PI* power as a client in the PC case studies to actively involve and influence the design of their home technologies, which can again lead to ineffective PV practice.

Another disadvantage of the DB contract in the PC case studies, is that the client (the inhabitants) is required to provide a clear brief and information with all the necessary operational considerations at a very early stage of the project (Hughes, 1992, Hughes, 1991), which they might not be at all familiar with, particularly in relation to the required affordances of their PV systems or other home technologies. The participating project manager in the case study A was an expert in Co-housing projects. However, he had little knowledge in terms of PV affordances and load matching strategies.

To develop the client inhabitant/PI knowledge of what the appropriate requirements are for their home technologies, the existing actor-network need to be extended by providing a new participatory 'PV champion' actor (e.g. Soft Landings champion or an expert in home technologies and energy efficiency), to be involved and integrated with the client inhabitant in the preparation stage and before employing a DB contractor, particularly for large low carbon housing projects or mixed projects, given that neither architect nor contractor have oversight of whole PV provisioning process from the beginning. In smaller DB housing projects (50 houses and less), where the high cost of a Soft Landings champion might not be justifiable, this role could potentially be covered by the project manager (an existing actor with an extended role), but only after providing him/her with an appropriate training in the relevant energy efficient technologies within an extended actor-network, as they may be relatively uninformed concerning detailed energy efficient requirements and technologies, given this is not part of their formal training.

The participating energy expert in case study A was confined to only determining the energy strategies and the necessary technologies to achieve Code for Sustainable Homes (CSH) level 4; however, there were no details about these technologies in his final energy report. Energy experts, thus, could be another potential actor in the extended actor-network to perform this new PV championing role, by identifying and discussing all the required affordances and specification details of the home technologies with the client inhabitants/PI during the preparation stage and beyond, if their role is expanded in this way. It is also important that the energy expert role extends to the other PV provisioning stages, particularly to the design stage, to ensure that the system design and installation are as intended. They also need to play a new intermediary role in the extended network that integrates the inhabitants with the home technology designers and installers in order to ensure that the contractual actor-network functions appropriately.

New policies, as a part of an extended network, are needed to ensure the involvement of these significant actors in the PC case studies. In the NPC DB case studies (type 2), this was less of an issue, due to the client developer having a clearer insight and knowledge of what they wanted to achieve from their installed technologies and how.

More specifically, the extended DB contract intermediary empowered the main contractor in the Type 2 and 3 case studies (A, E, F) to form a new contractual PV actor-network during the design and installation stages but in isolation form the network that was previously formed by the client/PI. As a result, the actors in the new network had no connection with the actors in the previous network and the client developer/PI completely lost any controlling role and power when deciding the system affordances and integration into houses. This was due to the absence of any extended intermediary actors to mediate through this type of contract and extend the actor-network to maintain the connection between the two networks. The project managers in these case studies did not perform this extended role in relation to the PV provisioning process – a significant omission. This extended role of project managers, thus, should be clearly articulated and literally written in the contract, to ensure that they do not withdraw from the home technologies provisioning process. Where there is no project manager in a housing project, this extended intermediary role could also be assigned to the architect (an existing actor), by the client employing him/her directly after the completion of all the detail drawings, while the new extended actor could be the Soft Landings champion, particularly in the NPC case studies, where these projects tend to be large housing and mix used projects.

By contrast, the SBC contract, as a mediator in the extended actor-network type 1, maintained one PV network and empowered the PI to have a controlling role and power over the whole PV provisioning stages. However, installing the PV systems in the SBC case studies raised problems of severe Process fragmentation, given that the PI and Installer were unable to influence the contractor and the architect's decisions at an earlier design stage (Figures 8.3, 8.4, 8.5). This is particularly so if the client inhabitants decide to retrofit a PV system design after the completion of the project design or during the construction stage. To avoid this Process fragmentation, any potential PV installation intention and requirements should be decided from the outset in order to stimulate an early discussion with the architect and the contractor to decide the best location and orientation of the houses on site and the location of chimneys on the roofs, which were evidenced to be problematic in the case studies B and D. This could be achieved through a new policy requirement in the contract documentation to ensure this happens, thus extending the contractual network and defining new arrangements of actors within a network as a result.

In the SBC contract, the architect is the potential actor in the extended network to connect the various PV actors, and to act as a managing actor. However, the PI in case study D (PC), changed his normal role as an intermediary between the inhabitants and the design team to more controlling and mediating role, making connections with PV actors (grant body consultant, PV installer) independently from the architect, and effectively undermined the extended controlling role of the architect, despite the latter having responsibility to manage the whole construction process. A suggestion was made previously in section 8.3.4, in terms of how to ensure that an intermediary actor stays as an intermediary actor. This was not followed in the case study D and resulted in poor PV management and disintegration between the architect and PV installer, with negative consequences in terms of PV performance (poor PV location on the roofs) and the missing home induction.

The previous fragmentation analysis and discussion has shown the critical disintegration between the various actors who have participated in the PV provisioning stages. The failure of relevant actors to participate in the PV networks, where their participation can be very influential in terms of improving PV provisioning networks and practices, is critical also. The next section discusses in more detail the wider issue of networks which resulted from some key actors missing in the PV network.

8.6 Key missing actors in the PV network

This section probes the case study actor-networks more deeply through the use of Fragmentation analysis to further examine the wider issue of networks in terms of the contractual relations and arrangements of actors related to PV provisioning process.

8.6.1 The missing actors

The principal missing actors and roles in the wider network of PV provisioning are the PV suppliers, local authorities, housing agencies and energy efficiency systems specialists in both the PC and NPC case studies. The PV suppliers as intermediaries/mediators were completely absent from all the PV professionals' discussions during the PV provisioning stages in all the case studies. This is perhaps not unusual, as historically, the "demand has been isolated from design, demand and design from manufacturer of components and all these from construction on site" (RIBA, 1964: 8). This isolation caused a long delay in supplying the PV appliances to the case studies on time, which was a particular problem in the PC case studies B and C (see 7.2.1.1).

On a wider networks and arrangements level, this particular disintegration hindered the supply side from understanding the different problems that were associated with the PV provisioning process (see 5.3.1.1 & 5.3.1.2) and having the ability to receive meaningful *feedback* from inhabitants in relation to the affordances offered in the PV appliances (see 6.2.2.3 & 6.3.2.3). Not only do inhabitants need feedback in terms of their PV and energy performance, but the supply side also needs feedback from the inhabitants during the occupancy stage in order to not to repeat the same mistakes and to improve the system design and affordance, particularly in terms of enabling inhabitants to actively manage their energy load efficiently. PV supply actors, therefore, should be integrated *directly* (e.g. face-to-face) with the other design team actors (e.g. client/PI, architect, main contractor, installer/service consultant) when inscribing and installing the PV systems in order to optimise the system design and to supply the PV appliances on time. An *indirect* connection in the wider network (e.g. specific forums) is also needed to receive feedback from PV professionals in relation to the provisioning stage, and from inhabitants in relation to the occupation stage. A non-human intermediary is, thus, significant to facilitate this integration in the wider network level which will be discussed in depth in section 8.3.5.

Another lack of engagement in the process of PV provisioning concerned local authority actors and housing agencies in all the PC case studies and in the NPC case study F, and their incomplete engagement in the NPC case study E. Sheffield City Council obliged the client in the case study E to build new houses with 10% PV installation through its planning department acting as a mediator (see 7.2.2.1). Although this had a positive influence in terms of encouraging the installation of PV systems in case study E, local authorities and professional institutions can play a more significant extended role in terms of improving PV practices, by taking part in the wider PV provisioning network. This could be achieved by developing interactive trainings for housing clients to learn how to brief the contractor and architect properly in order to ensure the effective functioning of a contractual PV network. Professional institutions and universities could also provide training for PV professionals *and* inhabitants in terms of improving energy efficiency through the design of PV system at both an individual and community energy levels when they become a part in a wider network of PV provisioning process. These types of training could be achieved through initiating new national polices, and by enabling new intermediaries (e.g. training actors) to be engaged within a wider network for the client and PV professionals, and for inhabitants. All of this can help to make PV provisioning and occupancy governance and practice more effective, thus critically helping to reduce carbon emissions.

In all the case studies presented in this thesis, none of the interviewed PV provisioning actors and inhabitants mentioned that they had received any training or workshop provisioning with regards to PV installation and energy load matching potentials respectively. This shows a significant lack of policy development and execution in this area as covered by government, local authorities and other policy makers, highlighting a significant wider issue of current networks and arrangements in the UK. This lack of training in relation to energy efficiency (Parag and Janda, 2014), is also the case in relation to effective PV installation. The fragmentation in the construction work makes it particularly hard for policymakers to approach these professionals with proper educational and training programs, and to promote other values, practices and norms for both the construction actors and inhabitants. New 'training' actors who have skills in improving energy efficiency, are needed to engage in the wider PV network, specifically within the local authority departments, the construction team, or even more powerfully, within local residents in a specific neighbourhood.

Critically, the ANT and Practice theory findings in the previous chapters show that all the existing provisioning actors in all the PV networks were unaware of the available strategies at a community scale for using energy communally (e.g. the use of micro-grid system, community energy storage) highlighting another key issue in the wider network and practices related to improving the use of PV energy and reducing energy cost as discussed in section 2.6.1. For example, none of the PV installers in the PC case studies, when visiting their websites, introduced PV technologies as a system that could be used communally. Unsurprisingly, when these installers introduced the benefits of adding a battery storage to the system, they only referred to the benefits on the individual level:

> "Adding battery storage will help you store your excess generation (that would normally be exported) for use later when your consumption is higher than your generation. As electricity prices rise this sort of battery storage system will become more and more cost effective … Adding battery storage for back-up will secure you against power cuts" (Wind & Sun)

In the NPC case studies, the developers (who introduced themselves to the public as developers that specialise in delivering sustainable homes) also understood the PV systems as individual systems for energy generation and consumption, rather than a system that has the potential to be used communally to increase the benefits. This lack engagement with a community level, led one inhabitant (A) to claim that the method used to connect the PV systems to the houses in his case study did not allow the energy generated from all the PV systems to be used communally by all the inhabitants. This led to an inefficient use of the energy generated from all the PV systems in their housing projects. He suggested:

> "Now, one item that has been put on the news at LILAC Co-op is that there is a technology, which will allow the PV panels to be used communally…Now, what would be far better is that, OK when we are at home and everybody else is out at work, there is a technology which would allow us to use the electricity from everybody's panels, so we could, for example, boil an electric kettle, which we could not do purely with one pathetic solar panel" (A2)

More worryingly, at a wider network level, UK policy places emphasis largely on the single/individual house scale rather than the community scale when funding PV installations for community projects (The British Academy, 2016). This individualistic account by policy makers, not only undermines the development of local energy grid practices and the introduction of other solutions, but also influences the sense-making of the PV provisioning team (installers, providers, energy experts, etc.) and their theoretical standpoints, by promoting the installation and practice of PV systems as an individual system rather than a possible communal one. All these factors suggest that PV Installers, main contractors, architects and other PV actors need broader training beyond individual house installations, to consider the PV infrastructure of a housing project at a community level to help make PV systems more effective and thus reduce carbon emissions overall.

In order to achieve the potential benefits of the micro-grid and energy storage systems, a presentation of similar community energy initiatives across the EU, their success and failure, could be given to inhabitants in the early stage of their occupation to aid their understanding. This would be not only useful in terms of showing them how to use their new energy system, but also to give community members a powerful idea of what is feasible through this project and how this project could affect them on an individual and community scale, thus removing unrealistic expectations by inhabitants about the project. This presentation could be given by various existing actors in the wider housing network, such as an officer in local authorities or housing developer organisations, existing energy organisations (e.g. Energy Saving Trust), or even by a member of the construction team (e.g. architect, PI). However, all these existing staff need to be sufficiently trained to do so. Local authorities could also encourage the development of a group of local residents who are interested in improving energy efficiency, and for the group to integrate with other actors (architects, energy trusts, etc.) in the wider housing network to facilitate and disseminate the energy efficiency concepts and best practices to other inhabitants on both individual and community levels and to locally govern energy efficiency issues as discussed in the next section. These existing and new actors should be prompted to do this even more strongly in the NPC case studies, given that the PC case studies are already engaged through their housing provisioning and lifestyle which are based on community housing principles (e.g. sharing resources and facilities).

8.6.2 The role of local authorities

Local authorities have a substantial role to play as a transition intermediary at a wider level in terms of extending the PV network and practices outside the contractual arrangements and networks of PV professionals by supporting and mobilising powerful integrations and networks between the various energy efficiency actors, to locally govern energy efficiency issues, and to encourage resilient communities (Gilbert et al., 2013). Nottingham City Council (NCC), for example, played a substantial and pioneering role in supporting the integration of a group of local residents in the Meadow area to promote community resilience and low carbon blueprint (Kiamba et al., 2017) and to integrate their local practices and networks with other wider networks concerned low carbon homes. More specifically, the architect of the case study F, in collaboration with the NCC, played a significant intermediary role in successfully aligning the interest of local residents in the Meadow area towards achieving a collective goal of resilient energy communities and forming, as a result, the (MOZES)[26]. The architect, later, became the *chairperson* of MOZES group, which enabled him to translate the latter group views to, and enrolling a new actor in the wider network (the Nottingham University climate and environment research team), in which the architect was *also* a member of this university research team, in order to build a wider actor-network. The wider network then enabled the development and implementation of an innovative energy resilience project: The Storage ENabled SustaInable energy for BuiLdings and communitiEs (SENSIBLE) project, and successfully sought funding from the European Union's Horizon 2020 research and innovation programme (SENSIBLE, 2014, Rodrigues et al., 2016, Kiamba et al., 2017). This project aimed to support homes and communities to be less reliant on national grid (by drawing on renewable energy) and to create more resilient cities. This programme involved an installation of additional individual batteries in 37 homes with existing individual PV systems in the Meadow area (including the case study F), as well as a new large community battery (University of Nottingham, 2016). The main benefits of this project as articulated by the architect (F4) are:

> "… making the most of domestic solar energy generation; this means more energy will stay within the community, reducing the need to draw on energy from the grid, thus reducing household electricity bills" (University of Nottingham, 2016)

[26] The Meadows Ozone Energy Services (MOZES) is an Energy Service Company formed in October 2009, with the assistance of the Meadows Partnership Trust and Nottingham Energy Partnership. O'DOHERTY, T., RODRIGUES, L. & GILLOTT, M. The role of community-based energy management schemes in supporting resilience. 14th International Conference on Sustainable Energy Technologies, 2015 Nottingham, UK.

This wider network approach towards built environment practice-based research (Dye and Samuel, 2015), which strongly links building professionals to local authorities and inhabitants, needs to be supported by the policy makers at a national level as well as other local authorities in order to positively influence the formation of actor-network related to the innovative transition to low energy and low carbon communities across the UK. This wider network and its arrangements is a missing opportunity in the UK just now (Dye and Samuel, 2015). This network can also provide valuable education for community members regarding the technical and behavioural aspects of energy management in close collaboration with the design team. The powerful form of collaboration between energy efficiency practices and research (Figure 8.11), identified in this thesis, extends the role of the architect into a 'middling- out' broker (Parag and Janda, 2014, Janda et al., 2014) in the wider network, showing that a professionals can bridge the gap between academic theory and professional practice and, thus, enabling wider network of practice based research (Hay et al., 2017) as a means of 'collaboration for change' (Morrell, 2015).

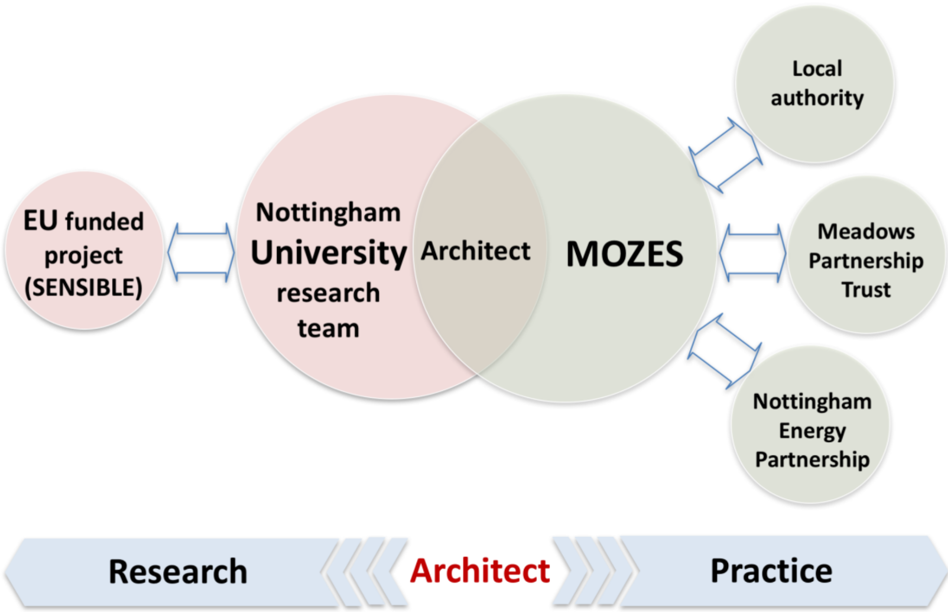


Figure 8.11: Practice based research for energy efficiency

Key building professionals (e.g. architects, PIs), thus, can take more dynamic role and relations in a wider network to enable a successful energy transition in housing. A positive example of this approach took place in the case study C, when the PI decided to install PV system before obtaining permission from the Local authority, challenging, thus, both the constant changes in the FIT polices and the Local authority's rigid policy in terms of the design team having to apply for PV permission independently from the main building construction permission (see 7.2.2.1). However, a negative example of this ‘middling out’ happened when the PI unilaterally removed the roof access from the original design in the case study A, in order to reduce the total building construction cost without the architect consultation. Thus, such an approach of ‘middling out’ and creating mediators out of intermediaries has to be very carefully handled with good communication and agreed decision-making between all the actors involved in the PV network.

8.6.3 Policy issues

Beyond the role of local authorities, there are wider policy issues at the national level that can influence the effectiveness of local authorities as a key intermediary organisation within wider actor-networks in terms of promoting the appropriate provisioning of PV systems and energy management strategies to reduce carbon emissions. Policies can either enable or curtail the practices and networks related to promoting low energy homes (Kivimaa and Martiskainen, 2018). Recent UK policy over the last few decades has not encouraged the utilisation of community micro-grid strategy at a wider scale through its funding programs. This has resulted in the UK’s community energy sector remaining very small today (1% of the UK’s renewable energy) compared to Germany[27] (40% of the country renewable energy capacity) (OVO Energy, 2014: 18, The British Academy, 2016). This suggests the need for further policy formulation at a national level to improve the utilisation of community micro-grid strategy, and the funding to do so, through the existing government sponsored organisations (e.g. Energy Saving Trust, Home and Communities Agency (HCA), Department of Trade and Industry (DTI), etc.).

New policies also need to play a significant role in promoting good practices through the development of appropriate actors, currently missing, to facilitate the integration of the construction industry and with inhabitants. One potential non-human actor for this purpose is the transfer of the existing ‘*Soft Landings*’ approach from the non-domestic to the domestic sector in the UK. ‘Soft Landings’ is a process (Way and Bordass, 2005), to ensure that all “operational needs of the building are fully

[27] The German government, through its KfW scheme, supports the use of local storage in conjunction with on-grid PV systems by covering 30% investment-grant on equipment purchased. It also provides low-interest loans for the other 70% of the cost through the German State-owned development bank. All these has helped to boost the residential energy storage from almost zero installation to around 35000 unit by the end of 2015.

considered and appreciated at the design stage and embedded in procurement and contractual obligations" (BSRIA, 2009). This process emphasises continual and multidirectional feedback between the design and construction team, operational staff and inhabitants (ibid). Soft landings also enables a greater integration of the supply side with other actors in the building construction network and inhabitants as adopted by the UK government for its own estate. The three stages of Soft Landings are: briefing/programming, pre-handover and long terms operation (Way and Bordass, 2005) and they ensure that:

1) The expectations and performance targets by the design and construction team and inhabitants are understood, and roles and responsibilities are set out clearly from the very beginning within a well-structured, logical and recorded context in the briefing stage.
2) The design team integrates with the building operators to illustrate how the building works. This might need skilled training operations and maintenance staff, developing building use manual, conducting appropriate building information sessions and tour, and installing monitoring equipment in the implementation stage.
3) Feedback takes place through the inhabitants providing feedback to building operators via complaints, real-time monitoring of the energy performance in the use stage and by representative users.

To facilitate these three stages, new agents and roles (both human and non-human) need to be developed and engaged in the wider building construction and operation networks to ensure a more powerful PV design and practice. This includes, additional documents (e.g. energy targets, specific roles for PV actors, building use manuals), training actors for both PV operation and maintenance works, PV and energy monitoring equipment and people. A *Soft Landings* champion also specifically needs to be provided as a new independent mediator, who checks on contract delivery, and recommends any necessary changes to help integrate and deliver a housing development programme according to the agreed specifications/targets of the original contract.

The introduction of new polices at national or local levels enabling this process and these significant intermediaries in the future housing construction networks could, however, simply increase the cost of the houses. This highlights another wider issue of networks for improving low carbon homes. This rise in the price might work against the government's aim to produce affordable low-carbon housing projects, as well as the client's desire to reduce the cost of a house in order to improve its saleability. Cost, therefore, need to be addressed at the national level using various strategies (e.g. via indirect carbon taxation). The questions here are who is going to cover these additional funding? Where is this funding to come from and how? These issues need to be addressed within wider networks and require further research, which is beyond the scope of this thesis.

8.7 Sequence, specialisation and fragmentation

A further crucial aspect concerning the degree of fragmentation in each of the case studies, is the increasing *specialisation* of roles and the *sequential* contractual involvements of the different actors to deliver the whole housing project. These are discussed next.

8.7.1 Specialisation

Increasing specialisation in the building industry leads to greater fragmentation in the building construction works in terms of both Entities and Process (Fayazi et al., 2017), influencing the PV installation actor-networks and practices as a result. This occurred particularly in the DB contract case studies due to the contractor, the key controlling actor in the network, having previously created his own network of sub-contractors (e.g. design consultants, supplier, installer) to complete the design and construction works on time. In the case study A, for example, all the PV panels were installed by the roofing subcontractor, while the internal PV appliances were installed by the Mechanical and Electrical (M&E) subcontractor, resulting in a clear fragmentation in the *Entities* in the PV installation works and change in actors' agency (see 8.3.1). All this division in roles resulted in a critical disintegration of some key actors from the whole PV provisioning process (e.g. PI, architect) due to the over-specialisation in the PV provisioning, where the construction of a project depends on the participation of several certified trades. Sub-contracting has been adopted in many building construction projects as a key provisioning strategy in order to achieve a better efficiency in terms of obtaining continuous work within the identified time, due to subcontractors unique skills and their ability to complete the different specialised and complex requirements of each task (Tam et al., 2011). However, the findings in this chapter showed that subcontracting was a key source of fragmentation in the PV design and installation works, highlighting another wider issue for the development of effective actor-networks within contracts. PV works, thus, should be completed by a certified PV installer, and the controlling actor in the wider network should enable a powerful integration of the latter actor with the other design team in the early stage of the building construction process to overcome this source of fragmentation.

8.7.2 Sequence

The sequential contractual involvements of actors for delivering all the PV systems in the presented case studies also led to an insufficient and/or ill-timed collaboration between the key PV provisioning actors (fragmentation in the *Entities*). Alongside the wider issue of the DB contract, in terms of reducing the integration of the architect with the other PV design team (A, E, F) and the development of actor-network, the *sequential* contractual involvement of actors to execute the project tasks in stages also significantly disabled the relationship between these team members, even when the architect was willing to be more integrated, highlighting another wider issue for developing networks and practices. The sequential approach also disintegrated the PV design and installation team from the home demonstrators, thus, disabling any connection and learning from one actor to the next, given that these demonstration actors (E, F) were not specialists in explaining the home technologies and controls to inhabitants (see 8.3.5/6). Therefore, the existing contractual network need to be re-arranged in terms of a greater focus on co-ordination requirements between actors and the involvement of new actors in the extended network in both the DB and SBC contracts, given that a contract is in effect a co-ordinating intermediary through its documentation. The extended co-ordination actors (e.g. Soft Landings champion, project manager, etc.), thus, have to be built in into the contract from the outset by the client to ensure a relatively independent voice from the start, aiming to check that things are happening as they are supposed to, with connectivity maintained. The architect in the DB contract could also be employed by the client as a Soft Landings champion in the extended network after the completion of the detailed design stage (stage D – RIBA frame of work), or take this responsibility from the start in the SCB contract.

Figures 8.12 & 8.13 shows the proposed new form of contractual actor-network (both the existing contractual networks and a new extended contractual co-ordination networks) between the various housing construction actors in both types of construction contracts: DB and SBC. This shows the actors (existing and new) that need to be involved in the two types of contractual networks. This proposition is based on the collective findings of this thesis and drawn from a wide range of data, as well as the issue of fragmentation discussed in this particular chapter. It helps to avoid fragmentation in terms of both Entities and Processes.

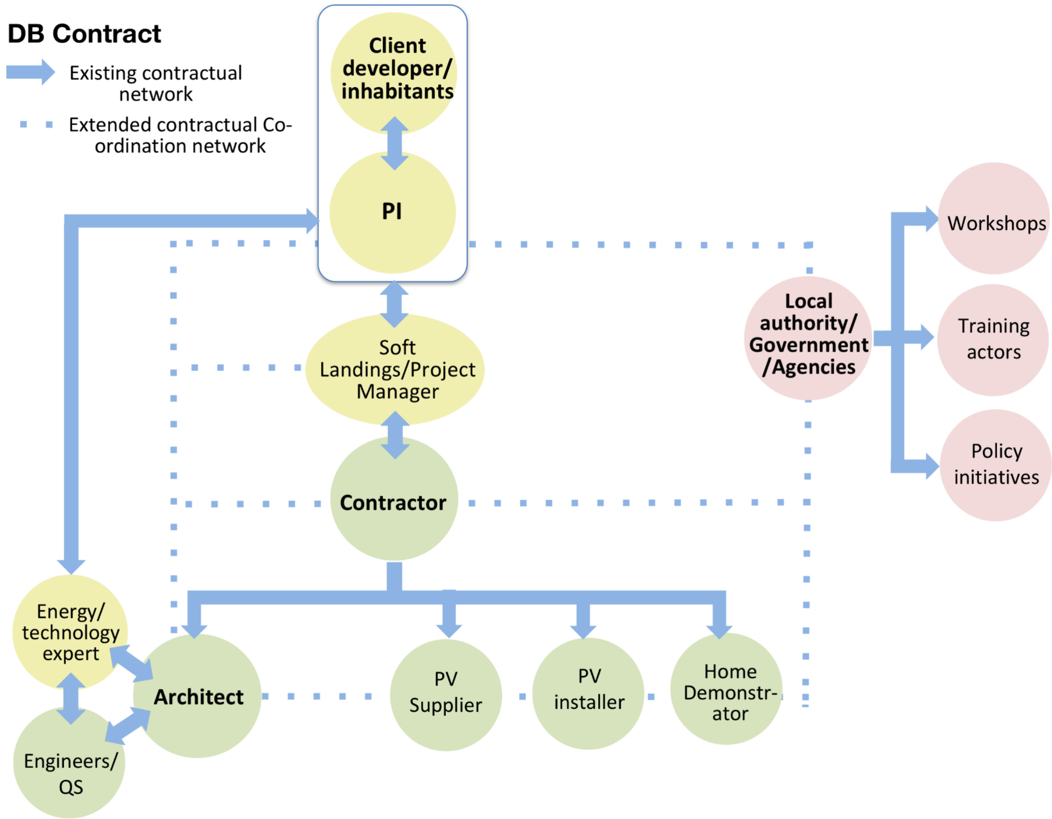


Figure 8.12: Contractual and co-ordination extended networks - (DB) contract

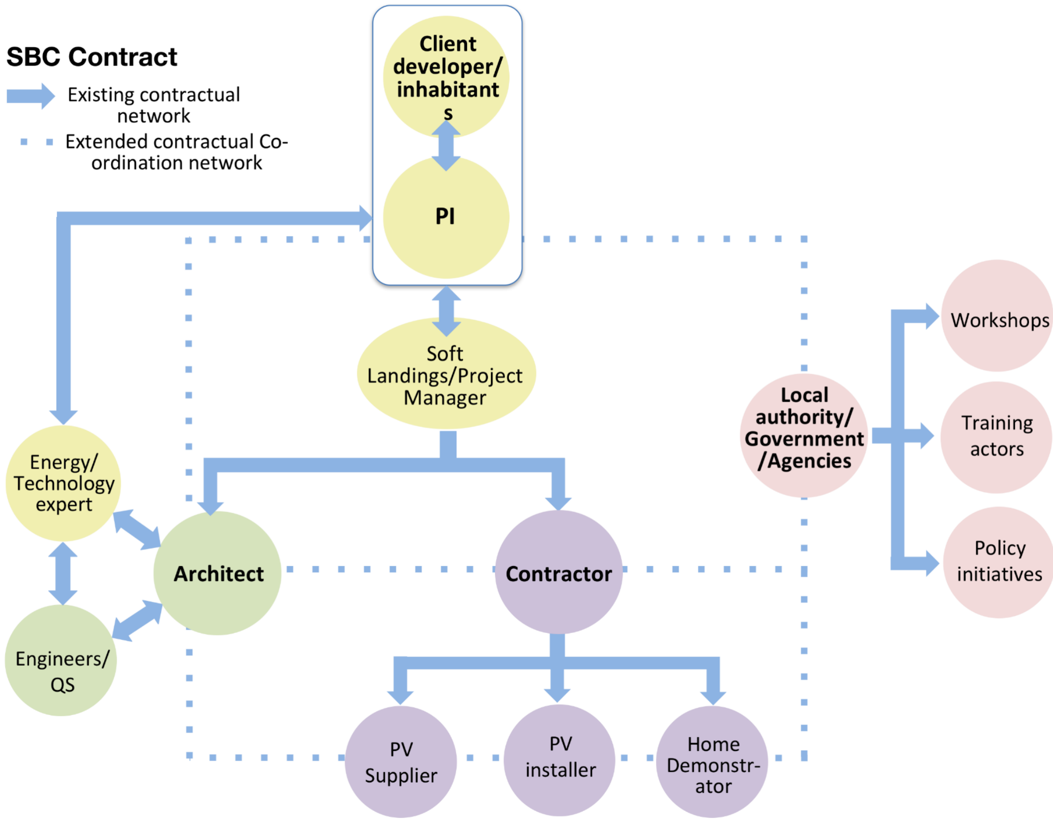


Figure 8.13: Contractual and co-ordination extended networks - (SBC) contract

8.8 Sub-conclusion

In this chapter, fragmentation analysis was introduced as a way for further examining actors' agency, power and integration/ disintegration in different contractual networks, which can influence PV provisioning practices and outcomes as a result. This is to interpret *why* there are differences in PV governance networks in the presented case studies – a key finding in chapter seven - by understanding how power, as an effect of the performances of practices, is variously distributed and transformed between PV provisioning actors in the various contractual networks. This chapter also examined the role of wider and extended governance actors and networks, such as national government policy, in improving the agency and power of PV provisioning actors and their integration in different contractual networks, which in turn influence PV provisioning practices and the outcomes in homes as a result. In this chapter, the boundary of contracts is opened up by including new actors and roles in the wider network, and new extended networks and arrangements are suggested. A number of recommendations will be also formalised in chapter 10 and Appendix 11, which is based on the findings of this chapter.

Two types of fragmentation: *Entities* and *Processes*, were identified and discussed in this chapter as a framework to examine the various disintegrations between the PV provisioning actors in two types of national building construction contracts: Standard Building Construction (SBC) and Design & Build (DB) contracts across the PC and NPC case studies presented in this thesis. This revealed that fragmentation in the *Entities* was more frequent in the SBC case studies, while fragmentation in the *Processes* was more frequent in the DB case studies. However, both types of fragmentation had negative influences on the PV provisioning networks and practices.

The findings here also show that PV provisioning networks are perceived by national policy makers and professionals as a simple 'Black box' network where the outputs can be automatically and unquestioningly anticipated from the inputs. This perception clearly undermines the understanding that the role of the actors and their relations within networks can change the PV outputs *even if the inputs are virtually the same* (e.g. the PV system design and integration into homes, and the subsequent energy performance, varied significantly due to the variation in the architects' role and connections with the other actors in the different PV networks' contracts). In one PC case study (C), the planned actor-network was maintained by the effective knowledge and action of the PI, despite the changes brought about by the grant body consultant. Changes have, however, undermined the effective operation of the PV provisioning process itself in the other PC case studies, as explained in this chapter. In the NPC case studies, the clients maintained a powerful association of actors in the network, but only in the preparation stage, due to their withdrawal from the PV network in the other stages, changing the whole actor-network and outcomes as a result. Opening this *Black Box*, therefore, is vital to further investigate the role of specific contractual networks and arrangements of actors, and the extended network in enabling/disabling good relations and integrations between the PV actors, their agency and practices, and PV outcomes (design and performance) as a result, which can in help to close the energy performance gap for PV systems and reduce carbon emissions as a result.

The key fragmentation occurring in the *Process* of PV provisioning across all the PC and NPC case studies and contracts concerned the poor participation of the client developer/inhabitants and the project manager in the design and installation stage of PV provisioning, and the poor participation of the architect in the main contract. However, in the PC case studies B and C, which had PV systems retrofitted after the main contract has finished, the architect would not be expected to be involved. This fragmentation in the *Process* led to a significant fragmentation in the *Entities* related to the provisioning of PV systems in the presented case studies, resulting in poor PV practices.

During the preparation stage, the most critical disintegration occurred in the PC case studies between the architect and the PV installer due to the client inhabitants not making decision to install PV systems from the outset (D) and the PI disabling this integration (A). In the NPC cases studies the most critical disintegration occurred when the client developer (the controlling actor in this stage) disabled any early connection between the architect and the installer (in all NPC case studies), despite both actors being previously enrolled in the building construction network. In contrast, during the design stage, the most critical disintegration in the PC case studies occurred between the client inhabitants and the PV installer due to the PIs disconnecting themselves from the PV provisioning network in this stage, thus disconnecting the inhabitants also, and changing their normal intermediary role to more governing and mediating role. In the NPC case studies, the most critical disintegration occurred between the client developer and the contractor, due to the DB contract which discouraged the client from actively participating in the detailed design aspects of home technologies.

In the inhabitant induction during the handover stage, a critical disintegration occurred in the NPC case studies between the PV installer and the home demonstrator due to sequential contractual involvements of actors to execute the projects' tasks in stages. In the PC case studies, a disintegration took place between the inhabitants and the installer/developer due to the PIs mediating between them.

All of the above fragmentation has been shown in this thesis to have a significant impact on the ability of inhabitants to practice their PV systems effectively in terms of reducing carbon emissions through managing their energy loads and other actions, and can be related to the different types of contracts as an extended network influence.

A significant difference in the actor-networks pattern operating across the PC and NPC cases studies was also identified in relation to two different national contract types, which influenced the integration between the PV provisioning actors and the distribution of the power in each set of networks as a result. This is attributed to the differences in the controlling actors' knowledge and agency in terms of integrating the construction team actors together to govern the PV systems, and the two very different contract types used to deliver the case studies. The client developer's controlling actor in the NPC case studies (E, F) was more successful than the client PIs controlling actor in the PC case studies (A, B, D) in enrolling the architect and the contractor in his network, to collectively govern the PV system during the early stage of building construction process in an integrated way. The PIs in two PC case studies (A, D) out of four disabled this powerful dialogue by meeting the architect, the energy expert and the contractor separately, and assuming that all actors had equal knowledge and understanding about PV systems, which they did not. This is because both PIs and architects are not trained generally to consider all the aspects and details that make the design of PV installations more successful, which is a wider issue influencing the contractual networks that require new actors and arrangements in the extended PV networks.

However, as part of a wider issue of networks affecting provisioning agency, the national DB contract as currently set out, and used in case studies A, E, F, *also* disintegrates the power of the architect during the construction works and after all the construction drawings are completed, thus disrupting the continuous actor-network that should remain in place during the briefing, design and installation stages. The DB contract also disconnects the power of the client developer/PI (PC and NPC case studies) during the design stage, which critically disconnects the client from the decisions concerned with the PV system affordance and context. These decisions are thus mainly dominated by the contractor and the PV installer. Further disintegration in Process, resulting from the DB contract concerned the critical disconnection of the PV installer from the PV discussions during the preparation stage. All this suggests the need to involve new actors and roles, and new arrangements in the extended contractual DB network.

Significantly, the fragmentation analysis also showed that an actor-network can also be changed if an actor in the network (the PI in the SBC case study D) changes his own role and agency (from connecting the actors to a more singular governance role), thus shifting the power of the architect as a controlling actor and disconnecting him from the PV installer in the design stages. The PI, in changing his own role in the both types of contract, also changed the distribution of power in terms of shifting the power from the client inhabitants to the PI, disintegrating the inhabitants from the other construction team as a result, which has a major impact on the outcomes for this project. This suggests that the involvement of new actors and polices (e.g. community housing network), in the extended network is needed to define the detailed role of the PIs. Janda et al. (2014: 913), however, interestingly suggests that building professionals can empower themselves as ‘middling-out actors’ (mediators) rather than intermediaries, and further suggests that these actors take on a more dynamic role and relations with other actors in the network rather than “reacting blindly to policy push from the top-down and market pull from bottom-up” – something which has been demonstrated in this chapter as needing careful handling if it is to be successful.

Redefining the PV provisioning process, by changing it from a *sequential* process to a *collaborative* process between the different provisioning actors is necessary to reduce the impact of contractual and statutory constraints as a wider issue of networks and arrangements (Hamza and Greenwood, 2007) by forming a more robust extended PV actor-network and practices, and to ensure effective feedback (Nicolini et al., 2001). However, in reality, collaborations that are non-hierarchical are very rare in a construction network, and so there is almost always an imbalanced power relationship.

A new and currently missing ‘PV championing’ actor role has been highlighted in this chapter as necessary in the contractual network to ensure a strong collaboration between the various PV actors in housing, and a powerful co-ordination and translation of the project’s targets and actors’ roles between the key actors in the different stages, particularly in Type 2&3 DB projects. This chapter has, therefore proposed two new extended network models for the contractual stage of PV provisioning (Figures 8.12 and 8.13) which show how all of this could work by enrolling the wider role of local authorities, professional institutions (e.g. universities, community housing network, energy trusts), energy providers and other governmental organisations. This is to provide effective training related to PV provisioning and practices, future proofing design strategies, feedback communication and translation, and to enable the involvement of another missing new ‘champion’ actor (e.g. a Soft Landing strategy and Soft Landing champion) within the extended network, but with a critical question remains concerning who is responsible to cover this additional cost. However, all these require the need for national policy changes related to PV training as requirement and the inclusion of other actors described above.

Finally, this chapter has built on previous chapters to show how the use of fragmentation analysis can provide a powerful contribution towards the understanding of specific situations of networks and effective arrangements of actors when governing PV systems, as a process defined by the relations and tensions between the different actors involved in a specific contractual PV network. However, the findings in chapter six show a significant variation in inhabitants' PV system practices and overall energy consumption even when performed within similar governance, actors and network during any operation (e.g. living in the same community case study). The next chapter, therefore, uses the elements of Practice theory identified in chapter three as a theoretical framework to examine the more *detailed* aspects of inhabitant's engagement with their PV system within the social and physical details of the context in which the networks are operating. This is in turn to understand what particularly shapes inhabitants' PV practices in relation to four particular elements of Practice theory (technology, know-how, rules and engagement) according to Gram-Hanssen (2010). This can help to further understand how the *critical* role of non-humans (e.g. materiality, rules and polices) can shape PV practices in a more detail and *in relation* to inhabitants' embodied know how and engagement (Gram-Hanssen, 2018) – the 4th & 5th objectives of the thesis. A detailed examination of how the participatory role of inhabitants (PIs) in the PV provisioning process influenced their practice of the system, through the same Practice theory lens, finally helps to more deeply understand the impact of provisioning practices on inhabitant practices.

CHAPTER NINE: GOVERNANCE AND PRACTICE: TECHNOLOGY, KNOW-HOW, RULES, AND ENGAGEMENT

9.1 Introduction

In chapter eight, the analysis of actors and networks extended beyond the boundary of contract and building professionals to address broader issues that can influence actors' agency, power and integration into a wider PV network and to identify more effective wider networks and arrangements for governing PV systems. This effectively defined how the PV system 'technology' aspect of Gram-Hanssen's definition of a Practice (2010) was envisioned and inscribed by the PV provisioning team, through 'institutional knowledge' and 'explicit rules' subsequently impacting inhabitants' practices during occupation. This chapter examines inhabitants as independent actors with social norms and intentions (Gad and Jensen, 2010), taking inhabitants' embodied know-how and engagement, as well as the role of PV technology affordance and integration into homes, and explicit rules into account when examining inhabitants' current practices of their PV systems. Once this is done, it may be possible to co-produce guidance that is more relevant for inhabitants in terms of their own practices, as well as further guidance and recommendations for other provisioning actors based on inhabitants needs according to their own practices.

This chapter more deeply understands inhabitants' practices of PV systems by revealing how they are shaped and related in different social and physical *contexts* through Gram-Hanssen's Practice theory lens (Gram-Hanssen, 2010, 2011). For example, having know-how, as a powerful intermediary to enact a practice (see 7.3.2), might be insufficient if the 'context' of the practice (both physical and social) does not enable the skilled person to perform the practice. The theory of Practice applied here also helps to understand the detailed role of technology affordance and integration into homes within the context of know-how, rules and engagements - an aspect not fully integrated in the previous chapters.

This thesis follows Gram-Hanssen's redefinition of Practice theory (Gram-Hanssen, 2011) for two key reasons: first, materiality (e.g. PV affordance) is seen here as a central element of practices instead of being only situated within a context of different practices, so that analysis can show not only how the affordances of a PV system can prefigure inhabitants' action in certain ways, but more significantly, it can identify these configurations in relation to the other elements of a practice (relational thinking) – a key ontological concept in Practice theory. Understanding materials as a Practice theory element can also help to see how materiality can change through practices drawing on users' know-how, habits, rules and engagements. Schatzki's approach of looking at materiality as a consequence of practices is a powerful approach in terms of understanding the role of various PV provisioning actors in shaping inhabitants' actions and practices through their construction of the system materiality and integration into homes, as discussed in chapters seven and eight in relation to ANT's theoretical approach (Reckwitz, 2002a). Secondly, identifying practices using Gram-Hanssen's four elements also helps to better explore the role of national polices, standards (explicit regulation), and established technical knowledge, as wider 'rules' in shaping the PV inhabitants' practice of the system independently from the role of implicit practical know-how and embodied habits (implicit rules).

The two different types of housing provisioning in the case studies are specifically compared in this chapter to now also show how the *governance* role of PC inhabitants in the PV provisioning process, influences their practice of PV system compared to non-governance role of the NPC inhabitants. This is done by revealing whether, or not, the PI governance in the provisioning stage of PV system helped to improve the four elements of provisioning practice discussed previously, and inhabitants' subsequent practices during occupancy.

9.2 Technology: material arrangements

The role of inhabitants in deciding the material properties and affordances of the PV systems with other provisioning team actors and the influence of these affordances on inhabitants' practices of the systems were initially discussed in chapter seven. However, the role of Gram-Hanssen's concept of material arrangements in homes in shaping inhabitants' practice of their PV systems and shaping their energy consumption everyday practice has not been yet discussed. This section therefore discusses how the physical location and integration of the PV appliances into homes can "prefigure" inhabitants' energy efficiency practices of their PV appliances during occupancy. Prefiguring "makes some actions easier or harder, shorter or longer, acceptable or not, as compared with other actions" (Schatzki, 2002: 225). In many ways, 'prefiguring' can be seen as a more complex form of combined affordances.

As "…material arrangements are themselves made, reproduced and transformed through, and as a part of, happening practices" (Shove and Walker, 2014: 51), the practice of locating PV appliances by the provisioning team (in both the PC and the NPC case studies), particularly the inverters and the panels, often includes aesthetic and functional considerations beside technical requirements of the system. As one PI stated, the team had provisioned the inverter and meter in the cellar "… because we did not want to lose any useful space to these devices. The cellar is not a very useful space and is invisible" (PI, B2). When it comes to inhabitants' lack of engagement with the system appliances, the video tours showed that this invisible location of the inverter had a very negative influence on inhabitants' understanding of their PV performance in different conditions by observing the display screen in their inverter and to see whether, or not their system is working. More significantly, the invisible location of the inverter also discouraged inhabitants to strictly match their energy loads and to achieve the potential saving as a result:

> "… we want to have like a remote reader … now, if I want to see how much our system is generating, I have to walk down to the cellar, where other people, outside our community, have a little screen which is maybe set in the kitchen and it tells them, like today or at the moment, the system is producing for example 200kW … and I think if we had that in the kitchen, I would be more interested to look at it every day, or every hour, and then that would affect my usage behaviour. We are aware that quite a lot of our energy generation goes back to the grid. It is an issue" (B3)

By understanding how much KW the system is producing during the day, inhabitants can match their energy loads by "changing the time of using washing machine or the kettle" (B3) and reducing the imported energy from the grid as a result. The question of where inhabitants spend the longest time in their house during the day (e.g. kitchen, lounge) is also important in terms of where and how the energy generation display screens and smart energy monitors should be integrated into the home as this positioning prefigures the inhabitants' later engagement with the system appliances and energy consumption habit formation, and sustains their practices either negatively or positively as a result. Another inhabitant claimed that understanding PV generation patterns by looking at the inverter display screen did not help them to match their energy loads individually by shifting the time of using heaters and lights:

> "… It is messy now. I can tell you that the PV adds units all the time, but the actual meter usage is not shown inside. In practice, it is just not practicable. It would be easier to understand what is happening at the moment, and to answer your question about whether the PV system is producing enough electricity when using a heater or a light in different weather conditions" (A2)

For such information to become useful, inhabitant A2 wanted the technology to relate to his own energy consumption practices. Therefore, he suggested locating the inverter or even the PV generation meter beside the energy consumption meter. One inhabitant in NPC case study F, pointed out that his engagement with the inverter was highly constrained by the overly high location of the inverter (9 feet high up) in the balcony area (see 6.3.2.3) according to his quote in section 6.3.2.3.

Three inhabitants in the case study A struggled to benchmark their PV performance because as one said: "I have nothing to compare with it, so I had no expectations about specific details or performance" (A2). By contrast, none of the inhabitants in case studies B – D referred to this problem during the interviews due to contractually (D) and habitually (B, C) monitoring their PV and energy performance collectively and sharing energy graphs for all houses (see 7.3.2.1). Where no collective monitoring took place in all the NPC case studies, or no shared energy generation and consumption graphs (A) were produced, inhabitant C3 (a housing developer) actually suggested a new method for arranging the identical inverters in a housing block, which would enable inhabitants to compare and benchmark their PV performance:

> "In a new building, I would have put the inverters outside the main door of each apartment, so that any inhabitant can observe and check the inverters of everybody else and compare if they are producing the same amount of energy" (C3)

Finally, the influence of the arrangements of PV panels/tiles on the roofs varied across the different case studies. In case studies A, B, D and E, the arrangements negatively affected inhabitants' practice of cleaning their dirty panels and to see whether the panels need cleaning or not due to locating them in inaccessible and invisible places. More significantly, it negatively affected the system performance in the case studies B – D due to locating the panels in the roof area overshaded by trees (C, D) or chimneys (B) (see 7.2.3.1) (predominant intermediaries). These are an example of how the decision on where to locate the PV panels by the provisioning team can lead to excessive problems in relation to the system performance and inhabitants' engagement with the PV appliances.

In general, the PV system material arrangements tended to affect the PC and NPC groups in similar ways due to inappropriate governance by the provisioning team of the system integration into homes, with significant negative consequences in terms of inhabitants' engagement with their 'invisible' PV appliances. This affected their desire and capacity to change their energy consumption practices (e.g. the use of washing machine, kettle, heater and light) to match their energy loads as a result. However, the PC groups were more able than the NPC groups to positively manage their energy loads to reduce carbon emissions. This was mainly due to their ability to *collectively* practice monitoring their PV and energy performance which provided indirect feedback for inhabitants to benchmark their PV and energy performance and to use their energy efficiently, particularly for those groups that disseminated this collective monitoring data among all the community members. Poor governance of integrating PV panels into homes also had negative impacts on effective PV performance and inhabitants' maintenance practice in *both* PC and NPC groups.

9.3 Implicit rules: know-how and habits

Integrating PV systems into inhabitants' everyday life depends on whether the system is designed as something which "does what it does" (A2), or it is designed for inhabitants to engage with it, in order to use their energy generated efficiently. This is clearly related to the *meaning* that the inhabitants obtain through their governance of the system provisioning, which will be discussed in the next section, but is also related to the inhabitants' *practical* know-how.

Allowing the installer or the other demonstrators to introduce the system to inhabitants as a routine is ideal, but does not always happen. In reality, the failure to provide inhabitants with a proper handover for their technology including PV system was highlighted as a key problem in both the PC and NPC housing groups (see 6.2.2.1, 6.3.2.1) leaving some inhabitants trying to familiarise themselves with the products as best they could, while others simply ignored it. More specifically, the lack of hands-on practice opportunities for inhabitants during the induction process in both groups, considerably reduced the inhabitants' subsequent engagement with the PV appliances that required some know-how to interact with the affordances offered. This resulted in a *variation* in terms of PV practices, particularly trying out the built-in display screens in the inverter and smart energy monitor, even between inhabitants in the same case study, who had identical PV affordances and arrangements in their homes. However, the findings also show that because the PC inhabitants participated in the system design and provisioning stage, they improved their know-how and their ability to engage with the system affordances as a result, compared to the NPC inhabitants who had poor engagement at this stage.

The video tours revealed that all the PIs in the PC cases studies with a display screen in their inverters (A, B), were aware of how to engage with their inverters to help them understand the performance of their PV system in different times and conditions. Two inhabitants in projects A and B were also aware of how to engage with their inverters' display screen which was mainly acquired from enacting the actual practice. However, the other community members interviewed in this thesis commented that they did not know how to engage with them. Inhabitant A1 replied when she was asked about the location of her inverter outside her flat: "Yes, that is fine, because I don't have to check it for anything. I don't know what is for or how to use it".

This was because this know-how was limited to the PIs who did not *transfer* this effectively to other community members – a vital omission. This weakness of the PIs is due to them not being trained to ensure the transformations of know-how and PV knowledge to other members which can help to engage with PV appliances and sustain positive PV practices, and promote carbon reduction by encouraging energy demand management. In case study C, however, the PI effectively transferred his know-how in relation to effective maintenance practices to other community members and this ensured regular cleaning of all the PV panels. The inhabitants' limited know-how can be also ascribed to the limited discussions that took place between the inhabitants, including the PIs, in case studies A, D in relation to how and why to engage with PV appliances and to use energy efficiently despite having good graphs related to their energy generation and consumption. Following the theoretical discussion on know-how as a combination between technology and user (Shove et al., 2012), the situation can be seen more contextually as a combination between the PV system and inhabitants performing the practice *together* in their real *context*, and not just as a know-how, habit or understanding that an inhabitant alone has to possess. The findings of the video tours show that the know-how of two inhabitants, who tried to strictly match their energy loads by engaging with their inverter display screen, was highly restricted by the poor integration of the inverter into their homes, despite them knowing how to engage with it (see 7.3.2.1) (location intermediary)

(Figure 9.1). Whether PV appliances are easy or difficult to engage with depends on the level of integration of the technology in the home which prefigures inhabitants' action as discussed above. These findings also support the relational thinking concept of Practice theory in terms of understanding the elements of a practice (e.g. know-how) in their sociotechnical context (e.g. technology arrangements and engagement).

Figure 9.1: Poor location of the inverter

In case study A, all the inhabitants knew how to engage with their PV and main energy meters (taking meter readings and observing if their system is generating energy), but many of them decided not to individually monitor their energy production and consumption, based on advice from their PI, who acted as mediator by telling inhabitants that monitoring their energy generation and consumption would not dramatically change their energy consumption practices. His assumption was based on the general 'institutional' knowledge and meaning in relation to PV systems, which was acquired from the other provisioning team through his participation in the PV provisioning process, and from his short-term individual practice of PV system (see 7.3.1). This transfer of 'institutional' knowledge significantly limited the engagement of the other community members with their PV meter to actively match their energy loads, which then confined them to applying for the FIT only. This resulted in a large amount of their energy generation being exported to the main grid (Figure 9.9), given that inhabitants do not have any means to store their surplus energy (e.g. individual battery, communal battery) and using it latter.

By contrast, none of the inhabitants properly engaged with their inverter in the NPC case studies due to lack of know-how. Only one inhabitant simply checked whether or not there was anything preventing the inverter from working properly:

> "I have been there few times to see the devices working and to check if there is something affecting the devices from working properly, such as dust… There are four buttons here. (Interviewer: Have you used them before?) No. I don't know how to use them" (E3)

The environmental ethics of this inhabitant encouraged him to take the risk of visiting the inaccessible and unsafe location of his inverter in the attic (Figure 6.23). However, due to his lack of tacit know- how, he could not fully engage with the affordance provided in the inverter's display screen in terms of monitoring, downloading and understanding his energy generation patterns which would have helped him to strictly manage his energy loads and to reduce carbon emissions. Similarly, the effectiveness of the smart energy monitor provided in the CSH-6 houses in the case study E (NPC) was undermined by the lack of inhabitant know-how (Figure 9.2): "I don't interact with it because I don't know much about its application" (Video tour E2).

Figure 9.2: The affordance offered in the smart energy monitor (inhabitant E2)

Again, this was due to the insufficient transfer of know-how to inhabitants by the contractor, who missed the opportunity to influence inhabitants' positive active energy management practices to reduce carbon emissions. By contrast, another inhabitant in the same case study, with a similar monitoring device, had previously learnt about the monitoring devices from the media and from his previous home. He was highly satisfied with using the device because:

> "It is a nice device that could help you to get a sort of idea about how much your system is producing energy and how much of the electricity you are using at the same time in a very visual way and in numbers … By pressing the bottoms here, you could know how much kW you are sending to the grid and how much you are earning" (E3)

The environmental manager who was responsible for monitoring the energy efficiency of the CSH-6 homes in the case study E claimed: "We were happy that the Code 6 was using less energy but not so much less as to justify the additional cost" (E5).

To sum up: in order to achieve the potential benefit of the installed technologies, inhabitants need to have appropriate know-how in terms of engaging with these technologies. In both types of the case studies, there was a lack of inhabitant know-how in terms of engaging with their inverters' display screen and smart energy monitors. This reduced their engagement and the potential to actively match their energy loads to reduce carbon emissions as a result.

All inhabitants in case study C and two inhabitants in case study F, who were asked by the installer and the developer respectively to check and clean their PV panels if needed, were also told how to clean them and who was responsible for cleaning them: "They (author: the developer) just said to wash them using water and a normal cleaner and that it is our responsibility" (F1). Therefore, this know-how and habit also needs to be articulated and transferred by the provisioning team through 'technical rules' or through 'hands-on' practice in order not to leave the inhabitants unclear about how to enact this cleaning practice which can in turn help to sustain the positive PV practices. As one inhabitant commented: "One issue that has come up is - we were unsure about how often we need to clean them and how to clean them if needed" (A3).

This section has shown the vital role that PI governance during the provisioning process can play in improving inhabitants' know-how and ability to engage with the affordances provided in their inverters and energy monitoring devices. This particularly helped many of them to be more literate of their energy generation and consumption patterns and to actively match their energy loads and to sustain PV positive practices in relation to the devices mentioned above. Importantly, this section has also revealed that the PIs in three PC case studies (A, B, D) were not trained to *transfer* their effective know-how to the other community members during occupancy. This means that they missed the opportunity to influence inhabitants' positive energy management practices to reduce carbon emissions. By contrast, the majority of inhabitants in the NPC case studies were disengaged with their PV appliances (inverter, monitoring devices) due to a lack of know-how as well as other influences. This means that they were not able to change their energy consumption behaviour very much to actively match with what they have generated, given that both PC and NPC inhabitants were not empowered to manage their energy consumption using additional technologies (e.g. batteries, smart controls and appliances, etc.).

9.4 Explicit rules: policies and technical knowledge

In chapter seven, policies and standards (FIT, CSH), as explicit 'institutional rules' in the wider governance network, were discussed as critical actors in shaping inhabitants' practice of PV systems. This section further discusses the impact of wider rules, now as a key element of practice, and explores the stability of PV practices over time as a result of any changes to the rules.

Three further explicit rules that influenced inhabitant practice of their own PV systems were identified from coding the interview and video tour data with inhabitants: 'community', 'technical knowledge' and 'sociocultural' rules. Gram-Hanssen's division of Shove's practice element of competence into two distinct elements: explicit and implicit rules (Gram-Hanssen, 2010/2011) enables a powerful categorisation and discussion in terms of the influence of sociocultural rules, which are often inaccurately categorised under the competence element, or under other elements of practice (e.g. meaning).

The large variation in rules and polices concerning the PV systems in the two kinds of housing provisioning, resulted in a significant difference in inhabitants' engagement with their PV system and energy load management as a result. For example, the different requirements of grant bodies in terms of enabling their beneficiaries to claim the FIT, determined the type and degree of inhabitants' engagement with monitoring their energy generation and consumption patterns, and changing their energy consumption behaviour consequently to match their energy loads. These institutional rules supported the PCs' beneficiaries to monitor their energy loads and to claim the FIT, but did not allow the NPCs' beneficiaries to claim the FIT (see 7.3.1). This is a significant finding that needs to be carefully considered as NPC housing forms the majority of housing provision in the UK.

In term of an individual community, inhabitants' routine engagement with their PV meter apparently changed significantly over time. This was because inhabitants in case study D stated that they had *stopped* monitoring and recording their energy generation and consumption readings, as well as the exported energy to the main grid, *collectively* and *habitually,* after the completion of their contract with the grant body, ended the institutional rule requiring monitoring. This was despite all the monitoring equipment remaining still in place when the contract ended. They were, however, still aware of the importance of conducting a collective monitoring process in terms of understanding their PV and energy performance and had the know how to do so. As a result, some inhabitants stated that they continued to monitor their energy generation and consumption patterns *individually* and irregularly, while others stated that they had stopped monitoring their system altogether. Without taking regular PV energy generation readings or observing the PV meter and the inverter, inhabitants were not be able to understand whether their system was producing energy or not and/or to compare their PV and overall energy performance with others. Inhabitant D2 claimed

> "But I know that there is a big gap, it is massive gap (author: in the energy performance between community members) … But anyway, we don't know now … because we stopped monitoring our energy generation and production collectively"

The same inhabitant also mentioned that taking regular meter readings encouraged him to change some energy consumption practice by "using energy more during the day such as having showers during the day, changing the light bulbs to the economy one … and using the communal washing machine" (D2).

Other energy consumption practice changes are illustrated in Figure 6.13.

By contrast, all inhabitants in the case study C stated that they had continued monitoring their PV systems collectively despite the completion of their contract and associated rule requirement with the grant body. Inhabitants' understanding of their PV system as a technology that can impact their energy consumption was the key reason for their not changing their habit.

The above findings show that an institutional rule cannot be relied on alone to ensure the stability of a PV practice and energy consumption reduction over time as a habit; other elements such as positive meanings and goals (e.g. reduced energy consumption) (section 9.5.2), also need to be sustained and developed continuously to sustain engagement (Buchanan et al., 2015, Friis and Christensen, 2016).

In terms of the influence of community rules on other practices, inhabitants in case studies (A and B) disengaged from learning about the different aspects about their PV operation and practice due to specific communal arrangements as an explicit 'rule'. One inhabitant ascribed her own low motivation to learning as being due to:

> "… … other people using the same system, I do not have to worry about it because I have always got somebody I can go and ask. So, from that point of view, I suppose if I was in my own home or just had one neighbour, I have to find out and understand everything about my system. I'm a bit lazy now" (A4)

She trusted that she would be told by another community member if she wants to understand any specific issue about the system. However, the video tour revealed that she had no idea about how to engage with her own inverter's display screen, which meant that she had no idea about how much energy her PV system was producing at any specific time, which may have encouraged her to match her energy loads. The question here is: how could she know that observing her inverter regularly would help her to effectively match her energy loads, given that there was no effective learning comes from the PV provisioning actors during the PV provisioning stage? One way to incentivise inhabitants to effectively discuss how to develop their PV practices could be through written bullet points in their HUG as technical rules about what is important to know about their system and how to engage with it effectively, in the first place.

The video tours findings also show how community rules can be broken according to particular PV affordances and context. For example, the rule of using electrical appliances during the day to load match was disobeyed over time due to inhabitants changing their energy provider after a year of their PV installations. As one inhabitant commented:

> "So, at that time (author comment: directly after installing PV systems), we were very strictly using our gas kettle at night and electric kettle during the day when we were generating our energy from the system. After that

> we changed our provider by buying our electricity from a green provider. Now, many of us do not follow the rules … we felt that it was less of an issue (authors comment: matching their energy loads), because in terms of global impact, it did not make much difference" (B1)

In case study C, the strict rule of the community, in terms of collectively and routinely monitoring their PV performance by downloading their PV generation readings from the monitoring logger, also stopped in three houses as a result of the failure of one of the monitoring loggers, and the incompatibility of the new loggers in the market with the old monitoring system in these homes. In the same case study, the PV panels of the Sustainable Resource Centre (SRC) were cleaned irregularly, despite the community having a rule to clean all their PV panels quarterly. The PV context did not afford them to do so, due to their inaccessible location.

> "I clean all of those, quarterly (Author: PV panels for the community houses). We shared the works and this is my responsibility. (Author: who is cleaning the panels for the SRC PV system?) Another member using a ladder, but irregularly" (C3)

To ensure sustainability of positive PV practices and low carbon targets, easy access and maintenance over time is required. Inhabitants' practice of their PV appliances relates to their practical knowledge as discussed above, but it also relates more specifically to the level of technical knowledge as rules that the inhabitants obtained from the provided documents, and from the circulating collective rules and know-how among inhabitants. Their practice is also related to how this technical knowledge was written and transferred to inhabitants by the provisioning team through the non-human HUG intermediary and influenced their practice as a result (chapter seven). In comparison to the major influence of practical knowledge on inhabitants' PV and energy consumption practices, the technical documents as an explicit set of rules had a little influence on sustaining inhabitants' engagement with their PV appliances due to poor provision and transformations of this knowledge to inhabitants (see 6.2.2.1).

By contrast, the most negative affordance scenario of inhabitants' lacking PV technical knowledge concerned their limited awareness of the significance of keeping the inverter well ventilated to increase the performance of the PV system. Only one inhabitant (A) in both the PC and NPC case studies was aware of that, and 4 inhabitants in the both types of case studies actually *covered* their inverter with clothing (Figures 9.1&9.3). This point concerning a formal ventilation rule needs to be made explicit for inhabitants, not only in the complex technical documents which inhabitants habitually do not read, but more significantly in the HUG document and through know-how transfer between the PIs and inhabitants in the PC case studies. This point also needs to be made explicit to an external energy expert actor (suggested in chapter eight) during occupancy stage in the NPC case studies. Again, this is to ensure the sustainability of positive routine engagement of inhabitants with the display screen of their PV inverters in order to understand their PV energy generation, and to achieve the designed performance and energy efficiency targets from the system.

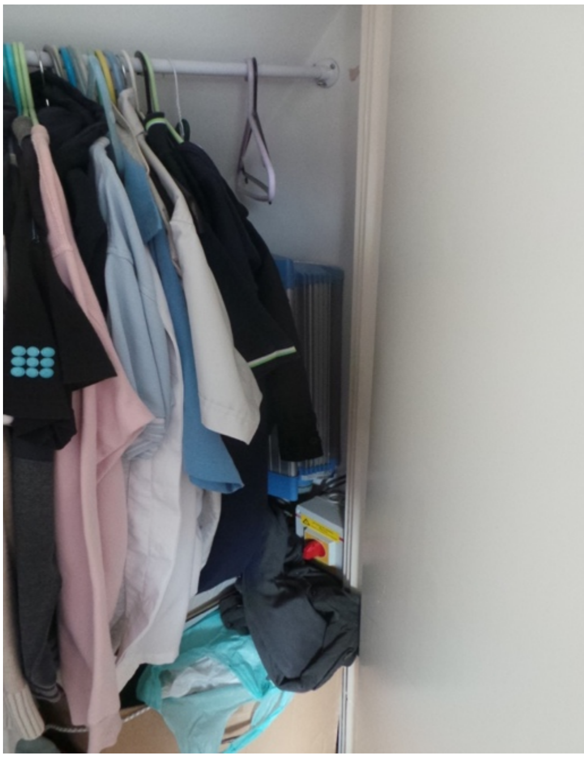


Figure 9.3: Inhabitants covering their inverters with clothes (E)

Insufficient technical knowledge relating to inhabitants, in both types of housing provisioning, also concerned the practice of cleaning their PV panels. For example, two inhabitants in the case studies D and E were completely unaware of the need to use a pressure washer to clean their inaccessible PV panels:

> "… cleaning the PV panels using a pressure washer, I don't have any expectation, because this is something completely new to us; we came to these as very naïve users. So, our expectations were very limited" (D1)

They did not clean their tiles/panels using a pressure washer despite the dramatic reduction in their energy generation, because they were told by other uninformed inhabitant that it might break the tiles. This informal and incorrect collective rule development and transformations is another significant drawback of the community housing approach in relation to inhabitant learning of their positive PV practices. The PV documents did not have any rules concerning how and when to clean the PV panels, assuming that PV panels don't need cleaning (see 7.2.1.3). Without having this technical knowledge set out as an explicit rule, people simply build their understanding on their cultural norms, perceiving glass material as something fragile and not to be power-washed. To sustain the practice of cleaning PV panels in order to ensure the designed PV performance, inhabitants need to be explicitly informed through technical rules that they can/cannot use a pressure washer to clean their inaccessible panels, in order to avoid the development and transformations of incorrect rules, particularly in the PC housing case studies.

One key *sociocultural*[28] rule that sustained inhabitants' engagement with their PV appliances (e.g. monitoring their energy performance) to reduce their energy consumption from the grid, and the overall negative impacts on the environment was related to minimising resource use:

> "The key one (author comment: energy saving influence) is from my working with VSO (Voluntary Services Overseas) in the Namibia. So, working there (author comment: Namibia) helps me to see how people could live in much lower energy resources than we do here. That was the biggest influences to install PV system and to reduce energy use from the grid" (PI, C1)

Another *sociocultural* rule indirectly led one inhabitant to monitor her energy performance by taking daily energy generation and consumption readings in order to reduce the imported electricity from the grid due to:

> "… a family influence because my father was a conservationist. I was aware from the young age about the effect role we have on the

[28] The thesis is looking at very specific aspects of sociocultural rules as explicit rules, which is: how values are communicated between people as culture rules, rather than discussing them as hidden rules. The hidden sociocultural rules were discussed in the aesthetic section (see 9.6)

environment. So, I have always been aware of insulating my home, of not wasting energy at all" (A4)

However, this inhabitant stopped monitoring her energy performance after a short period of time due to the poor translation by the PI in her community of the meaning of PV systems, stating that PV systems don't really impact and change the practice of using energy (see 7.3.1). She also stopped monitoring her PV energy generation due to the poor integration of the inverter into her home. This demonstrates again that rules on their own are not sufficient to sustain inhabitants' engagement with their PV system. Such rules need to be envisioned more contextually within the other practice elements (e.g. meaning, material arrangements, know-how) to ensure the designed low carbon reductions.

The above findings show how institutional, community, technical knowledge and sociocultural rules affect PC and NPC in different ways. The institutional rules were very effective in *both* PC and NPC groups in terms of sustaining/hindering inhabitants' engagement with their PV appliances (PV meters and monitoring loggers), while community and sociotechnical rules were only effective in the PC groups in terms of sustaining positive PV and energy monitoring practices in the one hand, and discouraging some inhabitants from learning to engage with the system in the other hand. The findings also show how the community rules for PC can be broken by other factors (affordance, context) and thus reduce effective PV practice for reducing energy imported from the grid and carbon emissions as a result. By contrast, technical knowledge documents, as an explicit set of rules, were ineffective in terms of developing positive PV practices and energy consumption practice changes in both the PC and NPC case studies due to their poor inscription and translation to inhabitants by the provisioning team. Poor provisioning of PV documents led to some PC inhabitants to develop an informal technical rule concerning the maintenance of the PV system which was mainly based on inhabitants' perception of cultural norms.

9.5 Engagement

The last element that holds practices together is 'engagement' which will be discussed in three sub-sections: engagement via understanding, active meanings and load matching and transformative stages of engagement as discussed below.

9.5.1 Engagement via understanding

This section compares inhabitants' understanding of their PV system between the two types of housing provisioning (PC and NPC case studies), and whether or not, these understandings developed inhabitants' goals and engagement with the system appliances, and sustained their positive energy saving practices.

Understanding affordances is critical for inhabitants' engagement with their technologies according to "the perceived and actual properties of the thing" (Norman, 1999: 9), which governs the types of inhabitant engagement with their PV appliances. Understanding here is different from know-how discussed in the previous section, which know-how refers to the practical knowledge of a participant to do an action (saying and doing), while understanding refers only to the abstract knowledge of a participant to do an action (only saying).

The failure to demonstrate the PV technologies adequately during handover, and the insufficient provisioning of the HUG and other PV documents by the main contractor/installer (see 6.2.2.1 and 6.3.2.1) were the key barriers for all the inhabitants interviewed, in relation to their effective know-how, PV technical knowledge and engagement with their system appliances. However, the impacts of these barriers varied significantly between the two groups of housing provisioning. The findings reveal that PC inhabitants' participation in the PV provisioning stage significantly improved their understanding and consequential engagement with system components, affordance, the positive PV engagement, FIT requirements and registration process, and maintenance (Figure 9.4), as discussed below.

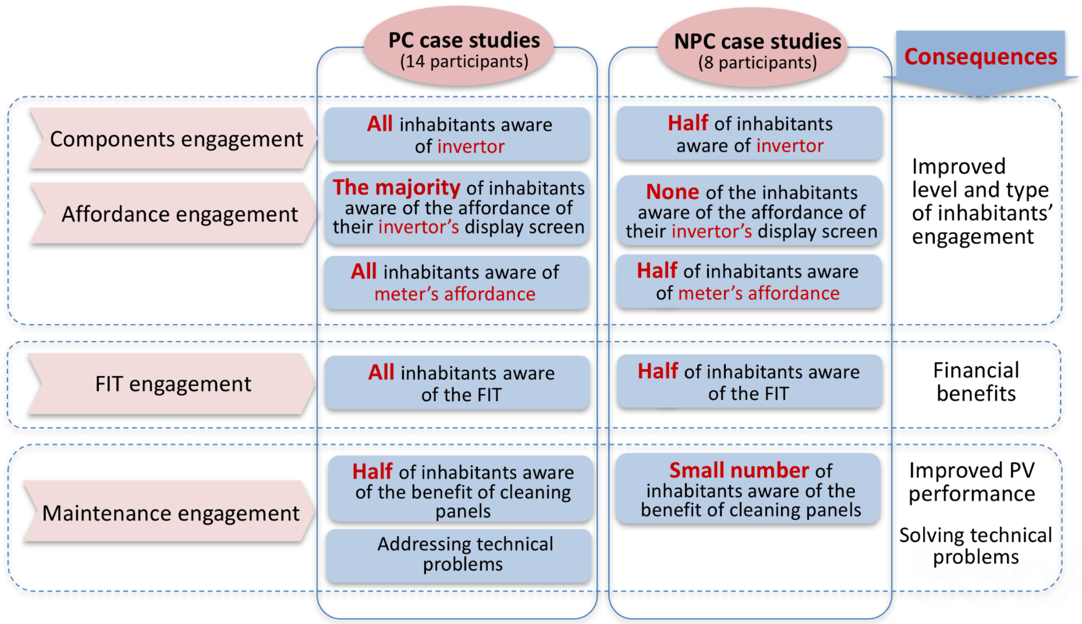


Figure 9.4: Inhabitants' relative understanding of their PV system

1) *Components and engagement*. The analysis shows that half of the interviewed inhabitants in the NPC case studies were completely unaware of their inverters in their home, which also means that they never engaged with them to understand their PV performance at different times and conditions in order to match their energy loads, due to them being located in a hidden place:

> "We know that our system has solar panels and a meter in the cupboard, but we have no idea about the inverter. Is it the device in the bath?" (E4)

By contrast, all the inhabitants in the PC case studies were aware of all their PV appliances, despite the failure in the home demonstration process and their hidden location (Figures 9.5&9.6). This means that PIs' governance of their PV system, and even limited, PIs' discussion with all community members in the PV provisioning stage, can increase the awareness of both the PIs and all other inhabitants of the system appliances and where they are installed in the houses, which is the key part of any engagement.

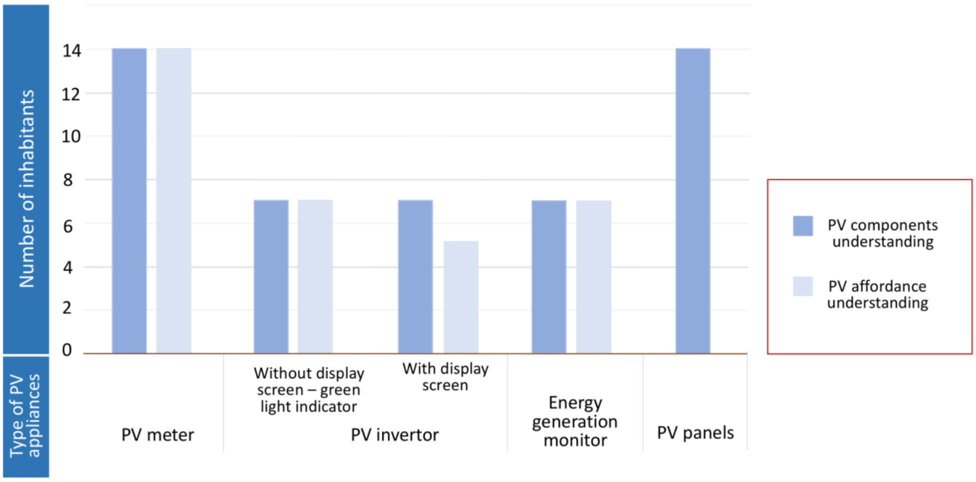


Figure 9.5: PV components and affordance understanding (PC Case Studies)

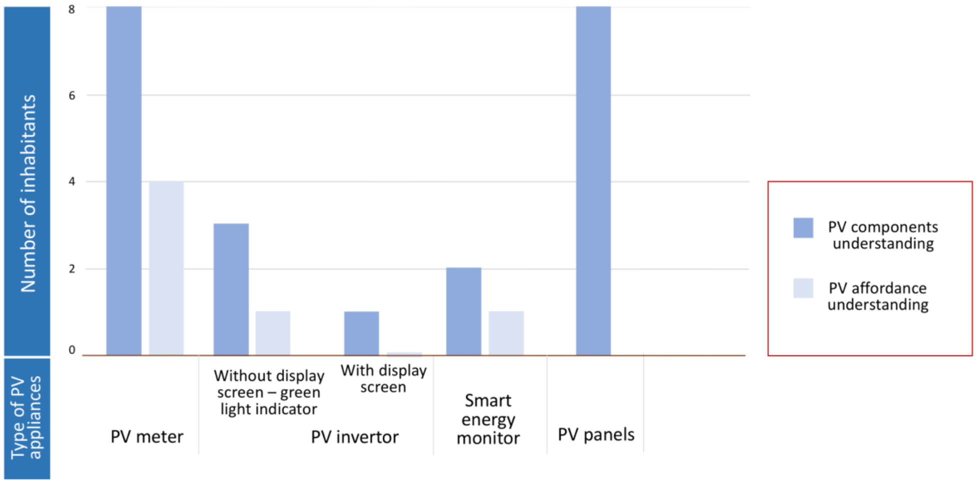


Figure 9.6: PV components and affordance understanding (NPC Case Studies

2) *Affordances and engagement.* A significant difference between the PC and NPC case studies was identified in terms of inhabitants' engagement with their system appliances, according to their understanding of the affordances offered in the PV appliances (e.g. inverter, PV meter, smart energy monitor) (Figures 9.5&9.6). In the PC case studies, all inhabitants were aware of the affordance and meaning of their meter, particularly the built-in green light indicator which shows that the system is generating energy when it is flashing, while only half of inhabitants were aware of in the NPC case studies when they were asked about the flashing light during the video tours: "(Interviewer: Do you know what this flashing light means?). Very good question, I don't know … They never told me that" (E3). Some of the NPC inhabitants did not know whether their system was generating energy or not, while the others knew from reading and checking whether the numbers in their PV meters were increasing or not.

However, the main engagement by the PC inhabitants was to take meter readings for the FIT (Figure 6.1). This means that although peoples' goals and habits are shaped, to a high degree by their understanding of the affordances provided in the system design, their engagement is also formed by their goals and purpose, which is to claim the FIT. This understanding and communication of goal action possibilities needs to be improved on by the PIs and the rest of the provisioning team in relation to inhabitants' understandings and meanings related to the system affordances. Significantly, the regular habitual engagement of some inhabitants with their PV meter as a means to claim the FIT led them to realise that they could achieve new goals using the functionality of the meter, not communicated by the PI and installer, mainly in terms of matching their energy loads (A, D). As one inhabitant stated:

> "I used to regularly take the meter readings and recording it in a paper … at that point, I understood the significance of using my appliances during the daylight hours" (A4)

The majority of inhabitants in the PC case studies understood the basic meaning of the affordance offered by their inverters display screen in the case studies A and B - a technology that provided them with direct feedback to understand their PV performance instantly and over a period of time, while none of inhabitants understood this in the NPC case studies despite having the same display screen (Figures 9.5&9.6). This indicates that the PIs participation in their PV provisioning, and discussions with other community members also increased the inhabitants understanding of their inverters affordance, particularly the PIs understanding, which was mainly acquired from governing their PV system with the other provisioning team. This understanding enabled inhabitants to engage with their inverter's display screen in order to understand their PV performance and to detect underperformance problems, while insufficient understanding of affordances led two inhabitants in case study A and all inhabitants in case Study E to ignore their inverters, or even to limit one inhabitant's engagement:

> "I have been there few times to see the devices working and to check if there is something affecting the devices from working properly such as dust … I would like to have a Wi-Fi connection in the inverter to have view for the system (interviewer: But your

> system has Wi-Fi connectivity?) But I didn't know about it before you told me that" (E3)

However, only a small number of inhabitants, who understood the affordance of their inverters in the PC case studies, were engaged with studying their inverters' display screen in order to understand the system performance, whereas one inhabitant (A3) gave up very soon, for reasons related to the hidden location of the device (see 7.3.2.1) and changing their own goals and related meanings of the system. This means that simply providing adequate affordances in the PV appliances and understanding of these affordances is also not enough to ensure the anticipated engagement designed for. Affordances should be understood within the other elements that hold practices together (know-how, rules, engagement) and other intermediaries (chapter seven). A few inhabitants (B), for example, did not study their inverter display screen due to a community member looking after and monitoring the PV system (see 7.3.2.1), as a community rule discussed above in section 9.4. This consequently reduced their motivation to strictly match their energy loads.

The above findings align with Ingold's claim that an affordance can change in terms of its meaning and engagement across different physical and sociocultural contexts, even though its materiality and understanding does not (Ingold, 2000).

Surprisingly, several inhabitants in the case study F (NPC) were completely unaware of the basic meaning of an affordance offered in their inverter – the built-in green light indicator that showed whether their system was working or not. As a result, they did not visit their inverter at all:

> "Interviewer: Do you know what this flashing light means? No. (Interviewer: It means that your system is working). Oh, does it? See, I did not even know that" (E3)

However, they knew whether their system was producing electricity or not by taking PV meters readings quarterly for the FIT. One interviewed inhabitant in the same case study who understood the built-in green light indicator in their inverter also still did not regularly engage with it due to the invisible location of the inverter.

3) *Positive PV engagement*. The majority of inhabitants in the PC case studies (mainly in the case studies B – D) were aware that the habit of taking regular meter readings of their energy generation and consumption would help them to understand their PV performance and empower them to actively manage their energy loads, whereas the number was very small in the NPC case studies. All the interviewed inhabitants in the case studies B – D were aware that collectively taking regular meter readings of their PV meter would also help them to detect underperformance problems. As one inhabitant said:

> "From our discussion, we became aware that unless somebody is monitoring the systems, a system could be not working for months. So, that led to me to regularly check if the systems are working by looking at the inverters and taking meter readings every week for all the houses" (B1)

Again, enacting the engagement was the key source of inhabitant understanding of the meaning of monitoring and engaging with their system appliances. Another source of this understanding was the powerful translation of this knowledge to other community members by the PIs during the occupancy stage (C), which sustained their positive practice of collective energy monitoring (both energy generation and consumption) and helped them to individually compare their energy saving with other community members. Inhabitants' understanding of the significance of cleaning their PV panels regularly in case study C in terms of energy generation consequences sustained their engagement with their PV panels, which will be discussed later in this section.

In general, inhabitants understanding of the positive reason for their engagement with their PV appliances was very influential in sustaining a regular engagement with the PV panels (C), the energy generation and energy consumption meters (B – D) and a regular observation of inverters (B). These understandings were either acquired from enacting practices or from the PIs by transforming their positive knowledge to the other members.

4) *FIT* engagement. Knowledge of the FIT and its profitability sustained inhabitant engagement with the meters in all the PC case studies. By contrast in the NPC case studies, the inhabitants' lack of understanding of the FIT

registration requirements and responsibilities prevented many of them from reading their PV meters and claiming the FIT payback in time (Figure 9.4):

> "Because no one told me that I have to register my PV system, I did not register my PV when I first moved into the house, and when I discovered the problem and discussed with my neighbours, I discovered that a lot of the neighbours did not know either; and because of that, for the date we moved in, the FIT rate was like 40p/h set for 20 years, the year later when I registered, it had gone down to maybe 11p/h set for 10 years" (F1)

> "My neighbour told me how to apply, because I moved in and I did not know about it and never applied. So, he told me that I can apply for the FIT and get the benefit from what I generate … I never used to read the meter until I applied for this FIT last month" (E2)

This inhabitant also stated that she had only "… just started to record (author: her) energy usage and generation for the last month to compare…", (Figure 6.17) and because of that she became aware of her PV performance and the energy saving that she could achieve from actively using her PV energy, after previously having not had "…much expectation about PV system to compare with. So, I do not know if the system is working efficiently or not, if I'm using energy efficiently or how to do better…" (E2), before taking the meter readings. And because of this new knowledge she said that she "… changed the way of using energy during the day" due to developing a new meaning and goal that they could achieve from using the functionality of the meter as discussed above. Again, undertaking a specific engagement with PV system for a specific goal (FIT) can lead to inhabitants developing a positive meaning for the system and a new goal for engagement (actively matching energy loads) which require a daily reading of energy generation and consumption, rather than quarterly for the FIT.

PV inhabitants, particularly in the NPC case studies, should be told by PV provisioning member (e.g. installer, developer, home demonstrator) from the outset that they could apply for the FIT, and how to apply for it, if the full benefit of the system is to be exploited.

5) *Maintenance engagement*. Around half of inhabitants in the PC case studies (mainly in case studies C and D) understood the significance of cleaning their

PV panels in terms of critical low carbon energy generation consequences, while a small number of inhabitants understood this in the NPC case studies (Figure 9.4). The PV home demonstrator was the key actors for enabling the inhabitants' maintenance understanding and subsequent practice in the case study F, while it was ascribed to the PI transferring his knowledge with the inhabitants in the case study C, as stated by one inhabitant:

> "We had a tour about the renewable energies and water systems by (X) (Author comment: the PI – the name is anonymised) who introduced us to the PV system when we first moved in the community" (C2)

Moreover, inhabitants' participation in the governance of the PV provisioning process in the case studies B – D enabled them to address and engage with significant technical problems and suggest/apply solutions concerned with:

- The stability of the PV panels on the roof (C).
- Losing monitoring data due to the low capacity of the logger memory and subsequent loss of data.
- Trees shadow problems. The inhabitants in the case study C collectively decided to cut down the overshadowing trees that faced the PV panels which significantly reduced the energy output.

The findings in this sub-section show how various barriers have had a critical impact on the ability of inhabitants to engage in effective PV practices which help to reduce carbon emissions overall by empowering them to actively match their energy loads.

9.5.2: Active meaning vs passive meaning

PV systems are generally perceived by policy makers and industry through their 'institutional knowledge' as a technology that requires very limited engagement with inhabitants, and as a 'passive' technology that only generates green and free energy without impact on energy consumption practices, with a subsequent focus on the generation side and disregard of the demand side management in the system design. This clearly influences the way that PV systems are formally introduced to the public, for example as "… green renewable energy and doesn't release any harmful carbon dioxide or other pollutants" (Energy Saving Trust, 2015) or "By installing a solar PV system on your business premises or your residential home you are reducing your carbon footprint" (Green Team Partnership, 2015). However, and in contrast to this ‘institutional knowledge’, the finding shows that the large number of PC inhabitants, mainly in case studies B and C, understood their PV systems as an ‘active’ technology that had the potential to impact on energy consumption practices through ‘folk knowledge’. In the NPC case studies, however, only a small number of inhabitants (E) had this active understanding (Figure 9.7). The other NPC inhabitants simply held the passive PV meaning, which clearly undermined their motivation towards positively engaging with their PV appliances in order to match their energy generation and consumption loads and and/or, to reduce their overall energy consumption. Accordingly, a large number of PC inhabitants wanted to have a deeper understanding of their energy generation and consumption patterns to actively manage their energy demand and to reduce the imported energy from the grid, whereas the large number of NPC inhabitants remained passive suggesting the addition of an energy storage technology to the system (a battery) to improve their use of PV energy. This demonstrates that significantly increased levels of inhabitant engagement with their PV technology (active recipients of a technology) are achievable when the technology has an active meaning, despite being given poor initial information, and this activity can help to sustain positive inhabitant practices, driving energy demand management through active load matching and reducing overall energy consumption as a result.

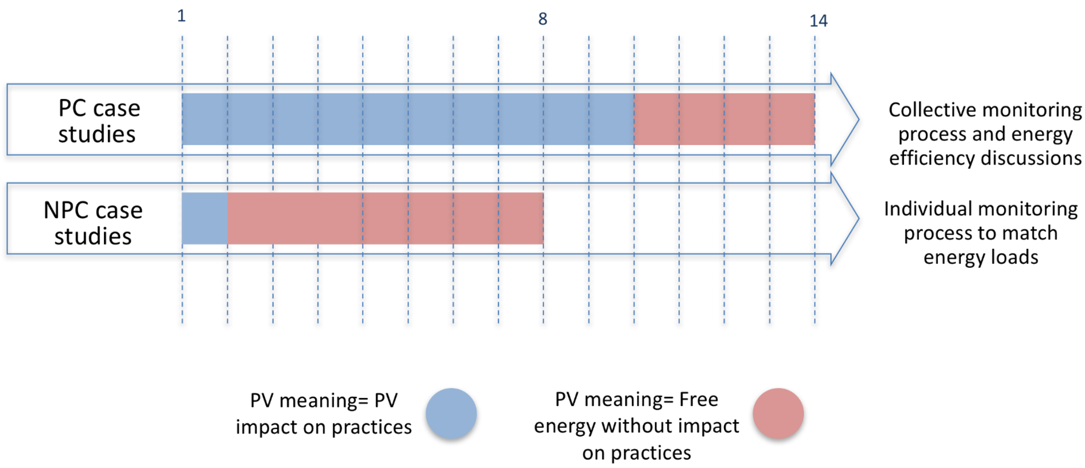


Figure 9.7: PV meanings for inhabitants

The PIs’ knowledge of the system, in the PC case studies B & C, and its *active meaning* to them was the key source of improving and translating this effective *load matching* meaning to other inhabitants in their community, during operation. Inhabitants enacting actual PV practices (e.g. reading their PV generation meter and monitoring their energy generation and consumption to match their energy loads) was another source for acquiring the active meaning of PV system (A, C). All these helped inhabitants to conceive of themselves as *active recipients* of the technology rather than passive ones. The PIs' knowledge was acquired from having a PV system in their previous house (B) and, or, from their interest in renewable technologies and how it works (C). One PI stated (B):

> "I have lived in a housing co-operative before coming to this co-operative community and we had an off-grid PV system … It certainly made me aware of a potential of the low energy consumption. It made me aware of how many little things we use, we adapted quite a lot, and then the solar would actually cover the use of a lot of those" (B1)

Unexpectedly, none of the PIs during the interviews ascribed their acquisition of their specific load matching 'active' meaning to their participation in the PV provisioning process - a significant omission. Either the PV professionals or the people who introduced the PV systems to the inhabitants did not understand the load matching meaning, or the load matching concept was not a priority for them, set against other technical and financial main concerns. This resulted in an inadequate translation of meaning from the PV professionals and other provisioning team to the PIs/inhabitants which created another barrier to positive engagement with the PV appliances in order to effectively use the energy generated from the system and to reduce their carbon emissions.

9.5.3: Transformative stages of engagement

Another significant variation in inhabitants' collective engagement with their PV system among the PC case studies concerned the *transformations* of the *active* (load matching*)* meaning of PV over the different PV stages (e.g. provisioning, operation). The most effective *transformations* were found in the case study C, where inhabitants positively transferred their *active* PV meaning and identity as a '*zero carbon community*' to their daily practice of energy consumption through reducing their energy consumption and strictly matching their energy loads. This strongly encouraged them to have regular energy collective discussion meetings during the initial occupancy period of the development, and empowered them to sustain their positive collective energy demand management practices over time. One inhabitant stated:

> "In terms of influencing our behaviour, we set out in the beginning to make sure that we would get the most energy efficiency appliances where available at that time … also we have ongoing discussions about how can we use our appliances most efficiently" (C4)

By contrast, the least effective *transformations* found in the PC case study A, where their PV meaning and value as '*low impact living community*' did not transfer effectively into their daily practice of energy consumption (Figure 9.8). This was due to the PI in this case study inaccurately assuming that all measures to be a low consumer were fulfilled in the building construction stage, simply by adopting several strategies (e.g. selection of natural materials (Modcell), higher performance insulations, PV installations) to achieve their low energy target of CSH level 4 and over.

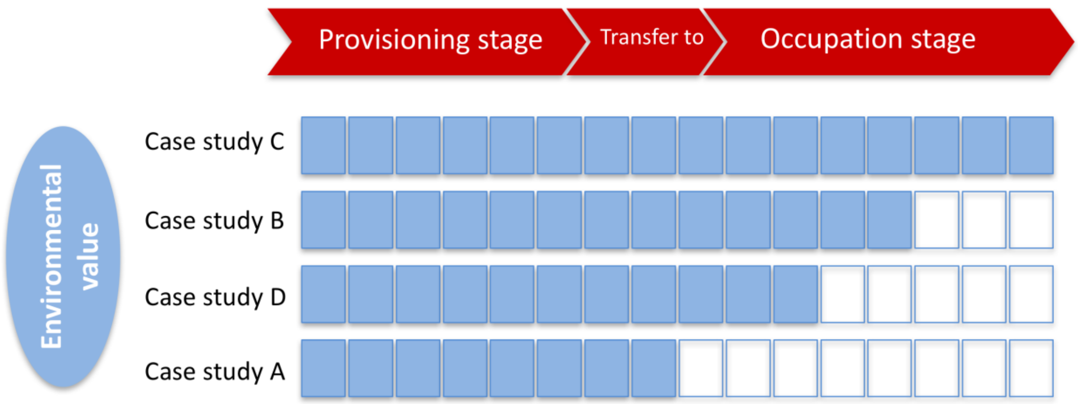


Figure 9.8: PC Case Studies - PV 'active' meaning transformations

As a result, this PI stated there was no need to use further strategies (e.g. energy load matching) during occupation to achieve their energy saving target. This inadequate transfer of the meaning of load matching from the provisioning to the occupancy stage also led to a significant error in this PI's assessment of his overall energy consumption in his own home when he was inhabiting it. When he was asked if he was happy with his energy consumption in relation to energy generation, he said he was:

> "… because each house generates just a little bit less than it uses. It is pretty good - actually as expected. I have got the figures in my house … from what I calculated for my house from April 2013 to April 2014, for one year, the PV system generated 1040kW, and from what I calculated from

my bills, I used 1307kW. Basically, I just used about 250kW more than what I have produced, which is great" (PI, A3)

Critically, he was unaware of how much PV energy he was using, and how much energy he was actually exporting to/importing from the main grid as his meter did not show this information. Given his role as the PI, all the community members trusted him as an expert when he translated this misunderstanding to them during the initial occupancy period. This critically weakened the inhabitants' understanding in relation to the potentials for energy consumption practice changes afforded by the community context, which could have been achieved by comparing the energy generation and consumption of the identical houses in the community to understand the differences as shown in a study carried out in parallel to the authors (Baborska-Narozny et al., 2016) (Figure 9.9). The resulting practices in the case study A clearly reveal a significant difference in energy outcomes between the identical houses/flats, which the community was unaware of. As a result, understanding home energy consumption was not a top priority for this community, and load match opportunities to lower peak energy demand on the grid were generally ignored and not sustained for those who have individually tried to improve their energy saving.

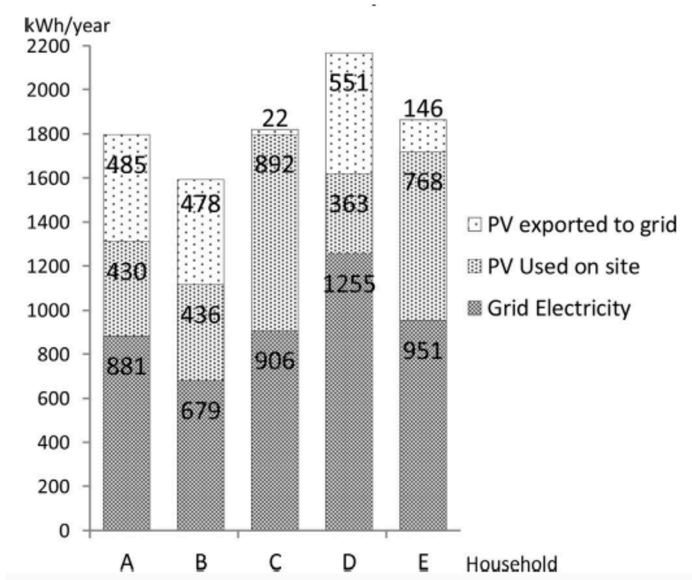


Figure 9.9: PV and main grid energy consumption in the Case Study A (Baborska-Narozny et al., 2016)

After seeing the initial findings of this study, the PI then engaged with the idea of community energy discussions as a significant method to improve their understanding in relation to energy saving potential:

> "Just now there is a desire to have a meeting to look at our energy use and discuss ideas about how we could reduce it further. I think it is useful for sharing ideas" (A3)

This shows the power that explicit and formal technical knowledge can have in transforming inhabitants' engagement and helping to develop and sustain positive PV practices which can in turn reduce their carbon emissions.

In case study B, energy demand management practices were confined to the PI rather than all inhabitants, as their: "co-operative remit was to provide low cost housing for its members and not to be an environmental organisation" (B1). This clearly restricted the PI's motivation to encourage inhabitants to collectively match their energy loads. As a result, the other inhabitants did not strictly involve in active energy demand management to reduce the energy imported from the grid. In case study D, one inhabitant held the 'active' PV meaning, while the other two held the 'passive' PV meaning, which was derived from their individual PV practices and values over time, uninfluenced by other inhabitants. Without the PI engaging with collective load matching, and no translation of this meaning to inhabitants during occupation, this positive energy consumption practice adaptation was not obvious to the inhabitants, and it was not sustainable.

A deeper interpretation in relation to the previous *discrepancy* in the transformations of PV meaning and sustaining of positive PV and energy management practices across the four PC case studies can be drawn from Tuckman (1965) model of group development (*Forming, Storming, Norming, Performing and Adjourning*)[29]. Inhabitants in the case study A (the latest established group – 2013), were still in the *forming/storming* stage of their occupancy period as a group when the interviews were conducted with them in 2014, and as such they were highly *uncertain* about their rules and practices. Therefore, they were always looking for a *leader* to guide any action. For them, the PI was the leader, and they trusted him when he transferred his 'passive' meaning of PV system to them.

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[29] Tuckman suggested a model of team development which consists of five stages: *form* (team orientation – testing and dependence), *storm* (emotional respond to task demands), *norm* (establishing behaviour norms – development a group cohesion), *perform* (efforts directed towards an action, emergence of solutions) and adjourn (termination) TUCKMAN, B. W. & JENSEN, M. C. 1977. Stages of Small Group Development Revisited. *Group and Organizational Studies,* 2**,** 419-427.

By contrast, inhabitants in case study C (the oldest established group – 2002), were in the *performing* stages as a group, with personal conflicts exposed and addressed over long time. Therefore, they were very well-settled and had different views and meanings concerning their PV system, which were mainly built on their actual practices. These experiences led them to become very efficient in terms of communicating their ideas as a group in order to achieve their low carbon objective by using their PV energy efficiently. As a result, they had regular energy discussion meetings to share experiences and to solve problems.

In case study D (established in 2003), the inhabitants had already moved to the final stage in this group development model: the *adjourning* stage, which was added later by Tuckman and Jensen (1977) to his initial four stages model. At this stage, a disengagement of relationship between community members started to emerge, and sometimes the operation of a team was disturbing for members. This led some inhabitants to develop their own PV and energy efficiency meaning individually without discussing this with other inhabitants despite having a Google mail for the group (see 7.3.2.1).

> "… but I know that there is a big gap, it is massive gap (author: in the energy performance between community members). But anyway, there were no formal discussion between the community members … I did compare, and there was one house in particular … the energy use was very, very high. So, I knocked on the door and told him that, but they did not care about that, and they were aware of it" (D2)

The disintegration between the community members, which occurred in the case study D but did not occur in the case study C, could be due to the large size of the community (38 houses - D) compared with the smaller sized community in case study C (5 houses). The larger the group, the harder it becomes to sustain positive PV and energy management practices, due to this adjourning stage issue where members start disengaging. It could also be due to the lack of having a leader (e.g. PI) for the community when the buildings were constructed (during the provisioning stage), and during operation:

> "We did not feel that we had a project manager (author: PI) that was looking after our interests … So, we (author: community members) all thought that was harming our interest or not helping our interest" (D1)

To translate PV meaning through energy discussions and practices as a result, a creative leadership model is necessary generating procedures to sustain the creative performances of team members (Rickards and Moger, 2000). This can help to improving energy saving practices through PV systems and low carbon transition. The role of PIs needs to be developed in terms of them being able to creatively generate collective energy discussions as a procedural activity that improves and sustain inhabitants' positive PV and energy saving practices.

This section has shown how inhabitants' engagement with their PV appliances and change of energy consumption practices to match their energy loads is significantly related to their understanding of the system's components and affordance, and the purpose of their engagement (positive monitoring and maintenance practices) in both PC and NPC groups. It has also shown the effective role of community housing in developing these understandings through the PIs' governance of their PV system during the PC provisioning stage. However, poor translation of these understandings to other inhabitants by the PIs in some case studies discouraged other PC inhabitants to engage in positive PV and energy management practices. By contrast, these understandings were poorly translated to all inhabitants in the NPC groups by the contractor, and ineffectively engaged in positive PV and energy saving practices.

This section has also shown a significant variation in the PV meaning (active vs passive) between the PC and NPC groups and its critical impact on inhabitants' impetus to engage with effective PV and energy management practices to reduce carbon emissions. For the majority of NPC inhabitants, the system only meant 'free' energy' and the inhabitants conceived of themselves as a passive recipient of their PV technologies, negatively influencing their motivation to routinely engage with their PV inverters and meters in order to manage their energy loads. By contrast, only small number of the PC inhabitants held this passive meaning, having other more positive motivational meanings (active meaning) towards energy consumption and load matching, encouraging them to sustain their positive PV practices over time as a result. This was mainly acquired from the collective practice of energy governance and ensuing discussions in the PC groups during occupancy, which significantly improved their understanding of the positive PV engagement and sustained their collective habitual energy monitoring practices. This collective practice helped to achieve new goals from the affordance offered and new meanings of the system, essentially in terms of its load matching potential. However, incorrect translation of positive PV meaning to other community members by the PIs discouraged some inhabitants from engaging with their PV controls to strictly manage their energy loads. This positive collective PV monitoring and energy management practices and active PV meaning however is completely missing in the NPC case studies, which also means that the NPC inhabitants are unaware of the benefits of a collective governance in terms of generating interaction between inhabitants, and resulting in improved know-how, understanding of, and engagement with PV technology.

All these findings show that PC groups are generally more effective in promoting positive PV meaning and engagement and the consequent energy consumption practices to reduce carbon emission than NPC groups, due to different governance networks and arrangements.

The strong environmental norms of one tenant inhabitant (NPC- E3) led him to attend three seminars about the eco-houses and to see different video presentation about the PV system. This helped to improve his understanding of the PV components and the meaning of the system in terms of load matching potential. He finally visited the well-hidden inverter in the attic and monitored his energy performance to match his energy loads by actively engaging with the smart energy monitor provided by the developer. Clearly, the provisioning team aesthetics regarding PV appliances (e.g. hiding away the inverter) did not help him, however. Aesthetics play a powerful role in developing successful PV system practices, as discussed next.

9.6 Engagement via aesthetics

This section now discusses aesthetics as something between humans and objects found during actual use and related to inhabitants' feelings, sensory perception, cultural norms and meaning (highlighted in the literature in section 2.6.3). This is in turn related to the material inscription and arrangements, and inhabitants' know-how and meaning of the PV system. Thus, different arrangements, perceptions and meaning of aesthetics can sustain or change inhabitants' engagement with their PV appliances and other related feedback technologies in terms of improving their energy consumption.

The perception of aesthetic, as something that can be only found through the actual engagement of an inhabitant with his/her object, was found in one inhabitant suggestion (E) to improve the usability of and engagement with his energy monitor display screen:

> "I would prefer having a big *colourful* and *touch* screen panel instead of this monitoring devise, which could give you more pleasure during use and better interactive information" (E3)

The inhabitant here wanted to improve the design and aesthetic of the device. This conforms with the literature (Fitch, 1961, Hekkert, 2006) where a positive aesthetic is related to *total* sensory perception (seeing, touching and hearing), in improving inhabitants 'post-perception' of the system usability and attaining pleasure through engagement. However, this abstract quality of pleasance can be inaccessible for inhabitants if they feel that the benefits from their engagement is time consuming, with efforts associated with monitoring and maintaining these technologies requiring inhabitants to participate in new form of labour to save energy and, in some cases also, requiring the learning of new software and apps (Strengers and Nicholls, 2017, Strengers, 2018). One inhabitant in case study A, for instance, stated that he did not have time to maintain his smart energy monitor when he found it was not compatible with the PV system (see section 6.2.2.2), resulting in him not using the energy monitor at all despite its potential in terms of saving energy: "I'm sure there is a solution, but it is very complicated, so I left it for now…I'm now too busy" (A3). The same inhabitant also mentioned that he was interested in studying his PV inverter's display screen when he first moved into the house, but soon gave up:

> "… once you have monitored your inverter for a little amount of time, it is boring, it stops being interesting…it is time consuming, it is not interesting anymore"

The above quotes show that a positive feeling towards a technology is a key element in promoting preferences and positive engagement which can also, however change during the engagement. Such positive feelings may emerge in everyday engagement with PV systems if the controls are not only easy to engage with, but also *enjoyable* to engage with by inhabitants in their everyday engagement, thus helping to sustain a practice.

Aesthetics, therefore, should be related to meaningful patterns of activity associated with total sensory perception resulting in the emergence of feelings that stimulate the construction of potential interest in them over time (Xenakis and Arnellos, 2014), in order to help promote and sustain practices. To enhance this sustainability, Chapman (2005), suggests different strategies that enable users "to think, experience and re-evaluate their assumptions about the way things are over time", including a provisioning of *multi-layers* meaning in a product, and implementing a "*fuzzy*"[30] design strategy when designing products (ibid: 78). Similarly, Djajadiningrat et al. (2004: 297) suggests a "*freedom of interaction*" model to stimulate an emotionally rich interaction by providing users with a variety of orders and combinations of actions. All these methods can potentially encourage inhabitants to be more of a *co-producer* of the PV system narrative rather than just a passive observer, and help to positively sustain their practices for reducing carbon emissions over time.

Another inhabitant in case study A ascribed his lack of motivation to monitor his own PV generation patterns to an emotional irritation with the new digital meter design:

> "In the old days, there was a wheel in your meter, which could show how much electricity you are using when using a kettle as compared with using just a light … the new meter is irritating" (A2)

The above finding aligns with various studies concerned with improving users' engagement with their objects through the cultural norms and meanings promoted in the design of these objects and mediated through its script, in other words, to create emotionally durable design to improve practices and relations (Chapman, 2005, Winther and Bell, 2018, Akrich, 1992).

PV appliances need to be designed in a way that provokes a positive emotional response from the user in order to ensure that these appliances become integrated and domesticated as the objects are negotiated and taken in actual practice (Winther and Bell, 2018). Therefore, a "meaningful association must be *first* perceived within an object before users may experience any arousal and subsequent emotions" (Chapman, 2005). Meaningful design also helps increase the sense-making of inhabitants, reduces the uncertainty of engagement, and promotes the sustainability of a practice (ibid). Moreover, different inhabitants have different aesthetics which results from having different *backgrounds* and *experience*. Whilst some inhabitants were not concerned about the location of their PV meter in a small hall, others saw the location as aesthetically unacceptable, resulting in an emotional detachment from the device:

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30 Fuzzy interface "present users with complex, artful scenario that must be learned and mastered – a novel departure from the unconsciously simple, spoon-feed manner in which interface design has become accustomed, toward a craft-like engagement in which the skill and mastery of an object must be acquired slowly, over time" (ibid: 78).

> "… It just affects the space aesthetically. Maybe, this is because I'm an artist. If you have a small space here, the more objects you have on the walls, the smaller space it becomes" (A4)

Emotionally rich interactions with PV systems may also be engendered through the incorporation of positive "*inherited feedback"* in the aesthetic design of a system interface (e.g. PV system) to stimulate an empathic engagement (Chapman, 2005: 76) which can help inhabitants to make choices about their energy consumption by relating habitual behaviour to its socio-economic and cultural contexts (Hargreaves et al., 2010) as discussed deeply in section 2.6.2. The powerful role of feedback provisioning for reducing energy consumption was clearly highlighted by one client: "… to having the data from the inverter available for inhabitants. So, people could understand the PV generation pattern and changing their behaviour" (Client representative- E6).

This can "reduce both the cognitive and emotional gap between the subject and object" (Chapman, 2005: 76). Here, engagement should not only be seen as something that occurs momentarily when using a PV interface, but more significantly, it should be seen "as a relationship that has to grow over the years" (Van Hinte, 1997: 126) through emotionally rich interactions, to help sustain a practice. The significance of *inherited feedback* provisioning (visual, auditory and tactile) in the PV design led one client to suggest:

> "Having something within the property that is consistently reminding people when to use their appliances such as using the washing machine" (Client representative- E6).

This was also highlighted by inhabitants when suggesting various methods to improve their aesthetic engagement with PV display screens by adding acoustic, tactile, visual and colour elements as shown in the following quotes

> "…or like adding some sound "click" to the inverter when producing or using PV energy. I mean we need a more visual or audio device that glowed or vibrated when you are using your own energy. So, it's not written or set of numbers or graphs, its more tactile, or easier to see or hear, without spending time to interpret it" (C1)

> "It would be very useful if we have some visual kind of display in our home to enable us to manage our energy usage for different times. I think,

> adding figures to the display would be easier to understand and remember than numbers" (A4)

> "I prefer to have something, which is clearly displays energy insight without having to react to it. So, the system we have here has a little a box and you have to press the bottoms to shows you a little graph. I think it would be easier if it could change its colour according to the amount of its energy production" (C1)

Significantly, all these aesthetic preferences for joyful displays and meaningful practices can be ignored by the poor positioning of any object in its physical environment (Winther and Bell, 2018). This occurred in case study B when the PV installer and the PI decided to locate the PV inverter in a very narrow and dim passage in the cellar, in order to be very close to the existing main power socket. The PI replied when he was asked about the poor location of the PV inverter in the cellar:

> "Because the main consumer box for this house is here, so he has put the PV parts (author: inverter and isolating switches) beside the consumer box to reduce the cost of wiring … it restricts the passage" (PI)

This poor positioning discouraged inhabitants from studying their inverter in order to actively load match their energy and was identified as one of the key problems that reduced inhabitants' engagement with their PV appliances as discussed in sections 6.2.2.3 & 6.3.2.3. This conforms with the literature on how positive aesthetics can be reduced by the poor architectural design of the homes as discussed in section 2.6.3.

To sum up, aesthetics clearly has a consequence in terms of influencing inhabitants towards developing an effective PV practice of the display screen of their inverter, PV meter and smart energy monitor due to the potential of aesthetics to evoke positive feelings, sensory perception and emotionally rich responses from the users over time.

9.7 Sub-conclusion

Practice theory was used in this chapter to enhance the understanding of what shapes inhabitants' practice of PV system in different physical and social contexts, taking the embodied know-how and engagement of inhabitants, and their goals towards reducing their overall energy consumption into account (4th objective), as well as giving a greater attention to the role of PV affordances provision and perception in homes in influencing inhabitants' practices (5th objective) as these were not fully investigated in the previous chapters.

Gram-Hanssen's theoretical framework of Practice was selected due to its examination of 'technology' as a key element in its own right, enabling a detailed examination of the critical role of PV affordances (the physical property of the PV appliances) in shaping inhabitants' PV practices, and in relation to other practice elements. This framework also enabled an exploration of 'explicit' and 'implicit' rules and their influences on inhabitants' practices of using PV technologies. Examining inhabitant practices of using their PV systems also enables a better understanding of the variation in PV practices over time as shown across the case studies, and how a withdrawal of some actors (e.g. institutional rules) in a specific network during occupancy can change the type and degree of inhabitants' PV practices and the subsequent energy consumption practices to manage their energy loads.

Prefiguring and sustaining positive inhabitants' practice of their PV appliances and energy demand management practices requires an examination of these practices as a combination of PV materiality (physical property and arrangements) and rules, and inhabitants' embodied know-how and engagements, rather than investigating the influence of each of these practice elements individually.

The findings in this thesis shows that the provision of affordances (the physical properties) in the PV appliances by the provisioning team is not enough to ensure the anticipated engagement designed for and energy performance targets. Instead, affordances should be seen within their material arrangements in homes and in relation to inhabitants' know-how and engagement. Know-how similarly should not be seen as something that an individual possesses, instead, it should be seen as a combination between a technology and its users in a specific physical and social context, and in relation to the meaning and goals that users have in order to prefigure and sustain a certain practice. The relatively meaningless technology arrangements in homes undermined inhabitants' ability to engage with the system appliances in the case studies presented here. Inhabitants could not engage with their PV controls if they were hidden and out of reach. This was particularly disabling for people with the know-how to enact the interaction where they wished to lower peak demand on the grid by matching their energy loads using PV energy. The findings also show that inhabitants' goal, meaning and know-how are not fixed when enacting PV practices, but interchangeable, changing inhabitants' engagement with their PV system as a result.

Defining institutional rules is not sufficient to sustain inhabitants' engagement with their PV system and energy consumption practices, these rules, instead, should be envisioned more contextually within the other practice elements (e.g. meaning, material arrangements, know-how) to ensure the designed energy and low carbon reductions. The findings show that inhabitants disengaged with their appliances to monitor their energy performance and reduce carbon emissions after the ending of the institutional rules of monitoring requirement. The powerful PC community arrangement as a rule should not be understood only in terms of sharing resources and responsibilities, but more significantly, it should be envisioned in terms of encouraging collective learning in relation to positive low carbon engagements and practices. This is particularly significant in relation to empowering the role of the PI as an intermediary in transferring and circulating their positive knowledge and practices to other community members, which was poorly performed in the PC case studies due to lack of training. Technical knowledge as a set of 'rules' need to be inscribed carefully by the provisioning team and transferred effectively to inhabitants through the HUG/documents non-human intermediaries. This is to improve know-how and engagement of inhabitants with their PV appliances and to perceive themselves as active *recipients* of the technology rather than passive. This is to sustain positive energy demand management practices to reduce their overall energy consumption and lower carbon emissions, particularly in the NPC case studies.

Inhabitants' type and level of engagement can be highly influenced by the meaning of the system to them, which can shape their goal of undertaking a practice in terms of what they could achieve from the affordance offered in their PV appliances. In the UK context, it is important that the positive load matching meaning of the PV system is effectively understood by the provisioning team and discussed with the PIs in the community housing projects as a 'win-win'[31] for both users and environment in terms of driving total overall energy savings, instead of limiting the promotion of the PV system simply as a source of 'free' energy. It is also important that this *active* meaning is powerfully transferred by the PIs to inhabitants if an effective PV practices for larger

[31] Win-win means that inhabitants could get free energy when they engage with it at the time of generation (during the sunlight) and they could also get a payment for a half of their generation according to the FIT rules even if they used all the generated energy from their PV system.

carbon reduction is to be achieved. For NPC communities, which includes the vast majority of inhabitants in the UK, this positive meaning needs to be positively translated by the provisioning team themselves through a trained agent.

Aesthetic considerations are important and should be understood through actual engagement of the inhabitants with their objects where cultural value such as norms, fashion, religion, etc. drive the level of engagement, alongside feelings, sensory perception and emotional rich responses which develop from the actual engagement. This is to form the potential aesthetic attachment of an agent to an object, improve inhabitants' practices with their PV controls and sustain the engagement pleasure over time. However, this should be understood in relation to the visual integration of these controls in the architecture of homes and inhabitants' perception such that the benefits from their engagement with these controls should not require time-consuming efforts which require new form of labour to save energy, rather, that they should experience monitoring as a socially meaningful practice to reduce energy consumption and carbon reductions as a result.

The findings in this Chapter also demonstrate that good governance of a domestic PV technology should always examine and understand the practice of using a technology in detail, in their specific context, and in relation to the other elements of practice, rather than only examining the role of multiple actors in a governance network in shaping inhabitants' practices. By understanding the variation in inhabitants' practices in different physical and sociocultural contexts and intermediaries during any operation, and understanding how practices inform good governance by provisioning team in the provisioning stage of the technology, and taking all these factors into account, a more effective deployment of PV systems can be achieved in UK housing, resulting in greater energy efficiency and lower carbon emissions.

It is also clear from this chapter that the current governance of NPC housing developments, both during provisioning and occupancy, could benefit from some of the governance networks and practices in PC housing. In particular, the collective learning that takes place through community engagements, and the role of a well-trained PI. However, care needs to be taken with community governance as some rules and practices can also backfire, when collective responsibility overrules positive individual initiative.

To sum up, this chapter shows that each element of practice should be seen as part of a relational assembly for sustaining effective PV and energy consumption practices, which are developed and sustained through inhabitants performing them. This chapter also demonstrates the significance of Practice theory for an enhanced understanding PV system performance and practices in combining the different elements that are significant to perform any practice (Guy and Shove, 2000), while re-emphasising on the role of affordance *within* a practice. The next chapter links all the findings of the previous chapters together and clarifies the significance of using different theoretical lenses to examine the overall provisioning and inhabitants' practice of PV system in conclusion.

CHAPTER TEN: CONCLUSION

10.1 Introduction

This final chapter synthesises all the chapters described in thesis, showing how the thesis aim and objectives were achieved, how the research question was answered and how this has made a valuable contribution to knowledge in terms of domestic PV provisioning and inhabitants' practices.

The chapter starts with a summary of the thesis. This is followed by discussion of how drawing on different approaches and insights from ANT, Practice and Affordance theories enables a broader analysis of how various actors and relations involved in the wider governance network of PV system shape inhabitants' PV and energy consumption practices when engaging with the system appliances during occupancy, taking inhabitants know-how and engagement into account. Next is a discussion of the specific practical, methodological and theoretical contribution of the study to the existing knowledge in the areas of domestic Photovoltaic (PV) systems provisioning and practice, and energy efficiency in low carbon housing communities in the UK. This chapter then discusses the key limitations of the thesis and suggests routes for further research. Finally, a series of recommendations for policy makers, professionals, relevant organisations and inhabitants is proposed in terms of developing the system design and integration into homes, and improving inhabitants' engagement with the system to reduce the energy consumption from the grid and to achieve the low carbon targets in housing.

10.2 Summary

The overall purpose of this research, as described in the Introduction of the thesis, was to help improve sustainability in housing sector, due to the latter being responsible for 29% of total CO_2 emissions in the UK during operational practices, which contributes significantly to the problem of climate change as a major challenge to sustainability. The overall aim was to provide a deeper understanding of *why* the predicted energy savings and carbon emissions reduction from energy-efficient technologies in new low carbon housing projects are not being achieved, resulting in a significant performance gap, with a specific focus on the provisioning of Photovoltaic (PV) systems in new housing developments. Whilst some energy efficient studies attribute this performance gap to inhabitants' energy consumption habits and practices in their homes, others attribute it to the inhabitants' insufficient understanding of their energy-efficient technologies, and to the poor capacity of policy and standards to deliver projected energy performances. However, the detailed role of PV provisioning actors and networks in governing inhabitants' domestic technology practices in relation to PV system design and affordances remains unexplored, providing the specific aim of this thesis in **Chapter one**. The key research question raised was:

> *How do PV provisioning actors and networks govern the PV system design, affordance and inhabitants' practices in low carbon housing communities in the UK?*

In **chapter two**, the governance approach was introduced and discussed as a way to address the performance gap associated with inhabitant practice of domestic PV systems and to achieve a radical change in energy transition in the housing sector, both in the UK and internationally. This approach aims to develop both individuals' and collective actions and practices between multiple energy transition actors (e.g. governmental organisations, local authorities, professionals, inhabitants) in order to govern inhabitants' practices in relation to their own PV systems. It reveals what forms of integration and networks are used to achieve a successful low carbon transition in housing sector. In line with the aim of this study, such an approach for domestic PV systems requires a detailed analysis and understanding of how multi-level actors are integrated together in a network to govern their common affairs, both individually when governing their own conduct, and in a continuous process of negotiation and cooperation to stern collective actions and decisions. This analysis is missing in previous energy efficient studies concerned with PV systems. Three key approaches used to interpret and achieve low carbon housing in general – technical, behavioural and contextual were also reviewed in this chapter. Analysis of the contextual studies revealed a further research gap concerned with PV systems in relation to the affordance, governance and the provisioning side of housing development. This showed why the contextualised sociotechnical approach is preferred for a deeper understanding of the governance, provisioning and practice of PV systems (1st objective). This chapter further discussed the role of PV technology in terms of empowering inhabitants' to actively manage their energy demand, as one strategy to reduce their overall energy consumption in order to tackle peak demand issues in the UK. This active load matching strategy was further discussed and compared against other strategies adopted for balancing the grid in the EU countries. Finally, the chapter examined the role of aesthetics in driving positive PV practices and identified in more detail the research gap in relation to PV governance networks and practices.

Chapter three, provided the theoretical approach of the research methodology and analysis to answer the main research question using three different theoretical lenses. ANT's notion of the sociology of translation was used to examine how a network of relations is built between PV provisioning actors (both human and non-human) to govern the design and practice of a PV system (2nd and 3rd objectives). This informed the data analysis in chapter five and the PV governance discussion in chapters seven and eight.

The theoretical and methodological insights and concepts from Practice and Affordance theories were *added* to ANT theory in this thesis to examine other dimensions that can shape inhabitants' engagement and practices of their PV systems, which were not adequately explored and analysed by using ANT theory alone. This is particularly significant in terms of examining how the role of the embodied know-how, norms, and meaning of individuals can change inhabitants' practices when engaging with PV appliances in real their contexts (Nicolini, 2017b) (4th objective). This informed the data analysis in chapter six and the PV practice discussion in chapter nine using Gram-Hanssen's (2010) four key elements: technology and products, know-how and embodied habits, institutional knowledge and explicit rules, and engagements. There is a gap, however, in Practice theory in terms of examining how power are transformed and translated between actors to deliberately shape actions and outcomes (Watson, 2017), which ANT can help with.

However, neither Practice theory nor ANT adequately focuses *in detail* on how the design aspects of PV controls relate to the inhabitants, in other words, how technologies and humans are imbricated and why (Leonardi, 2011). A refined Gibson's original meaning of affordances was thus developed for this purpose through revealing *action possibilities directly understood, or not understood by agents in a relational context of practical action* (5th objective) by defining them with a context of practical action as specified by Ingold.

In **Chapter four,** a mixed methods case study approach (Yin, 2013) was used to provides an in depth understanding of domestic PV provisioning and practice contexts. Two sets of contrasting housing cases studies in England were selected as representative 'exemplars' (Flyvbjerg, 2006: 219): four 'Participative Community' (PC) and two 'Non- participative community' (NPC) housing case studies. This was to identify and compare the governance networks and practices between case studies where inhabitants participated in the governance of their technologies (PC), and case studies where inhabitants did not participate, and to identify the potential impact on carbon emissions as a result. After literature and documentary reviews and site visits, the subsequent coding of 38 semi-structured interviews with PV professionals and inhabitants, and 18 home video tours with inhabitants provided an initial understanding of the PV provisioning networks and occupancy practices, as well as revealing how affordances offered in PV appliances were inscribed, understood and efficiently practiced by inhabitants in their context. A mapping analysis then visualised and compared the governance networks of the different PV provisioning case studies.

Chapter five provided an overview of the findings resulted from coding the interviews with the PV professionals (including PIs) and reviewing the documents in the case studies. This examined how PV provisioning actors and networks decided on the system design, affordance and integration into homes in the different stages of the building construction process during the provisioning stage (2^{nd} and 3^{rd} objectives). In this chapter, key PV provisioning changes were also discovered in all the case studies and the insufficient governance during this stage was highlighted in terms of the critical consequences on inhabitants' subsequent practice with the system appliances. The qualitative findings from coding were then quantified to compare specific aspects of PV provisioning between the case studies presented in this thesis and discussed more thoroughly in chapter seven.

Chapter six presented an overview of the findings resulted from coding the interviews and video tours with inhabitants in their homes, reviewing the Home User Guide (HUG) and the PV system manuals, and from observing inhabitants engaging with their PV appliances when conducting the video tour. The findings from coding were also quantified to compare specific aspects of inhabitants PV practices between the case studies presented in this thesis. This is informed the 4^{th} and 5^{th} research objectives in terms of identifying initially how domestic PV systems were being practiced by inhabitants in various physical and sociocultural contexts, and how their practice was defined by the different provision of PV affordances and contexts. Practice issues, inhabitants' engagement, and practice changes were all highlighted. The findings from chapters five and six led to three further questions arising out of the poor design and integration of the PV systems:

1) *How is the PV system envisioned by the PV provisioning actors and policy makers in the first place?*
2) *How are these visions outlined in the governance of the PV system by the different provisioning teams, in terms of deciding the affordances offered and the integration of the appliances into homes, taking into account the wider and extended issues of networks and arrangements?*
3) *How is the inhabitants' governance of the PV provisioning process influenced by the PV provisioning governance networks and arrangements in the first place, and does inhabitant governance improve their subsequent practice?*

Chapter seven, thus discussed how the PV systems came into play during the construction of a case study, and how the various people, both individually and collectively, and objects were involved together in a network to govern PV system design and the subsequent inhabitants' practices, using ANT's notions of mediators and intermediaries, and a mapping method. This is to understand the different roles and agencies of PV actors in a network through which PV design are specified and governed. The second section of chapter seven further explored the various mediators and intermediaries impacting the inhabitants PV practices during a period of occupation, and identified which key actors and impacts have been sustained from the provisioning stage to the occupation stage, and why.

In **chapter eight**, Fragmentation analysis was introduced in order to further examine particular disintegrations between actors in two contractual networks and arrangements, and to critically discuss the role of extended governance networks in influencing the provisioning team agency, power and network when governing the system design and inhabitants' practices as a result, which remained unexplored in the previous chapter. Two types of fragmentation (*Entities* and *Processes*) were identified and discussed as a framework to examine the various disintegrations between PV provisioning actors in two types of building construction contracts (Standard Building Construction (SBC) and Design & Build (DB) contracts) across the PC and NPC case studies presented in this thesis.

Chapter nine used four elements of practice identified in chapter three as a theoretical framework lens to interpret the differences in inhabitants' practices of their PV systems and energy demand management practices during a period of occupation as performed within a similar governance intermediaries and wider networks during any operation. This framework was chosen among others, to facilitate examination of ‘technology’ as a key element in its own right rather than as a conflated aspect of practices. The framework enabled an exploration of the critical role of materiality in shaping PV practices from a more *relational* perspective (with other practice elements). Findings related to aesthetics were also highlighted illustrating its powerful role in developing/hindering successful PV system practices. In order to fully recognise the practice elements in the two different types of housing provision in the UK, chapter nine also examined how the *governing* role of PC inhabitants in the PV provisioning process influenced their system practices in comparison to the NPC inhabitants, and in relation to the energy performance gap.

Chapter ten, the final chapter, links all the findings of the previous chapters together and explains how the use of different theoretical lenses and concepts to examine the PV provisioning and inhabitants’ practices is useful for understanding the governance of technology provisioning in practice in relation to low carbon transition in housing more generally (objective 6).

10.3 Governing in practice: developing an approach for effective low carbon transition in housing

10.3.1 Actor Network, Practice and Affordance theories in relation to a governance approach.

This thesis develops the existing debates and research on the low energy housing and energy performance gap created by new domestic technologies. It extends an interpretive approach for analysing and improving the energy performance gap in new low carbon housing case studies in relation to the governance of inhabitants’ practices of Photovoltaic (PV) systems by pragmatically drawing on three theories: ANT, Practice and Affordance as distinct lenses. It does this by using a multi-lens interpretive approach which examines how the PV technology provisioning process (both actors involved and integration in a specific governance network) preconditions inhabitants’ engagement, responses and practices when using the technologies and works backward from the empirical practices of inhabitants to improve the understanding of the provisioning process, which can potentially be applied to study all types of building technologies in domestic case studies.

Previous interpretive studies discuss the energy performance gap in relation to inhabitant’s behaviour and energy consumption practices using the Practice theory lens for understanding how social changes and practices are made of interrelated elements and practices. Other studies use the Practice theory ontology to reframe energy consumption issues by discussing the provisioning and practices of energy technologies together, thus overcoming the common dualism between supply and demand sides. These studies identify other participants, additional to the inhabitants, whose actions should be considered to close the energy performance gap. They clearly acknowledge the role and agency of building professionals (e.g. architect, developer, installer, etc.) in defining inhabitants' practices of their technologies when governing the physical properties and integration of these technologies into homes. These studies then suggest that provisioning actors are key 'change agents' who can create or prevent effective low carbon transition and changes and that change can occur anywhere in the practices as well as within the role of an individual practitioner to act with effect through diverse relationships. However, they do not include a detailed examination of how a technology governance and agency operates through actual practices in different PV governance networks and arrangements, and the role of wider actors and networks in influencing the links and relations that are taking place within practices which can in turn influence the agency and actions of the provisioning actors. This is due to these studies not engaging in a particularly deep analysis of how *powers*, as an effect of performances of practices, are distributed and translated in a network of heterogeneous *practices* and *materialities,* which the investigative approach put forward here does.

10.3.2 Governing in Practice

The investigative approach used in this thesis (Figure 10.1) states that technology provisioning and inhabitant practices should not be studied individually. Instead, they should always be considered together, and their influences should be interpreted strictly in a relational fashion between actors and their agency in a governance network subject to a specific contractual network, and in relation to the consequential practices of inhabitants during operation. This ensures an understanding of how a network of provisioning actors defines the actions and practices of inhabitants in relation to their energy technologies and identifies what form of relations and networks can work effectively in different contracts, and what new intermediary actors (both human and non-human) and arrangements are needed in the extended network in order to enable more effective integration and practices of the provisioning actors.

The multi-lens approach used in this study for analysis considers inhabitants' practices as an essential feedback loop for building technology governance, to inform the policy development (at local, organisational and institutional levels) in relation to the provisioning process of these technologies (Figure 10.1) and to define the new actors and roles that are needed in the extended network to circulate the feedback. This extended approach re-situates the agency, power and practices of provisioning actors and inhabitants in a relational network of heterogeneous entities, focusing on the transitional shifts that take place at the links between actors when examining the governance of a technology, taking the artifacts, as well as the embodied know-how and meanings of inhabitants into account (Figure 10.1).

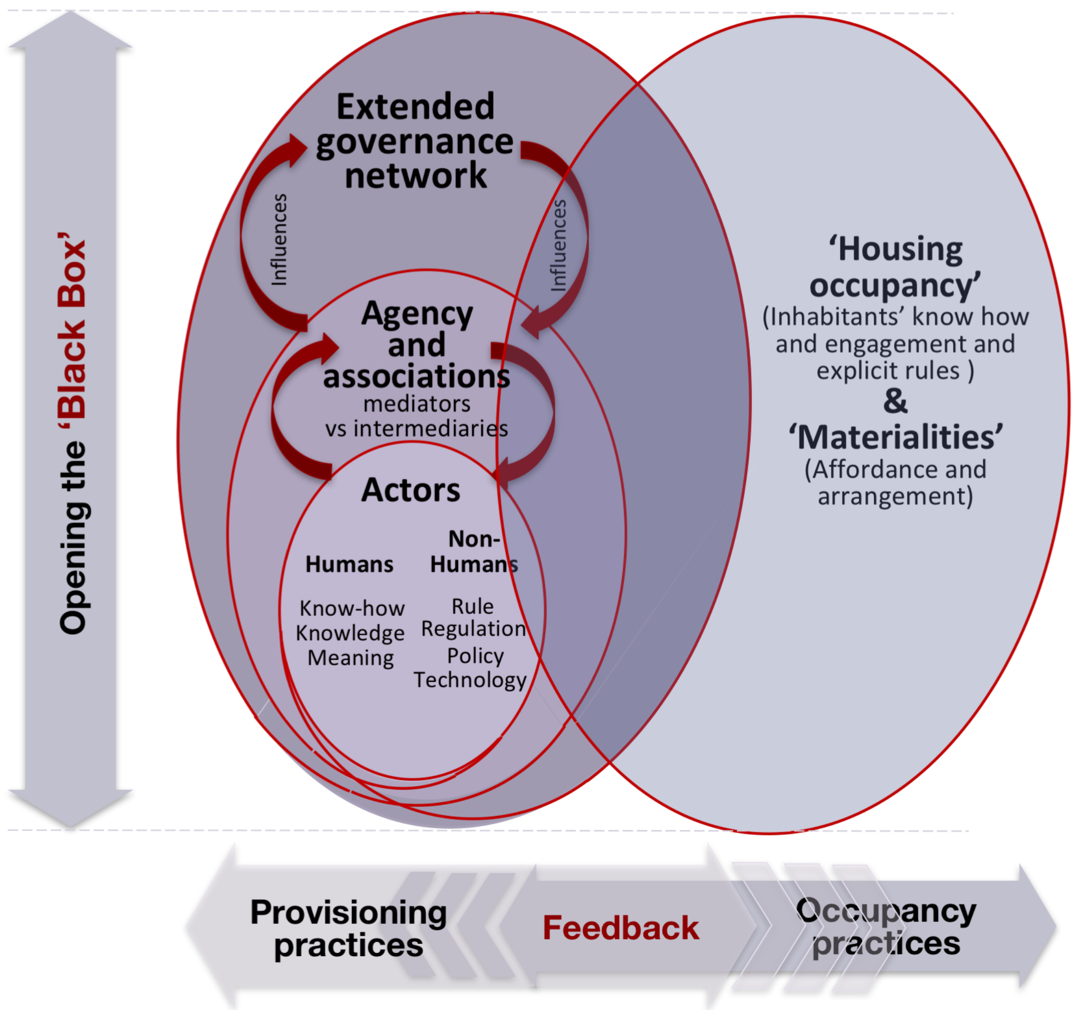

Figure 10.1: Governing in practice

The above diagram illustrates the multi-lens approach used in this thesis, showing how governance, provisioning actors and inhabitant practices are related to PV technology, which has largely been considered as a 'black box' model of production in previous studies. This approach opens up this black box by examining the actors (both humans and non-humans) and their agency (mediator vs intermediary) and practices within extended governance networks and arrangements rather than just examining the actors' actions that are involved in the contractual process of providing the artifacts for inhabitants. In this thesis, the governance and practices are also set in relation to the materiality of occupied homes, which is deemed a powerful influence on inhabitants' governance and practices during occupation through affordance, as well as being influenced by practice and governance of provisioning actors also. The approach also considers the translation of agency and power shifts between actors according to their associations and links with other actors and practices, which changes the action of actors, the quality of the entire network and the outcomes as a result. This move deals with previous criticism of Practice theory for not focusing on the detailed aspects of how power works in a network of relational practices (Watson, 2017).

The methodological design put forward in this thesis helped to understand how PV systems are governed through the lens of ANT and Practice theory and to place greater emphasis on materiality through the lens of affordance theory. Fragmentation analysis then helped to further understand the detailed role of actors and their integration/disintegration in maintaining or modifying the governance networks when enacting the real practices. It also helped to understand the role of the extended networks in influencing actors' agency and power, and their integration and practices as a result (Figure 10.1) subject to specific contractual networks and arrangements.

10.3.3 Mapping power in provisioning

Importantly, the investigative approach taken in this thesis, empirically demonstrates that critical changes in energy governance can occur within actors (e.g. agency, roles), as well as within the links between actors in the governance network, and the practices they engage with, which have a major impact on designed performance. Using this approach, a technology provisioning process can be examined to illustrate where different agents in the different contractual networks and stages of a project influence its governance and outcomes, through their associations with the other actors in the network, rather than simply investigating provisioning as separate aspects of what is an integrated process. This also helps to understand the role of wider and extended actors and networks in enabling/disabling good integration between the actors which can in turn influence their actions and decisions in relation to appropriate technology affordance and integration into buildings.

The ANT ontology which ascribes agency to both human and non-human also expands the governance approach by including non-human as well as human actors when defining actors in a specific network. Many previous studies in housing concerning innovative technology have been highly focused on the agency of human actors to understand the governance issues but have not necessarily considered in detail how agency has been 'designed into' non-human actors (Strangers and Maller, 2018). The multi-lens approach for understanding governance in this thesis captures the multiplicity of actors involved in the governance process by enabling an examination of the crucial role of non-human actors (e.g. standards, rules, regulations, products) in stabilising the social (Latour, 1996) by either *transforming* the meaning and outcomes of what they engage with when governing a technology design as mediators, or *maintaining* the connection between actors by transmitting information as intermediaries. This has been primarily achieved through the use of a mapping method.

Previous studies of intermediaries emphasise two key properties of governance and power: the 'actors' which they mediate and the type of 'relationship' in which they are involved (van der Meulen et al., 2005). The investigative approach used in this thesis introduces an emphasis on understanding actors' agency (mediator vs intermediary) and their relationships within specific contractual networks and in relation to wider/extended governance actors and networks, due to the latter playing a significant role in changing/extending the agency and role of actors and their collaboration, and practices as a result.

The understanding of the extended governance networks needs to go beyond the introduction of new actors (both humans and non-humans) as intermediaries, and rather, to situate these actors in the overall governance network (e.g. between actors and the specific stage of the building construction process). This is in order to design efficient arrangements of actors within a wider governance network for different building contracts (e.g. DB, SBC), and to enable better decisions to be made for successful implementation and practices of home technologies. The key identified actors and strategies in the extended network in this thesis are: local authorities (having an extended role beyond the contractual PV network), training programmes and actors for both professionals and inhabitants, professional institutions and universities, Soft Landings strategy and champion, economics and future energy proofing, and practice-based research strategies. However, all these require significant national policy changes to house these actors and strategies in the extended governance networks.

More significantly, previous studies suggest seeing building professionals (the provisioning actors) as ‘middling out’ mediating actors using agency to build their own practices, rather than recognising them only as intermediaries between the two key change agents (government & users) (Parag and Janda, 2014). The investigative approach used in this thesis builds on Janda’s notion of mediating professionals who ‘middling out’ by *mapping* the way in which provisioning actors actually work within specific contractual and extended governance networks, and the type of influence they have using the ANT’s actor lens of ‘intermediary vs mediator’ and fragmentation analysis. This approach has revealed that a professional actor’s (and other provisioning actors such as a PI) role and agency is not fixed, but *interchangeabl*e between Mediator and Intermediary and is the result of the way actors differently integrate within the wider governance networks subject to the different contract types and stages, as well as different rules operating in the different stages.

The approach also acknowledges the significant role of material artifacts (non-human intermediaries) in stabilising relationships by enabling the power and integration of provisioning actors in a governance network. This helps to identify new intermediaries as brokering between professionals, and other actors in the extended network, during the individual housing construction stages, and between the different stages overall in the housing construction and occupation process (e.g. preparation, design, installation, induction). This approach also considers the role of knowledge as ‘rules’ and ‘engagements’ (key elements of practice) of actors, in influencing their *agency* and action to identify whether they should perform as a mediator or an intermediary at any particular point in a governance network and process. For example, a *knowledgeable* PI in PV systems and energy efficiency can perform in certain circumstances as a mediator by making decisions rather than a neutral intermediary between the provisioning actors and client inhabitants. A PI without this knowledge, probably should not act as a mediator, but instead act as an intermediary between the design team and the inhabitants, to ensure effective knowledge transfer.

10.3.4 Understanding energy governance during occupancy

Empirically, this multi-lens approach towards understanding governance also offers a powerful means to examine the role of intermediaries (both human and non-human) as significant actors in shifting energy governance and practices during the operational stage of technologies. Intermediaries can largely configure and reconfigure inhabitants' practices and routines of their technologies and overall energy consumption by influencing the elements that hold practices together (e.g. technology, know-how, rules and engagement). By using three different theoretical lenses, this thesis has shown that inhabitants need appropriate training actors and/or, documents as 'intermediaries' in order to play a fundamental role in developing their *know-how* and *understanding.* This is in terms of engaging more appropriately with the affordances provided in their home technologies and encouraging specific PV practices (highlighted in this thesis), in relation to load match their energy consumption, monitoring the system performance and maintaining the system. These practices include: inhabitants studying their PV meter's display screens and the flashing light provided in the meter; observing the inverter's display screen, and changing the information on the display screen by using the button; studying/changing the information of any other monitoring and feedback technologies (e.g. smart energy monitors) that are provided with the PV system. All these PV practices help inhabitants to better understand their PV system performance at different times and conditions, and to reduce their consumption of grid energy by matching their PV energy generation and consumption more closely through the deliberately timed use of appliances (e.g. the use of washing machine, kettle, heater and light). These PV practices also encourage some inhabitants to adapt their routine of purchasing home appliances to the changing systems of electricity provision (e.g. replacing the old gas kettle with a new electrical one). This is to achieve the best use of PV panels and to reduce their consumption of gas, thus reducing their overall carbon footprints. This aligns with Christensen and Gram-Hanssen's recent examination of inhabitants routine of purchasing household products in relation to their engagement in specific practices related to a product (Christensen et al., 2019).

This active approach to understanding energy management can also help to reduce the total amount of energy consumed overall due to increased energy 'literacy' through these practices, as promoted through research and development.

The findings in this study have revealed that cleaning the PV panels is another significant PV practice that also need to be effectively translated to inhabitants and maintenance personal through intermediaries in order for the PV system to be more effective in terms of energy generation. Importantly, it has revealed that the construction and translation of an *active* meaning of a technology (as a system that can impact their energy consumption practice) to inhabitants, who need to engage with it, needs effective actors (both human and non-human) and networks to enable that engagement to work effectively in the UK, giving the limited role of the overall energy system (the grid system) in empowering inhabitants to use their energy generation effectively and to reduce the imported energy from the grid.

The use of three different theoretical lenses also places a particular emphasis on identifying the detailed role of affordances and physical context in relation to a sociotechnical understanding of practices. Technology *affordances,* for example*,* are routinely disregarded by inhabitants if the technology is installed in an invisible location as an intermediary and if a *passive* meaning of ‘institutional knowledge’ is translated to them by provisioning actors acting as intermediaries. The design of institutional *rules* (e.g. standards, codes, regulations, policies, etc.) as intermediaries can either greatly encourage or discourage inhabitants’ energy consumption practices to match their energy generation (load matching), depending on whether, or not, an appropriate translation is taking place in terms of what the PV system means to them (active vs passive), and whether appropriate affordances are available or not.

An understanding of effective governance must include an examination of all technological artifacts and physical systems in detail, in their specific context, and in relation to the other elements of practice. This can highlight the variation in inhabitants’ PV and overall energy consumption practices even when performed within similar governance networks and intermediaries during any operation. For example, having know-how, as a powerful intermediary to enact a practice, might be insufficient if the ‘physical context’ and affordances available for the practice does not enable skilled people to perform the practice in reality.

In this thesis, a detailed examination is also offered in terms of how affordances arise from the relation between the complex assemblages of multiple actors (Volkoff and Strong, 2013) in order to understand what new intermediaries (e.g. training actors) and the extended governance networks are needed in the different building construction contracts and stages to make provisioning processes more effective.

More significantly, the engagement with these affordances by inhabitants is also subject to the way the understanding of affordances is translated to inhabitants through various actors (both human and non-human) mediating between provisioning actors and inhabitants, and between the inhabitants themselves in any governance network. Moreover, the use of three different theoretical lenses in this thesis, *re-considers* practices related to innovative technologies and their affordances as subject to governance agencies and the extended governance networks.

The detailed examination of affordances through inhabitants' engagements in reality, which uses the ontological standpoint of Affordance theory, also provides a powerful feedback approach for technology designers and providers. This examination helps them to understand whether, or not, their notionally provided affordances actually exist in reality, and to improve these affordances according to inhabitants' preferences and practices rather than the designer's general assumptions. Again, this require new intermediaries in the extended networks (e.g. Soft Landings strategy and champion) in order to the feedback to be continuously and successfully circulated between the practitioners, including the inhabitants.

Finally, the use of multi-lens approach in this thesis helps to reveal different understandings of a phenomenon. One example of this is aesthetics which can help to better governing domestic technology provisioning and practices. The symmetrical analysis of ANT highlights aesthetic as a significant *non-human intermediary* that is, in many cases, governed individually (e.g. by the architect), negatively impacting PV provisioning networks and actors' integrations and arrangements as a result. Practice theory ontology, however, helps to understand aesthetics as something found in the *relation* between inhabitants and the PV controls in *contextual actions*. A Practice theory lens thus sees inhabitants' feelings, sensory perception and cultural norms, (the non-material dimensions of aesthetic) as being as important as the visual and material dimension when governing aesthetics, and in relation to inhabitants know how and meaning. Inhabitants can see their PV controls (e.g. inverter) as aesthetically unpleasing if they feel these objects and their contextualisation are odd to cultural norms and thus disengaging with them. Importantly, these aesthetic aspects can be seen as a specific energy saving 'element' of practice that forms and develops potential attachment of inhabitants to their PV controls, leading to better engagements.

10.4 Key contributions

10.4.1 Empirical contribution

Seven key empirical contributions are achieved in this thesis. Firstly, this thesis provides new empirical findings and develops a discussion that shows how a network of building construction actors and practices can strongly influence inhabitants' practice of their home technologies during occupancy (e.g. PV systems) and energy consumption practices overall, with a consequence for carbon reduction as result. This is demonstrated through the assumptions and decisions they have made in relation to the system design and integration into housing developments – an underexplored area in the literature concerning PV systems. Secondly, insights are provided to show how policy makers and industry understanding of PV technologies as a 'Black Box' process of provisioning, critically influences the development of appropriate PV policies and practices and weakens the construction actors' integration to collectively and adequately govern the system design within the building construction process during the provisioning stage. Thirdly, this Black Box is opened up by empirically comparing how the systems are actually governed in the different housing provisions (PC vs NPC) and contracts (SBC vs DB) and the consequences for energy consumption and carbon emissions. This is done by examining actors' agency and power in a distributed network of practices and the influence of their governance on the actual practice of the systems by inhabitants, which could be applied to other home technologies (Figure 10.1). The fourth empirical contribution concerns the development of two extended governance networks (Figures 8.12 & 8.13) to make the provisioning process more effective for two different UK building contracts (SBC vs DB) and in relation to the different stages during the contract. The new extended networks not only suggest the new actors that are needed to build a more integrated and collaborated network, but also define the form of collaborations of these actors in the overall governance network in terms of where (between actors) and when (building construction stage) these actors are needed. Fifth, this Black Box is shown to also undermine the development of 'active' meaning of the system for PV professionals and other provisioning actors. This happens when they fail to understand PV as a technology that impacts energy consumption practices and influences the decisions made by PV provisioning actors, in relation to the affordances offered to housing inhabitants to enable them to use energy generated more efficiently both on the individual and community levels. This 'Black Box' process has significant negative consequences on inhabitants' engagement with their PV appliances which would help them to better match their energy consumption with what has been generated by their PV systems, in order to reduce the imported energy from the UK largely fossil-fuel based grid and thus reduce carbon emissions as a result. The six empirical contribution of this thesis is the uncovering of the detailed role of affordances provided in PV appliances in shaping inhabitants' engagement with their PV appliances in a relational context of practical action, and as being inclusive of inhabitants' agency. The revelation of all these factors in this study contributes towards deeper understanding and potentially helping to achieve a positive low carbon transition and governance in housing sector through signalling how to improve the practice of energy efficient technologies by inhabitants.

This study thus provides a useful investigative approach for further research concerning the technology implementation gap in terms of more broadly understanding how governance during the provisioning stage of building development should actually function. The comparative findings between the PC and NPC case studies in terms of inhabitants' individual and collective PV system governance and practices showed that the inhabitants' participatory role in governance can be significantly undermined if an appropriate governance networks and arrangements, in terms empowering inhabitants to actively integrate with the other construction actors, is not provided. Figure 10.2 explains how a more effective governance network might work in terms of a housing development process, by encouraging inhabitants, through the role of the Inhabitants' Representative (IR), to provide feedback to provisioning actors in relation to the provisioning actors' governance and decisions concerning their intended technologies, thus, enabling two-way translation between the provisioning actors and inhabitants.

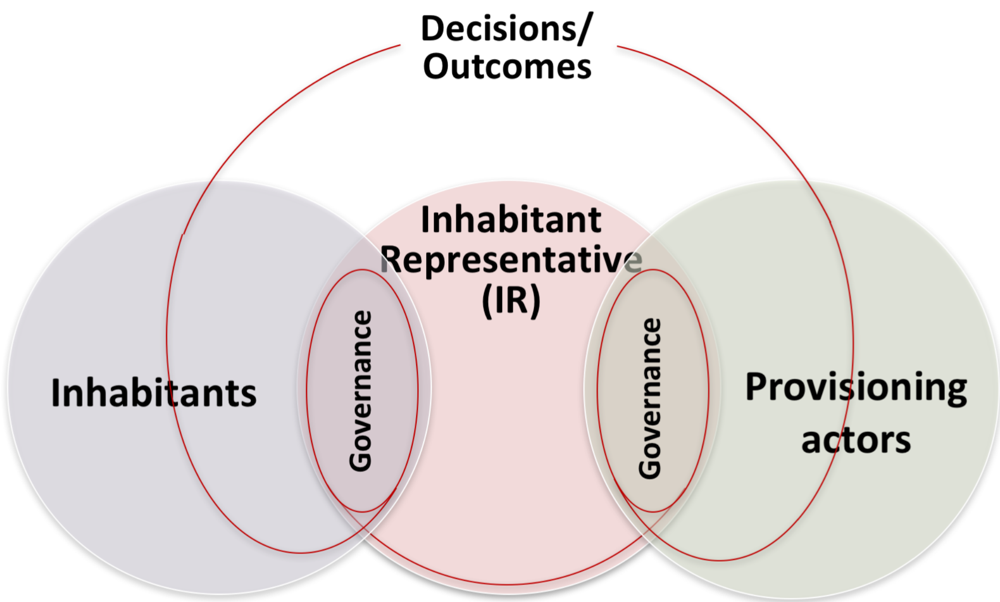

Figure 10.2: Governance process for active engagement of inhabitants in housing development

This type of feedback from inhabitants is needed to achieve improved implementation and performance from the installed technologies, in addition to framing a more successful intervention by policy makers and the PV industry in the extended governance network.

Finally, the thesis empirically analyses and explains how a change in any one of the elements of practice (e.g. engagement, know-how) can change how PV practices are performed (the key focus of previous energy efficiency research studies). More significantly, it demonstrates how these elements also vary due to the variation in the participating PV actors' understanding of the system (active vs passive), and PV governance network for both PV provisioning and occupancy stages. The thesis further shows how inhabitants' participation and governance in the PV provisioning stage, to different degree, affects these elements and inhabitants' practice of their technology as a result (chapter nine).

10.4.2 Methodological contribution

The key methodological contribution of this thesis concerns *mapping* the coding of the interviews and video tours data to understand the different agency (mediator vs intermediary) and links that defines the relationships of actors and the overall governance network in relation to PV provisioning process and inhabitants' practices, as described in detail in section 10.3.3. This is an innovative combination of mixed methods to generate new findings in relation to the provisioning of PV systems in new housing, particularly in terms of illuminating the impact of non-human intermediaries on human mediators. All of this can help to define how governance during the provisioning stage should actually function in terms of ensuring effective engagement of inhabitants with their home technologies.

Coding and quantifying the video tour data alongside the interviews data represents another methodological contribution concerning the strategy used to analyse the data, which has been analysed differently in previous sociotechnical studies concerned with home technologies. This is very useful to understand what aspects inhabitants are focusing on through the interview (saying), and what aspects they are focusing on during the video tour (doing). Significantly, this double coding helps to reveal any crucial gaps between what people are saying and doing, particularly in relation to their understanding of their technology affordances and energy consumption practices.

A further novel methodological contribution in this research is to particularly investigate PV affordances 'in greater detail' when examining PV practices in their real context, instead of analysing PV affordances as an element of practice. Understanding inhabitants' behaviour in relation to their broader practices of home controls (e.g. PV controls) within a context is unlikely to occur without understanding in greater detail whether and how the 'designed in' properties of PV technologies actually support inhabitants' practices. This approach also focuses on inhabitants' understanding of, and engagement with, the affordances offered by their controls in the home, which partly determines their usability. More significantly, using different theoretical lenses in this thesis (ANT, Practice and Affordance) provides a more thorough examination of how the provision of these affordances is highly influenced by the governance of various actors in a network and of their meaning of the system in terms of impacting energy consumption practices, when opening the Black Box, and effectively translating these affordances to inhabitants.

Another methodological contribution in this thesis is the use of Fragmentation analysis to diagnose where the broken links are in the provisioning network which resulted in critical disintegrations between actors, and how these can be re-formed and extended where necessary, through the involvement of new actors and/or, new forms of collaboration between the existing actors. This can help to develop a more extended and effective provisioning network and to avoid the disintegration between the PV actors in the different building construction contracts and stages.

10.4.3 Theoretical contribution

This thesis strongly advocates that domestic PV systems research should not just focus on the PV technologies itself, but more significantly on how PV systems are designed and integrated into homes within new housing developments or retrofit projects by the various building construction team members during the provisioning stage. As such this thesis is aligned with other Practice theory studies that focus on material integration, rather than single technologies to understand the issues of 'energy saving gap' between the calculated and actual energy performance (Gram-Hanssen et al., 2017, Shove and Walker, 2014). The findings in this thesis acknowledge the role of PV provisioning actors in constructing the material inscription and integration into homes, and defining inhabitants' practices of these materials during occupancy (e.g. PV appliances) as a result.

Previous studies have used Practice theory to understand the role of professionals in governing the inhabitant practice of energy efficient technologies. The use of three different theories as different lenses (ANT, Practice and Affordance) to analyse governance, represents the key theoretical contribution of this thesis, providing a deeper and more complete understanding of the PV provisioning process and its effects on inhabitant practices of technologies in housing. ANT decentres the embodied agency of humans, whereas practices can be developed through their embodied know-how, meanings and goals, and through creating effective materials arrangements and contexts as set out in Practice theory. In addition, a re-focusing on ANT (within practice) advances Practice theory by re-engaging with analysis of the "means through which power operates" (Watson, 2017: 172) in a distributed network of provisioning actors, which can determine actors' agency and action, and PV system design and integration into homes as a result. By including non-human as actors influencing PV provisioning and occupancy practices, this thesis provides an in depth understanding of what the physical properties of PV appliances afford to their users in the context, and examines users' understanding of these affordances. Drawing on these three theories as different lens subsequently also generates the key methodological contribution of the thesis, as outlined above, to generate different interpretations and findings with credible outcomes.

10.5 Limitations

A key limitation to the thesis concerns the relatively small sample studied creating a difficulty in generalising from particular events and situations (Schweber, 2015). However, the key contribution of the thesis is the use of different theoretical standpoints as lenses as way forward to generate further research concerning the energy performance gap, rather than developing general laws (Yin, 2003). The quality of the case study in this thesis rests on the significance of various circumstances and situations (Table 4.1), which was discussed in depth in chapter 4.2.1.

A second methodological limitation in relation to the case study approach is that all the case studies are located in England, without an international representation, which was beyond the scope of this study in terms of cultural considerations. The mapping strategy and the use of multiple lenses in this thesis, however, is potentially applicable across different sociotechnical contexts.

A third limitation of the thesis concerns the lack of access to all key PV provisioning actors in every case study, particularly the PV installers (missing in all PC and NPC case studies) and the architects (missing in case studies A, B and E). This was because the timing of the interviews with PV provisioning actors had to occur well after the completion of the case studies in order to capture embedded inhabitant practices, by which time the PV installers were ‘off the radar’. As a result, the intermediaries between the architect, the installer and the client/contractor are not fully mapped, but this does not override other key findings. This limitation defines another path for further research (see 10.7). This significant gap in timing also prevented the author from examining the actors and their relations in situ during the provisioning process, which could further improve the understanding of PV provisioning networks within real building construction practices (see Pink et al. (2013) for more details). This would enable the examination of new mediators and intermediaries, and more significantly, discussion of the four practice elements in the PV provisioning stage -a key area missing in this study.

Additionally, although this study has investigated the emergence and function of various mediators and intermediaries that influence/impact inhabitants’ practices of their PV appliances during *inhabitation*, the wider influence of other mediators/intermediaries, such as media, public forums, energy trusts, and governmental campaigns in the extended network, on inhabitants’ practices remains underexplored. Understanding the influence of the extended actors and networks during inhabitation, apart from introducing some actors (e.g. FIT, energy supplier and experts) in section 7.3.2, was beyond the scope of this thesis, which is mainly focused on inhabitants' practice of their own PV system. The wider issues of networks and arrangements is extensively examined and discussed in relation to PV provisioning stage (chapter eight), but not in relation to occupancy. Further research is also required to deal with this limitation (section 10.7).

10.6 Recommendations

Based on the lessons learnt in this study, recommendations are provided in terms of developing appropriate Policies, Contracts, Practices and System design. These are made specifically in relation to how domestic energy and contract policy makers as well as, building construction professionals could benefit from drawing on research related to the ANT, Practice theory and Affordance theory approach developed in this thesis to improve the utilisation of domestic PV systems, reduce energy performance gap, and re-develop their provisioning processes for home technologies accordingly. Key recommendations (10.6.3.2) are specifically introduced to improve the growing number of new community housing (PC) projects in relation to the provisioning and occupancy practices of their home technologies, due to this type of housing provision having different governance networks from conventional housing. There are other more detailed recommendations in regards to building professionals, policy makers and inhabitants, which are located in the appendix 11. All these recommendations represent another significant contribution in this thesis, since PV governance is a relatively new area of focus in research and professionals' practices. The recommendations are now grouped in this section under four key categories: policy, contractual, practice and PV design, as described next. These recommendations are specifically designed for housing developments in England. However, they have wider implications for countries engaged in similar provisioning process of technologies in housing sector.

10.6.1 Policy recommendations

- Financial incentives (e.g. FIT, funds) need to be developed at a national level to encourage inhabitants to match their energy loads, and not view PV produced energy as 'free' energy.
- New policies are needed to encourage the utilisation of community micro-grid systems and technologies more widely in PV housing projects, and fund a

communal energy approach. This is to optimise the use of PV energy generation and to increase its economic value due to avoidance of network charges.

- Building standards should require PV-supplied homes to be provided with effective installation of meters/inverters which provide effective feedback for inhabitants to match their energy loads, and with good affordances/usability and the correct installation procedure clearly included in certification courses for installers.
- Guidance on collective energy data and forums offered in a community housing context, needs to be developed in relation to governing PV systems effectively in future low carbon housing projects. This will enable inhabitants to understand and compare their PV and energy performances and identify underperformance problems.

10.6.2 Contractual recommendations

- Existing UK building contracts need to be re-framed to focus more on the co-ordination and integration requirements between all members of the provisioning team at all stage of the provisioning process.
- All PV provisioning actors' roles and responsibilities, including the new co-ordination role (e.g. Site Sustainable Manager (SSM) and Project Manager, who are trained in managing environmental performance and home technologies), need to be contractually more defined in order to avoid the improper shifting of roles and powers that impede a network performing appropriately. The contract should also clearly define when professionals can change their roles (e.g. from a co-ordinating role to more governing role), if something goes wrong. This is also to enable powerful *integration* between the various actors at different stages of the building construction process to ensure that the sustainability agenda, aspirations, and targets are not overlooked.
- Project goals and priorities in regard to achieving low carbon homes should be clearly defined and literally written in the contract, and adequately discussed between all the PV provisioning actors from the outset. It is also significant to mention in the contract that these goals should be strictly

reached when making critical decisions at key stages by all the members in the network in order to achieve energy efficient houses.

10.6.3 Practice recommendations

10.6.3.1 Building professionals

- PV installation intentions and requirements, including the possibility for retrofitting, should be decided with the client from the outset. This is to ensure early integration and discussion between the client, architect, contractor, and the installer in a PV governance network to make appropriate decisions regarding the system integration on site.
- Architectural practice and education should include the wider role of future proofing design strategies in a PV provisioning network, at the outset of any student design project. This is to ensure that architects are trained to routinely consider all the aspects and details that make the installation of technologies successful.
- A specific agenda and budget should be allocated to PV systems and other home technologies by the Client and Quantity Surveyor (QS) as part of the design team contract, rather than simply including them in the total budget of the mechanical works. This is to stimulate a sufficient discussion between the PI, architect, contractor and PV installer when governing the system design (size and specifications), and to avoid individual decisions being made by the contractor alone in relation to PV affordances based on choosing appliances with the least affordances in order to reduce the cost.

10.6.3.2 Provisioning Inhabitants (PI)

- PIs should remain independent and not align themselves solely with the visions of the design team. This empowers inhabitants as clients and ensures their visions, interests, and understanding in terms of the system affordances and integration into homes are exchanged and developed with the design and build team.
- PIs in community projects should be trained in order to govern the PV system provisioning more effectively, and to avoid relying on the assumptions and views of other provision actors who can fail.

- Where a PC project does not have a Project Manager, PIs need adequate construction management training in order to ensure effective co-ordination between the key PV provisioning actors with regards to home technologies provision processes.

10.6.3.3 Inhabitants

- It is vital for all inhabitants to be appropriately informed in terms of how to engage with the affordances offered in their home technologies as intended at the point of handover. Inhabitants can be uncertain and look for guidance before taking any action. A PI trained in the practice of home technologies can perform this role in the PC projects, while in the NPC projects, a trained specialist in the provisioning stage is appropriate.
- Any institutional rules concerning PV system provisioning and governance must always be supported by a positive programme of energy efficiency goals and given meaning through contextualizing the rules for any given development. Load matching using PV systems, for example, should be communicated as a 'win-win' by PV professionals and other provisioning actors for both users and the environment, instead of limiting the promotion of the PV system simply as a source of 'free' energy. This is to ensure that inhabitants continuously engage with their PV controls to monitor their energy generation and consumption.
- It is important for an individual community (both PC and NPC projects) to have a separate energy discussion meeting, rather than considering it as a key feature with in the general meetings of the community. This is to ensure that a sufficient time and emphasis has been given to inhabitants to collectively govern their energy efficiency.
- It is important to keep PC inhabitants positively engaged throughout the lifetime of their inhabitation, as there can be a tendency for members to discard normative positive practices once they are very settled in, for a variety of other reasons.

10.6.4 PV design recommendations

- The possibility of attaching a micro-inverter for each PV panel, instead of installing one inverter for all the panels, should always be considered by the PV installer. This is to reduce the negative effect of overshadowing of the panels by enabling each panel in the system to act independently even if some panels are in the shade area, and to enable inhabitants to improve the system size by adding new panels on the roof, without changing the old inverter to match the new size of PV panels.

- Aesthetics should always be considered by PV appliance designers in relation to developing effective inhabitant engagement and the most effective positioning of any appliances in homes.
- PV appliances should be designed in terms of how they are actually used is vital to minimise inhabitants' confusion.

10.7 Future research

Given the limited nature of this thesis, further research involving a larger study of PV provisioning actors, particularly the architects and the PV installers, is needed to provide a broader understanding of how material inscription and arrangements develop in a variety of housing provision and contracts. Research is also needed to map wider networks and arrangements in relation to inhabitants' practices of their PV system including the influence of wider mediators/intermediaries on PV governance network during occupancy, such as media, public forums, energy trusts, and governmental campaigns.

Other future research areas as trajectories of Practice theory and ANT related to this thesis include:

- Investigating how inhabitants' practices of their PV systems and any other associated energy practices change over a longer period of time in the same case study due to potential changes emerging or being introduced in any elements of practices.
- Investigating the broader practice trajectories of the PV provisioning actors (e.g. architects, contractors, PV installers and even PIs) to understand how their practices have changed as a consequence of being involved in other low carbon housing case studies that included PV installations over time, and whether any extended actors and networks identified (e.g. new national policies, etc.) and relations emerged has impacted their PV actor-networks and PV provision practices as a result.

- Investigating community energy resilience (i.e.: adjustments in individual groups and institutional behaviour in order to reduce society's vulnerability to climate) in relation to PV provisioning governance. The inefficient use of the PV energy at an individual community level was highlighted in the PC case studies.
- A detailed examination of the role of economics as a wider network issue affecting PV provisioning and occupancy practices in relation to national policies enabling the involvement of new key intermediaries in the future housing construction networks to improve PV practices and actors' integration in the wider governance network.

10.8 Concluding remarks

Mitigating carbon emissions reduction in the housing sector is absolutely critical due to the recent estimate from the Global Carbon Project that "Global CO_2 emissions are set to rise 2% in 2017 after three-years plateau" (Global Brief, 2017), with a significant decrease needed each year to prevent catastrophic climate change. This is has become even more critical given that global warming above 1.5°C of pre-industrial level significantly increases the risk of drought, floods and extreme heat, given that it has already increased by 1°C (IPCC, 2018b). Unfortunately, the UK housing sector is currently failing to adequately reduce its carbon emissions according to the agreed carbon targets required to fulfil the UK's commitment to reduce all carbon emissions by 24% in 2030 compared to 1990 levels. The reduction is currently just 9%. (CCC, 2019).

The current focus in the housing sector is principally concerned with advancing technological provision and design which assumes that inhabitants will engage with their technologies as intended. Since the necessary energy savings and associated carbon reductions from new housing are not being achieved, it is clear that a new and more contextual approach is needed to understand how technologies are actually inscribed by professionals and policy makers, and practiced by inhabitants in practice. This thesis seeks to contribute to both academic and policy debates by examining these social and technical issues using a multi-lens approach to help develop effective low carbon transition in housing as described in section 10.3 (Figure 10.1).

Technologies are introduced into housing developments in very different ways, depending upon the governance and expectations of the building construction participants and policy makers. This variation in the provisioning of technology can confound appropriate inhabitant practices, generate new and inappropriate ones, and shift practices away from the initial intentions underlying the technology. This thesis has demonstrated how the evolution and installation of PV systems as a domestic energy efficiency technology does not consequently ensure the intended energy savings practices by inhabitants, due to the inappropriate governance networks and arrangements at the provisioning stage.

I advocate an investigative approach that drives forward practitioners, manufacturers, researchers and policy makers towards examining *the governance of technology-in-practice* in terms of what people are actually doing, and how these practices are shaped by the governance of an interrelation network of building professionals and policies, taking materialities and power transition into account. I have endeavoured to demonstrate empirically the effectiveness of using three different theories (ANT, Practice and Affordance) as different lenses to examine the different aspects of the overall networks and practices involved in the governance of energy efficient technologies in housing, as an approach for further research. In doing so, I hope that I have challenged the traditionally dominant technical approach of integrating technologies into housing developments, and thus enthused further debate and subsequent action regarding how technologies and inhabitants are considered in academic research and policy.

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APPENDICES

Appendix 1: Interview questions – Provisioning team

Thank you very much for giving up your time to take part in this discussion today.

My name is Frances, and I would like to begin by describing how the interview will work. The interview questions will be related to the discussions that have been taken place between you and other people during the procurement process of PV system in a housing project that you have been involved with contractually. This is to understand how and why these decisions have been made and to identify any specific problems during the installation process.

The interview will last 30 minutes and take the form of short open questions covering your view. During the interview, you can talk as freely as you wish on any issues you feel are relevant. You don't have to talk about anything you don't want to and you may end the interview at any time.

All the information you offer will be kept entirely anonymous and will only be shared with research team members in The University of Sheffield. With your agreement, I will record the discussion, to catch all your comments. I will also produce a transcript of the recording, and take photographs for some documents if needed. You will then be able to review the transcript and only after you have done so and agreed to it, will we be able to use it in our project. The recording itself, the transcript, and any notes taken during the interview will be destroyed after the completion of the research. I could only retain and use the record and transcript in future research up to five years if you give an express consent in Consent form.

Before we move on, is there anything you would like to ask at this stage? Are you happy with everything?

Okay, let's start with some simple information.

The demographic information

Office/company name:

Office/company address:

Role of the participant:

Participant's name:

Contact E-mail:

Age: 18-24 25-34 35-44 45-54 Over 55

Gender:

ID:

PV actors and networks

1- What position do you hold in your organisation/office? Do you have any specific role or responsibility in your community?

2- What position do you hold in relation to this PV provisioning process?
Prompts: Do you have any specific role?

3- What were the reasons behind installing the PV system in your in this project?

4- Have you been involved in the meetings with other people (agents) when discussing issues related to the provisioning of PV system for this housing project? or you have just informed by a person about the decisions from these meetings and why these decisions have been made? If yes,
- Which stage: preparation stage, design stage, installation stage, all stages?
- Did these discussions have any influence on the design of the PV system? In what way?

5- Who was involved in the process of PV provisioning?
Prompts: PV installer – architects – contractor – Project manager – Client – Quantity surveyor - Others/what?

6- Whom did you have the most meeting with in relation to PV provisioning process? Why? Which stage?

7- What was the main purpose (discussion topics) of your meetings in relation to your PV system?

8- What form did this discussion take between you and the other participants? Is it like group discussions or paired discussions or others?
Prompts: 1- Group discussions? Whom? Why?
2- Pair discussions? Why?
3- Others/What?

9- In terms of the people involved in the PV design and procurement process, who had the authority "power" to make decisions and in which stage?

10- Which form of discussion was the most effective in relation to decision-making about specific issues? Why?

11- Who set the agenda for the meeting? Who is structuring the conversation in your meetings? Why?

12- How often were your meetings have hold?
Prompts: Every week – Every month – Were needed – Others/What?

13- Were there aspects that have not been discussed in your meetings and had an effect on the performance of the PV system, doing interaction by occupants or even doing maintenance? What?

14- Did any occupant(s) participate in your PV procurement meetings? If yes, when "which stage"?

PV Changes

15- Have any changes been made in the PV system through these discussions in your meetings?
Prompts: What kind of change? Which stage

16- Who asked for this change(s) and Why?
Prompts: Financial – Technical – Others/What others?

17- Who had the most influence in making decisions in your provisioning team in relation to deciding on any change? Why? Were there any other influences?

18- Did the group have any expectations about the performance of the PV system as a result of the changes agreed?
Prompts: Positive – Negative – Neutral - Others/What? Why?

19- If negative? Why did you agree to make the change?
Prompts: Financial – Social – Technical – Others/What?

20- Were there any obstacles that stopped doing a positive change?

The design intention

21- What type of PV system was selected for this scheme by your team? Why?
For example:
- Occupants are allowed to interact with the PV system.
- Occupants are not allowed to interact with the PV system "do not touch the system".
- Others/What?

22- If the selected PV system enables occupants to interact with it, what are the part(s) that occupants could interact with them? How? Why?

23- Did you provide all the means that enable occupants to interact with these parts easily and safely? What?

24- Did you remove some of these means through your PV procurement meetings? What? Why?

25- If the selected PV system disable occupants to interact with it, who is responsible to do the maintenance works and to fix some problems in the system during the use?

26- Have you introduced the PV system to the occupants in this project when they moved into their houses? Did the occupant know how to interact with each part of the PV system and how to get the best out of the system?

27- Are there any other comments would you like to make?

28- What new features do you think are important to add to the system in your home to improve it or your interaction with it?

I'll be analysing the information you have given me, and preparing a draft report.

I will send you a copy to review at that time.

Thank you again for your participation

Appendix 2: Interview questions - Inhabitants

Thank you very much for giving up your time to take part in this discussion today.

My name is Ziyad Frances, and I would like to begin by describing how the interview will work. The interview questions will be related to your interaction with solar PV system in your home. I am also interested in the role you may have played during the installation process, to understand if there are any problems. This will help with the design and development of more efficient solar energy technology systems for existing and future housing developments.

The interview will last for 45 minutes and take the form of short open questions covering your views. During the interview, you can talk as freely as you wish on any issues you feel are relevant.

All the information you offer will be kept entirely anonymous and will only be shared with research team members in The University of Sheffield. With your agreement, I will be recording the discussion, to catch all your comments. I will also produce a transcript of the recording, and take photographs if needed. You will then be able to review the transcript, and only after you have done so and agreed to it, will we be able to use it in our project. The recording itself, the transcript and any notes taken during the interview will be destroyed after the completion of the research. I could only retain and use the record and transcript in future research up to five years if you give an express consent in Consent form.

Before we move on, is there anything you would like to ask at this stage? Are you happy with everything?

Okay, let's start with some simple information.

The demographic information

Development address:
House number:
Participant's name:
Number of people in household:
Age:
18-24 25-34 35-44 45-54 Over 55

Gender:
ID

General questions

1- Are you the:
Owner – Tenant - Others/What

2- When did you move into this home?
Prompts: Which month?

3- What is the type of your previous home?
Prompts: House – Villa – Flat – Others/What?

4- Are there any environmental, social or economic influences in your life that have affected your energy use? If yes, What? In what way?
If no, any other influences?

5- How often are you in your home?
Prompts: Most of the time – Evening - Weekends only – Others/What?

Actors and networks

6- What position do you hold in your community?
Prompts: 1- Do you have any specific role? What is it?

7- What is the role of your community/neighbours now in developing your knowledge in relation to your interaction with your PV system or how to make the best benefit from it during your occupation of the home? **If yes,** How? In what way?

8- Were there any group discussions about PV interaction that highlighted problems?
If yes, how? Did these discussions introduce solutions?
If no, Are there any group discussions now?

9- Are there any negative issues from living in a community housing in relation to your PV system for both “provisioning” and “occupation” stage including maintenance?

PV practices, problems and changes

10- What were the reasons behind installing the PV system in your home?
Prompts: 1- Financial – Environmental – Social - Others/What?

11- Were you ever introduced to the PV system and how to use it before you moved into the house?

12- Did this guidance have any influence on your interacting with your PV system or how to make the best benefit from the generated energy? How?

13- Have you changed your way of using energy after the installation of your PV system in your home? How?

14- Did you have any experience of using PV systems before you lived here?
If yes,
Prompts: What kind of previous experience you had?

15- Did this affect your practice of interacting with your current PV system? How?

16- Are you aware of what type of PV system do you have?
Prompts: Are you allowed to touch, read or monitor the PV appliances or you are not allowed?

If you are not allowed to interact with any part of your PV system?
- Who is responsible to do that such as, doing maintenance, taking meter reading, others?
- Are you satisfied with that? Do you have any suggestions?

If you are allowed to interact with your PV system

17- What are the parts that you could interact with in your PV system?
Prompts: Are you aware of the function of each part and how to interact with it?

18- Has this interaction had any effect on your energy bills?

19- Did your interaction with your PV system meet your expectation in terms of practice/energy generation or others?

20- Are there any specific problems in your PV system or your daily interaction with any parts? If yes, what?
If no, go directly to the question (13)

21- Did these problems affect your use or interaction with the system? How? Why?

22- Did you make any change in your PV system or how you interact with the system to increase the performance? If no, go directly to question (15)
If yes, What kind of change:

23- Have any changes been adopted by other people in your neighborhood?

24- Do you know how much energy you are using every month or how much money you are paying to the supplier every month/quarter?

25- Are there any unintended consequences from having a PV system in your home?

26- What new features do you think are important to add to the system in your home to improve it or your interaction with it?

Key lessons and recommendations

27- Would you use this PV system again? If yes, Why?
If no, Why not?

28- What good practice "interaction" in relation to the different part of your PV system should be used again? Why?

29- Are there any other comments would you like to make in relation to your PV system?

I'll be analysing the information you have given me, and preparing a draft report. I will send you a copy to review at that time.

Thank you again for your participation

Appendix 3: Invitation/Information letter – Provisioning team

The University Of Sheffield.

School of Architecture

INVITATION/INFORMATION LETTER - PROVISIONING TEAM

Dear Sir/Madam,

My name is Ziyad J. Frances, and I am a Ph.D. student at the Architecture department of the University of Sheffield in the UK. I would like to invite you to take part in a research project aimed at understanding the relationship between occupants and solar energy technologies (photovoltaic systems) in low carbon community housing schemes in the UK. Initially, I would like to describe you why this research is being done and what it will involve. Please do not hesitate to ask me if there is anything that is not clear or if you would like more information.

Background and rationale of this research

In recent years, there has been a focus on installing renewable energy technologies in the UK housing sector, particularly solar energy technology (photovoltaic systems), which represents the highest percentage of domestic renewable energy installations in the UK to date. This is to help reduce carbon emissions levels from the housing sector, which represents approximately 30% of all carbon emissions in the UK. Despite good progress, solar technology does not always reach the intended design performance level. We are keen to understand why this is, particularly in relation to the practical processes of design and installation by others, and the use and maintenance by occupants.

What is the aim of this research?

The overall aim of this research is to reduce energy use through a greater understanding of the procurement and use of photovoltaic systems (PV) in low carbon community housing developments.

My research sub-aims are:

1- Understanding how people are interacting with and using solar PV technology in their everyday practice in low carbon community housing schemes in the UK.

2- Understanding how people involved in the procurement process of solar PV installations such as, architects, developers, installers, and others, have influences on how occupants subsequently use these systems.

The benefits of this study

The outcomes of this research will be very useful for designers, developers, manufacturers, and policy makers to help design and develop more efficient solar energy technology systems for existing and future housing developments. Future occupants will also benefit from an improved understanding of how these systems operate in reality. You will also be able to access publications arising from this study, on request.

What is involved in terms of my participation in the project?

I will contact you by telephone/email to arrange a meeting between us to review the procurement documents for a particular project that you were involved with contractually. These documents include drawings, specifications, instructions, contract variations (variation order), as well as decision-making notes from meetings with others during the PV procurement and installation processes. Where these documents are not available, I will arrange to conduct a semi-structured interview with you to discuss particular aspects once only for 45 minutes.

What are the possible disadvantages and risks of taking part?

The only disadvantage of taking part in this study is the time taken for completing the interview and reviewing the documents. There is zero risk to you and your documents when conducting this study. If you do decide to take part, you have this information sheet and are asked to sign and return the Expression of Interest form attached with this letter, using the paid envelope provided. If you have received this letter by email, you are asked to sign and return the Expression of Interest form by email. You will be asked to sign a Consent Form at the arranged interview after the process has been explained to you, and you have had a chance to ask any questions. You can still withdraw from this study at any time, without having to give a reason.

Will my taking part in this project be kept confidential?

All the information that I collect about you and your project during this study will be kept strictly confidential. The research is conducted in accordance with the Sheffield University policy on data storage. All data will be anonymised, and express consent will be requested in the event that photographs are taken for use in publication. The interview records and transcripts, and any data about your documents will be destroyed after the completion of the research. We will only retain and use these data up to five years (the records, transcripts and documents) in future research if you give an express consent in Consent form.

What should I do if I wish to find out more?

If you have any concerns about any aspect of this research or wish to find more, you can contact me “Ziyad Frances” or contact Professor “Fionn Stevenson”, who is the academic supervisor of this study.

What to do if a serious issue arises or I wish to complain

If you have any concerns about any serious issues or to complain you can always contact the office of the University Registrar and Secretary (registrar@sheffield.ac.uk).

Regards,
Ziyad J. Frances

Ziyad, J. Frances, PhD candidate
School of Architecture, The University of Sheffield
Building Room 9.03, The Arts Tower, Western Bank
Sheffield S10 2TN, UK
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E-mail: zjfrances1@sheffield.ac.uk

Professor Fionn Stevenson, Head of School
Co-Director Centre of Excellence in sustainable Building, Sheffield School of Architecture, The Arts Tower, Western Bank, Sheffield S10 2TN,
Telephone: ++44 (0) 114 222 0391
E-mail: f.stevenson@sheffield.ac.uk

Appendix 4: Invitation/Information letter – Inhabitants

The University Of Sheffield.

School of Architecture

INVITATION/INFORMATION LETTER - INHABITANTS

Dear Sir/Madam,

My name is Ziyad J. Frances, and I am a Ph.D. student at the Architecture department of the University of Sheffield in the UK. I would like to invite you to take part in a research project aimed at understanding the relationship between occupants and solar energy technologies (photovoltaic system) in low carbon community housing schemes in the UK. Initially, I would like to describe you why this research is being done and what it will involve. Please do not hesitate to ask me if there is anything that is not clear or if you would like more information.

Background and rationale of this research

In recent years, there has been a focus on installing renewable energy technologies in the UK housing sector, particularly solar energy technology (photovoltaic systems), which represents the highest percentage of domestic renewable energy installations in the UK to date. This is to help reduce carbon emissions levels from the housing sector, which represents approximately 30% of all carbon emissions in the UK. Despite good progress, solar technology does not always reach the intended design performance level. We are keen to understand why this is, particularly in relation to the practical processes of design and installation by others, and the use and maintenance by occupants.

What is the aim of this research?

The overall aim of this research is to reduce energy use through a greater understanding of the procurement and use of photovoltaic systems (PV) in low carbon community housing developments.

My research sub-aims are:

1- Understanding how people are interacting with and using solar PV technology in their everyday practice in low carbon community housing schemes in the UK.
2- Understanding how people involved in the procurement process of solar PV installations such as, architects, developers, installers, and even the end users, have influences on how occupants subsequently use these systems.

The benefits of this study

The outcomes of this research will be very useful for designers, developers, manufacturers, and policy makers to help design and develop more efficient solar energy technology systems for existing and future housing developments. Current/future occupants will also benefit from an improved understanding of how these systems operate in reality and how to get the best benefit from the energy produced from the system. You will also be able to access publications arising from this study, on request.

What is involved in terms of my participation in the project?

I will visit your house once only, arranged at a time of your convenience. I will use the following methods for data collection:

1- A 45 minutes interview with questions related to your everyday interaction with your solar PV system as well as, the role you may have played during the procurement process. The questions will be open-ended; the interview will be audio recorded, and photographs will be taken only if needed. The visit will be arranged at your convenience.
2- A 30 minutes video tour visiting the solar PV features in your home will follow the interview. This will give you a chance to point out any negative or positive aspects of solar PV features as you see them.

What are the possible disadvantages and risks of taking part?

The only disadvantage of taking part in this study is the time taken for completing the interview and video tour. There is zero risk to you and your home when conducting this study. If you do decide to take part, you have this information sheet and are asked to sign and return the Expression of Interest form attached with this letter, using the paid envelope provided. If you have received this letter by email, you are asked to sign and return the Expression of Interest form attached by email. You will be asked to sign a Consent Form at the arranged interview after the process has been explained to you, and you have had a chance to ask any questions. You can still withdraw from this study at any time, without having to give a reason.

Will my taking part in this project be kept confidential?

All the information that I collect about you and your home during this study will be kept strictly confidential. The research is conducted in accordance with the Sheffield University policy on data storage. All data will be anonymised, and express consent will be requested in the event that photographs are taken for use in publication. The video tour and interview records, the transcripts and the other formats of data will be destroyed after the completion of the research. We will only retain and use these data for up to five years (the records, the transcripts and the other formats of data) in future research if you give an express consent in Consent form.

What should I do if I wish to find out more?

If you have any concerns about any aspect of this research or wish to find more, you can contact me “Ziyad Frances” or contact Professor “Fionn Stevenson”, who is the academic supervisor of this study.

What to do if a serious issue arises or I wish to complain

If you have any concerns about any serious issues or to complain you can always contact the office of the university Registrar and Secretary (registrar@sheffield.ac.uk).

Many thanks for your participation in this study.
Regards,
Ziyad J. Frances

Ziyad, J. Frances, PhD candidate
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Appendix 5: Consent form – Provisioning team

The University Of Sheffield.

University of Sheffield
School of Architecture

Title of Research Project: Domestic Photovoltaic Systems: The Governance of Inhabitant Practice in Low Carbon Housing Communities

Name of Researcher: Ziyad J. Frances, Sheffield School of Architecture, The University of Sheffield, Art Tower, Western Bank, Sheffield S10 2NT

Participant Identification Number for this project: **Please initial box**

1- I confirm that I have read and understand the information/invitation sheet explaining the above research project [dd / mm / yy].

2- I have had the opportunity to ask questions about the project before signing this consent form.

3- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.

4- I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and will not be identified or identifiable in the report or reports that result from the research.

5- I agree to take part in the above research project and to give a permission to get an access to the procurement documents for a particular project that I have involved with contractually.

6- I agree to take part in the above research project and to the audio recording of my views.

7- I agree to have photographs taken and published where relevant for the study.

8- I agree for the data collected from me to be used in future research up to five years.

Name of Participant/Organisation Date ________ Signature

Name of researcher ____________ Date ________ Signature

Appendix 6: Consent form – Inhabitants

University of Sheffield
School of Architecture

Title of Research Project: Domestic Photovoltaic Systems: The Governance of Inhabitant Practice in Low Carbon Housing Communities
Name of Researcher: Ziyad J. Frances, Sheffield School of Architecture, The University of Sheffield, Art Tower, Western Bank, Sheffield S10 2NT

Participant Identification Number for this project **Please initial box**

1- I confirm that I have read and understand the information/invitation sheet explaining the above research project [dd / mm / yy]. ☐

2- I have had the opportunity to ask questions about the project before signing this form (Consent form). ☐

3- I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐

4- I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and will not be identified or identifiable in the report or reports that result from the research. ☐

5- I agree to take part in the above research project and to the audio recording of my views. ☐

6- I agree to a video recording taken during the tour of the photovoltaic system features in my home. ☐

7- I agree to have photographs taken and published where relevant for the study. ☐

8- I agree for the data collected from me to be used in future research up to five years. ☐

Name of Participant/House No ____ Date ____ Signature ____

Name of researcher ____ Date ____ Signature ____

Appendix 7: Video Tour questions – Inhabitants

Thank you very much for being willing to take part in this video tour discussion.

I would like to begin by describing how the video tour will work. The video tour questions will be related to your actual interaction with PV parts in your home. This can help to explore which PV parts in your home enable you to interact with them and to highlight if there are any problems. It will also help to identify any changes you may have made in your PV system through interacting with it.

The video tour will last for 30 minutes. With your agreement, we will walk through your home visiting your PV system. I will ask you to video each part of your PV system using a video camera while I ask questions and take notes. I will also ask you to use some parts of your PV system if possible while I video your use. I will produce a transcript of the video recording. I want to assure you that no records of the video tour will be kept with your name on them. The video tour record and transcript will be destroyed once the report is complete. I will only retain and use the record and transcript in future research if you give an express consent in consent form.

Before we move on, is there anything you would like to ask at this stage? Are you happy with everything?

The demographic information

Development address:
House number:
Participant's name:
Number of people in household:
Age: 20-25 26-35 36-45 46-55 over 56

Sex:
ID:

Video Tour questions

1- What parts does your PV system have? Where?
   Prompts:
   Solar panels – Inverter – Meter/What – Consumer unit (Fuse box) – AC and DC isolator switch - Others/What?

2- Which part(s) of your PV do system you have an interaction with them in your home? How?
   Prompt: regular interaction, were needed, no interaction

3- Is there any particular part in your PV system you want to draw my attention to at the start of our tour?

4- Are there any specific aspects in relation to your interaction with this part of your PV system you would like to highlight?
   If yes, what? Where?
   If no, go directly to question 11

5- Did this problem affect the efficiency of the system's energy generation or how to make the best use of energy produced by the system? If yes, How?

6- How did you deal with this problem?
   Prompts: Making change – Making no change – Others/What?
   If you made a change, did you make the change to the part itself or changed how you practice with it?
   Prompt: What? Where? When did you make the change?

7- Did this change enhance the efficiency of the system? If yes, How? Why?
   If no, How? Why?

8- Did you advise other members in your community to make this change?
   Prompts: If yes, how did they respond? Why?

9- If you did not make a change, why did you not make any change despite the problem?
   Prompts:
   1- Are you allowed to make any change?
   2- Do you know how to find a solution for this problem?
   3- If you are living in co-housing, are you allowed to individually make changes if you use an expert.

10- How usable are your PV features in this home? If usable, How?
   If not usable, Why?

11- Were there any issues relating to the maintenance of your PV system?
   Prompts: What? When? Why? Can you show me that?

12- Are there problems in terms of you having easy access to do maintenance effectively, safely, and with less cost? If yes,
   Prompts: 1- What is the problem?

13- What improvements could be made to your PV system or your practice with it?

14- Are there any other comments you would like to make in relation to this system?

I'll be analysing the information you gave me, and preparing a draft report. I will send you a copy to review at that time. Thank you again for your participation

Appendix 8: Ethical approval

The University Of Sheffield.

Downloaded: 12/02/2018
Approved: 08/10/2014

Ziyad Frances
Registration number: 120249299
School of Architecture
Programme: PHD in architecture

Dear Ziyad

PROJECT TITLE: Low carbon community housing governance and participation: the relationship between occupants and solar energy technology performance
APPLICATION: Reference Number 000197

On behalf of the University ethics reviewers who reviewed your project, I am pleased to inform you that on 08/10/2014 the above-named project was **approved** on ethics grounds, on the basis that you will adhere to the following documentation that you submitted for ethics review:

- University research ethics application form 000197 (dated 15/09/2014).
- Participant information sheet 002757 version 1 (15/09/2014).
- Participant information sheet 002758 version 1 (15/09/2014).
- Participant consent form 002759 version 1 (15/09/2014).
- Participant consent form 002760 version 1 (15/09/2014).

If during the course of the project you need to deviate significantly from the above-approved documentation please inform me since written approval will be required.

Yours sincerely

Michael Phiri
Ethics Administrator
School of Architecture

Appendix 9: Detailed Pre & Free coding schedule (PV Governance dimension)

Age: 35-44	The interview ID: A3	Number of people in home: 2 adults and 2 children Tenure: Mutual Home Ownership Scheme [MHOS]	Moving into the house: March-2013 Previous house: A house

Dimension	Pre/Free-Coding Categories & subcategories				Pre/Free-Coding Sub-categories	No	Descriptions	No.
Dimension (1) PV governance (actors and networks)	Provisioning team intentions in relation to inhabitants' practices of their PV system			1.1	Interaction is partially allowed	1.1.1	• *Occupants could not interact with all the PV parts. (Author: Do you mean that occupants are not allowed to interact with some part*? We could read the meter *(1.1.1)*	Co-59/60 /61
	PV provisioning actors (1.2)	Type of actor(s) (1.2.1)	Human actor	1.2.1.1	Community group (Client)	1.2.1.1.1	• I was the secretary of the LILAC company for the last five years and now I have just stopped been a secretary … Now, you are just a resident? yes … During the development phase, I was responsible for helping make all the decisions about the infrastructure, like the solar PV. So, how many and that kind of things. So, I was responsible for making choices about the environmental features like solar PV and solar thermal unit …To make decisions (1.2.1.1.2) (1.2.2.1)	Co-6/7/15
					Provisioning Inhabitant (PI)	1.2.1.1.2		
					The main contractor	1.2.1.1.3		
					Architect	1.2.1.1.4	• I was involved in the monthly project meetings with other people. Particularly, with the contractor when we made the decisions … It was mainly with the contractor … The contractor, all through the contractor (1.2.1.1.3) (1.2.2.1)	Co-8/36/25
					PV installer	1.2.1.1.5		
					Energy consultant	1.2.1.1.6	• We contracted a company to write an energy report for us. The energy report outlined the options we could implement … It (author: the report) did not directly cover the PV, because PV was not a part of our heating strategy (1.2.1.1.6) (1.2.2.1) (1.2.3.1)	Co-9/11
					Project manager	1.2.1.1.7	• We always wanted to buy as many PV panels as we could afford … LILAC made all the decisions (1.2.1.1.1) (1.2.2.1) (1.2.3.1)	Co-52/33
					PV installers	1.2.1.1.8		
					Quantity Surveyor (QS)	1.2.1.1.9	• We were aware that the Feed-in-Tariff (FIT) was decreasing in the UK during this period. So, the quicker we could finish the project, the more money we can get (1.2.1.2.1) (1.2.2.2)	Co-12
			Non-human actor	1.2.1.2	FIT	1.2.1.2.1	• So, there was the LILAC project team, and we met every month with the contractor to make those decisions … all through the contractor (1.2.1.1.3) (1.2.2.1)	Co-16/25
					Cost	1.2.1.2.2	• Yes, there were meetings with the architect but not directly for the PV system (1.2.1.1.4) (1.2.2.2) (1.2.3.1)	Co-19
					Standards (CSH-4)	1.2.1.2.3	• There was the project manager (author: A5, the name is anonymized), he worked with us for four years from the beginning … He gave us an advice … We asked 'A5' to come to our meetings to give us expert information … This is when 'A5' reed from Co-Ho Ltd, a firm specializing in project and housing management, came into our lives and became the bedrock of support for us over four long years (1.2.1.1.7) (1.2.2.2) (1.2.3.1/2)	Co-21/23/39 Documents - p.49
					Group social image	1.2.1.2.4		
					Group' environmental motivation	1.2.1.2.5		
		Role of actor(s) (1.2.2)	Mediators	1.2.2.1			• Were there any meetings with PV installer? No, they just did what we asked for. The contractor had a subsidiary company called 'x' (author: name is anonymized) and they did the PV installation … 'X' putted the solar PV on the roof (1.2.1.1.8) (1.2.2.2) (1.2.3.3)	Co-24/32
			Intermediaries	1.2.2.2			• There was a meeting with our quantity surveyor at a company called 'Z' (author: name is anonymised). He would be at the meetings and he would also give us advice in terms of money … He was always telling us what we can afford and what we cannot afford that (1.2.1.1.9) (1.2.1.2.2) (1.2.2.2) (1.2.3.1)	Co-27
		Participation stage (1.2.3)	Preparation stage	1.2.3.1				
			Design stage	1.2.3.2			• There was a meeting with the electrical installer - "the subcontractor" who was doing the electrical installations … He was called 'Y' (author: name is anonymized) … The contractor	Co-28/29/30/32

			Construction stage	1.2.3.3				has contracted him … 'Y' did all the inverters, meters and all the wiring system … They worked with 'X' (author: this was the roofing subcontractor). 'X' putted the solar PV on the roof, and then 'Y' (author: this was the M&E subcontractor) did all the inverters, meters and all the wiring system (1.2.1.1.8) (1.2.2.2) (1.2.3.3)	
			Induction stage	1.2.3.4				• My concern is about climate change. So, I would say my desire is to reduce carbon emission from our environment (1.2.1.2.5) (1.2.2.2) (1.2.3.1)	Co-1
								• Yes, they (author: Y) gave us a brief guide to show where the things were working in the house, but it was not very much to see (1.2.1.1.8) (1.2.2.2) (1.2.3.4)	Co-56
								• However, out of the blue, "… just after Christmas 2009, X (author: architect- the name is anonymised) emailed me, excited about the opportunity of a grant from the UK's Department of Energy and Climate Change, and Home and Communities Agency (HCA), which aimed to get fledgling supply chains off the ground specializing in natural materials …. Modcell had been designated one of the materials, which a grant of £20,000 per home available. That was worth £400,000 to us … The Home and Communities Agency (HCA) were officially part financial backers of our project through their Low Carbon Investments Fund (1.2.1.1.4) (1.2.2.2) (1.2.3.1)	Documents - p.56
								• In the Autumn of 2010, we enlisted the help of another close friend, Olly… We employed Olly to write us a short report that generated a number of energy options which met our principles … Olly stressed that we needed to consider three elements for an integrated approach to energy. These included energy efficiency measures through a rational use of energy-efficient appliances, an emphasis on demand reduction based upon changing resident behaviour, and only then to finally focus on low carbon and renewable energy systems as appropriate … In his report, Olly stated that the most feasible strategy was one that involved the following elements: A 29 kw/h (kilowatt peak) solar PV array across the site (1.2.1.1.6) (1.2.2.1) (1.2.3.1)	Documents - p.123/125
								• Our overall target was that we had a grant obligation to meet Level 4 of the UK Code of Sustainable Homes (CSH4) (defined as a 25 per cent reduction of the dwelling emission rate over the target emission rate … Through the grant we received, we were required to meet the UK government's Code for Sustainable Homes (CSH) Level 4 certification, achieving a %44 reduction in 2006 Building Regulation Co2 … To achieve Code for Sustainable Home (CSH4) or even the top rating of CSH5/6, we would have had to invest in further measures, including more solar PV (1.2.1.2.3) (1.2.1.2) (1.2.3.1)	Documents - p.122/125
								• The others would be a kind of image or publicity … our image is as a project, for which it is important we had a PV… Because we are a land mark project, it is important that we support that kind of technology (1.2.1.2.4) (1.2.2.2) (1.2.3.1)	Co- 4/5
	PV provisioning networks (1.3)	Discussion actors		1.3.1	Between the PIs and (1.3.1.1)	The contractor	1.3.1.1.1	• I was involved in the monthly project meetings with other people, particularly, with the contractor when we made the decisions … So, there was the LILAC project team, and we met every month with the contractor to make those decisions … Whom did you have the most contact with? The contractor … all through the contractor … Yes, there were meetings with the architect but not directly for the PV system … the kind of contract we had, the architect worked for the contractor. We had design and build contract. The architect works for the contractor. It was mainly with the contractor … The project development group was tasking to liaise to make contact with the contractor. (1.3.1.1.1) (1.2.3.1/2)	Co-8/16/25/19/18/36/38
						The project manager	1.3.1.1.2		
						The community group	1.3.1.1.3		
						The Quantity Surveyor (QS)	1.3.1.1.4		
						The architect	1.3.1.1.5	• Yes. We increased the number of Kilowatts on each house … This is because, they came to us (author: the contractor) and they said that most of the money is going to the inverter and the wiring. There was 0.75KW on each house and they said to us, we just want to give the option that you could add an extra 0.5KW for a small amount of money (1.2.3.2) (1.3.1.1.1) (1.3.2.4)	Co-46/47
						The energy consultant	1.3.1.1.6		
					Between the contractor and the sub-contractors who installed PV systems (1.3.1.2)		1.3.1.2.1		
		Discussion topics		1.3.2	The cost of the mechanical works and the allowance for renewables		1.3.2.1	• We were not involved in the choices of where things were placed in the house and some	Co-

				Enabling a grant for the project	1.3.2.2
				To design the energy strategy for the project (including PV systems or not)	1.3.2.3
				The scale/cost of individual PV systems and the annual payback from the systems (FITs)	1.3.2.4
				All the issues related to implementation of the PV systems	1.3.2.5
				The roofs accessibility for inhabitants	1.3.2.6
				Ratifying the decisions made by the Provisioning team	1.3.2.7
		Not discussed topics	Free-1	The integration of the PV appliances into homes	F- 1.1
				Load matching considerations	F-1.2
				PV maintenance- cleaning the panels	F-1.3

poor choices were made. The inverter was placed in a cupboard under the stairs, which is difficult to get to; the meter was in the hallway, in not very good place … just because it could be put somewhere more aesthetically pleasing and out of the way … We were never talked about the location of the PV parts through the design stage until I saw them … They never told us, they have never been a part of the design process of PV system. (F-1.1)	64/65/70
• There was the project manager (author: A5, name is anonymised). He worked with us for four years from the beginning … the chair of the project team meeting was 'A5' … He gave us an advice, but we (LILAC team) made the decisions … We asked the project manager to come to our meetings to give us expert information … Do you think that he had an influence in making a specific decision about the PV system? About the PV system, I don't remember, but in general as an expert yes … This is when 'A5' from CoHo Ltd, a firm specializing in project and housing management, came into our lives and became the bedrock of support for us over four long years (1.3.1.1.2)	Co-21/26/23/39/42 /documents -p.49/52/53
• There was a meeting with our quantity surveyor at a company called 'Z' (author: name is anonymized). He would be at the meetings and he would also give us advice in terms of money. Because, he was always telling us we can afford that and we cannot afford that … Our quantity surveyor had estimated that the total available budget for mechanical services in the project was just over £100,000. This figure included an allowance for renewables as well as the conventional equipment. This was not enough to cover ambitious renewables strategies … We were fairly limited in what we could achieve (1.2.3.1) (1.3.1.1.4) (1.3.2.1)	Co-27/ Documents -p.123
• LILAC made all the decisions. All those people gave us the information and we made the decisions … We had a monthly meeting with the members where we presented information and we choose as a group … LILAC member group discussions were the most effective in relation to decision-making (1.3.1.1.3) (1.2.3.1/2) (1.3.2.7)	Co-33/34/40
• I would also have chosen an inverter and meter with Wi-Fi capability. So, we could download the data somewhere by using 3G connectivity yes. The ones we have got do not have Wi-Fi … Exactly yes, but I think if we bought a meter now, we will decide to have a Wi-Fi enable (F-1.2)	Co-72/73
• Where there any group discussions now? One issue has come up is - we were unsure about how often we need to clean them (author: PV panels) and how to clean them if needed; We can't get a definitive answer (F-1.3)	Co-83
• However, out of the blue, "… just after Christmas 2009, X (author: architect- the name is anonymised) emailed me, excited about the opportunity of a grant from the UK's Department of Energy and Climate Change, and Home and Communities Agency (HCA), which aimed to get fledgling supply chains off the ground specializing in natural materials (1.3.1.1.5) (1.3.2.2) (1.2.3.1)	Documents - P.52-53
• In the Autumn of 2010, we enlisted the help of another close friend, Olly… We employed Olly to write us a short report that generated a number of energy options which met our principles … Olly stressed that we needed to consider three elements for an integrated approach to energy. These included energy efficiency measures through a rational use of energy-efficient appliances, an emphasis on demand reduction based upon changing resident behaviour, and only then to finally focus on low carbon and renewable energy systems as appropriate … In his report, Olly stated that the most feasible strategy was one that involved the following elements: A 29 kw/h (kilowatt peak) solar PV array across the site (1.3.1.1.6) (1.3.2.3) (1.2.3.1)	Documents - P. 123/125
• Why you did not put safe stairs there for each block for doing a general maintenance? Because it would cost more money to add like that thing. It is not necessary for a big cost. We only have to go there once a year … Did you discuss this point before with other procurement team? Which stage? Yes, at the design stage, because there is no point to do that, we could not justify the cost because, we only going up once a year…we could use a ladder for that. (1.2.3.2) (1.3.1.1.1) (1.3.2.6)	Co-31/32

							• Were there any meetings with PV installer? No, they just did what we asked for. The contractor had a subsidiary company called ‘x’ (author: name is anonymized) and they did the PV installation … ‘X’ putted the solar PV on the roof (1.2.3.3) (1.3.1.2.1) (1.3.2.5)	Co-24/32
	PV provisioning changes (1.4)	Stage of change	1.4.1	Preparation stage		1.4.1.1	• Yes. We increased the number of Kilowatts on each house … This is because, they came to us (author: the contractor) and they said that most of the money is going to the inverter and the wiring. There was 0.75KW on each house and they said to us, we just want to give the option that you could add an extra 0.5KW for a small amount of money. So, we took the decision at pre-construction stage to do that and it was great, because it means we have got more 29KW of electricity with a small amount of money … just that one and it was very good … Who asked for this change? Actually, the contractor has offered this change and we (LILAC group) agreed … Why? Financial. It was just to increase the FIT and get more pay back … The LILAC membership had the most influence in making decisions in relation to deciding on any change. We chose to install the most of solar PV we could afford … Yes, because, we had an accurate estimate of the annual income from the PV and the expectation at that time was positive and it worked out very well … To get us over our target of CSH4, our contractor designed in 0.75kw of PV in each home. However, it became apparent that a large part of the outlay on the PV system was the inverter and wiring rather than the panels. So, we were offered the option of upgrading each home to a 1.25kw peak array for an extra £8000 in total. We accept this, as it would seriously increase our income from the Feed-In-Tariff (1.4.1.2) (1.4.2.1.1) (1.4.3.1) (Free-2.1.1)	Co-46/47/48/50/51/52/53Documents-P.126
				Design stage		1.4.1.2		
		Type of change	1.4.2	System design changes (1.4.2.1)	Inhabitants’ increasing the scale of the individual PV systems	1.4.2.1.1		
					Inhabitants’ changing their original decision of having one big system for all the community houses to individual systems	1.4.2.1.2		
				Context changes (1.4.2.2)	Changing the accessibility to the PV panels on the roof	1.4.2.2.1		
		Reason for change	1.4.3	To increase the FIT		1.4.3.1		
				To adapt to the FIT payback polices in terms of inhabitants’ eligibility to apply for the FIT		1.4.3.2	• There was some debate about whether we should have a very big inverter for just one block to reduce the number of appliances, but we reject this idea because we will exceed the 4KW limit and it means that the FIT will be reduced because, you will be considered as a commercial installation (1.4.1.1) (1.4.2.1.2) (1.4.3.2) (Free-2.2.1)	Co-49
				To bring the building cost in line with the total budget of the project by reducing the total cost		1.4.3.3		
		Change outcomes	Free-2	Positive (Free-2.1)	Increase the annual FIT payback for each system	Free-2.1.1		
				Negative (Free-2.2)	Theoretically, reduces a system efficiency by 10-25% due to lose in the inverter and wiring	Free-2.2.1		
					Inhabitants’ inability to go on the roofs to clean their panels	Free-2.2.2	• Why you did not put safe stairs there for each block for doing a general maintenance? Because it would cost more money to add like that thing. It is not necessary for a big cost. We only have to go there once a year … Did you discuss this point before with other procurement team? Which stage? Yes, at the design stage, because there is no point to do that, we could not justify the cost because, we only going up once a year…we could use a ladder for that. (1.4.1.1) (1.4.2.2.1) (1.4.3.3) (Free-2.2.2)	Co-31/32
	Inhabitants’ participation influences		1.5				• Yes, mainly to understand about the finances. So, how much money is it going to generate? Where will that money will get spent? I would say, yes, it is positive.	Co-54
	Good practices		1.6					
	Actors’ recommendations		1.7				• I would have liked to have influence over where they (author: PV appliances) would be placed. It was too late. They never told us, they have never been a part of the design process of PV system • I would really recommend maximizing the size of any PV system, especially in countries where there is a FIT. • Exactly yes, but I think if we bought a meter now, we will decide to have a Wi-Fi enable … Even if it cost you more money? Yes.	Co-70 Documents - P. 126 Co-73/74
	General remarks						• Black text: Interview codes • Red text: video tour codes • Blue text: Documents codes (Low Impact Living: A field guide to ecological, affordable community building (Paul Chatterton, 2015) (Document-1)	

Appendix 10: Detailed Pre & Free coding schedule (PV Practice and Affordance dimension)

Age: 35-44	The interview ID: A3			Number of people in household: 2 adults and 2 children Tenure: Mutual Home Ownership Scheme [MHOS]		Moving into the house: March-2013 Previous house: A house	
Dimension	Pre/Free-Coding			Pre/Free-Coding		Descriptions	No.
	Categories		No.	Sub-categories	No.		
Dimension (2) PV practice and affordance		Inhabitants' motives to install a PV system	2.1	Environmental	2.1.1	• My concern is about climate change. So, I would say my desire is to reduce carbon emission from our environment (2.1.1)	Co-1
				Financial (FIT)	2.1.2	• It is financial definitely and definitely environmental … So, the quicker we could finish the project, the more money we can get… the financial reason was very important for us (2.1.1) (2.1.2)	Co-2/3/12/14
				Social image	2.1.3	• The others would be a kind of image or publicity. Our image is as a project, for which it is important we had a PV… Because we are a land mark project, it is important that we support that kind of technology (2.1.3) • The main thing is fantastic that we have a £4000 a year. We have free money from the sun (1.1.2) • The PV's offered the most cost-effective and highly efficient way to achieve a high rating in the (2.1.1)	Co-4/5 Co-85 Documents (p.126)
	PV practice formation (2.2)	Type of appliances	2.2.1	PV generation meter	2.2.1.1	• We could read the meter … We have to do that every three months; every resident has to give us (author: the maintenance team) their meter reading to get the FIT … Every three months we logged the amount of kilowatt used for each house. So, we had a record of all the kilowatts generated and used … The generation meter - "reading the meter" as a kind of observation and that is all … Has this interaction had any effect on your energy bills? Yes, it helps to make your bills cheaper, yes. For a 4-bedroom house, I'm just paying £250 a year, which is very cheap comparing with the other houses … The money thing, the money … Absolutely yes, because each house generates just a little bit less than uses. It is pretty good actually as expected. I have got the figures in my house (2.2.1.1) (2.2.2.1/2) (Free-1.1) (2.2.3.1/2) (Free-2.1/2/3) (1.2.1.1.1) (1.2.2.1) (1.2.1.2.1) (1.2.2.2) (Free-3.1)	Co-59/60/61/75/ 90/95/96/79
				Inverter	2.2.1.2		
				Energy generation monitor	2.2.1.3		
		Type of practice	2.2.2	Taking reading	2.2.2.1		
				Doing observation	2.2.2.2	• In the inverter there is a display, it gives information but often residents did not interact with it. I did, sometime in the beginning … I mean there might be some interesting information about the generated electricity at a specific moment … Very little in the beginning, because it gives you like daily generation readings … Do you have an interaction with the inverter? Not now. Sometimes in the beginning when I moved here. I used to look at the screen, but I lived here for a year now, so I know roughly how much energy I have produced a year and how much I have used. It will not tell me anything new. Because every year will be the same roughly within 5-10% change (2.2.1.2) (2.2.2.2) (Free-1.2) (2.2.3.2) (Free-2.1/2) (1.2.1.2.2) (1.2.2.2) (Free-3.2)	Co-62/63/91/18
		Pattern of practice	Free-1	Regular interaction	Free-1.1		
				Irregular interaction	Free-1.2		
		Effect of practice	2.2.3	Energy consumption/bill reduction	2.2.3.1		
				Understanding the PV and energy performances individually	2.2.3.2		
		Inhabitants' understanding of practice	Free-2	Components understanding	Free-2.1	• We have an obligation to use smart energy monitoring; we have got energy monitors from the electricity company, which shows the electricity generation and use in your house … I mean the energy monitor that was provided by the electric company. All of us have disconnected them and we are not using them any more … Did this happen when you moved into your house or just now? In the beginning, when we moved into our homes in 2013… I have tried to use this to see the generation level … This is the energy monitor and we have got one for every house … why you are trying to use the monitor? Because it was a requirement of our grant to monitor the energy … We have got a grant, which says you must monitor your energy … The grant really helped, and it was the largest grant with the smallest number of conditions. We had to commit to using Modcell and monitor our energy … The Home and Communities Agency (HCA) were officially part financial backers of our project through their Low Carbon Investments Fund … We had to commit to using Modcell and monitor our energy (1.2.1.1.1) (2.2.2.1) (1.2.1.2.1) (2.2.2.2)	Co-67/81/82/6/7/ 11/15 Documents (p.52-53/ 56)
				Affordance understanding	Free- 2.2		
				FIT understanding	Free-2.3		
				Positive engagement understanding	Free-2.4		
		Practice drivers	Free-3	To claim the FIT	Free-3.1		
				To understand the PV performance	Free-3.2	• I think we have understood how much energy we have used and how much energy we have generated and that is quite useful … This is the PV meter and it is very easy to read. The display comes up now. I mean- when that red-light flashes in the meter, it means the system is generating electricity ... So, from	Co-78/5/19
				To understand the energy performance	Free-3.3		

	PV practice networks – Occupancy stage (1.2)	Type of actors	1.2.1	Human actor (1.2.1.1)	Grant body policies		1.2.1.1.1	what I calculated for my house from April-2013 to April-2014, for one year, the PV cells generated 1040kw, and from what I calculated from my bills, I used 1307Kw. Basically, I just used about 250kW than what I was produced, which is great. So, the annual bill for that period was £240. (2.2.1.1) (2.2.2.2) (2.2.3.2) (2.2.3.2) (Free-2.1/2/4) (Free-3.3)	
				Non-human actor (1.2.1.2)	FIT		1.2.1.2.1		
					Skill		1.2.1.2.2	• We have to do that every three months, every resident has to give the maintenance team their meter reading to get the FIT (Free-2.3) (1.2.1.2.3) (1.2.2.2) (Free-3.1)	Co-60/61
					Social arrangement		1.2.1.2.3	• But it is quite a small display and they have put it in the storage room for the houses and outside the flat for the flats, so people do not interact with it (1.2.1.2.5) (1.2.2.2)	Co-63
					Aesthetic values		1.2.1.2.4	• So, we put the meter in a box, because as I said it is just terribly in the way. Do you mean Aesthetically? Yes, yes. It is in the wrong place … I have just covered the meter and the consumer box with a small box (1.2.1.2.4) (1.2.2.2)	Co-4/25
					Location		1.2.1.2.5		
					Cost		1.2.1.2.6	• But for the problem of connectivity, I did not make any change. Why you did not make any change despite the problem? I think the cost of doing the change, I could by a wireless smart meter or inverter but the cost will be prohibited. You know it could cost me £400 for just the smart meter. I'm not going to do that, as it will cost me lots of money with a little money back (1.2.1.2.6) (1.2.2.2)	Co-26
		Role of actors	1.2.2	Mediator			1.2.2.1		
				Intermediary			1.2.2.2	• Why are LILAC members, or particularly, the maintenance team are not cleaning the solar PV? Because it is difficult to get up there as there is no stairs there. Why you did not put a safe stair there for each block for doing a general maintenance? Because it would cost more money to add like that. It is not necessary for a big cost. We only have to go there once a year (1.2.1.2.6) (1.2.2.2)	Co-30/31
	PV practice problems (2.3)	Type of problem	2.3.1	Inhabitants' engagement problems (2.3.1.1)	Uncertainty in regard to whether or not the PV panels need to be cleaned and how frequently		2.3.1.1.1	• But it is quite a small display and they have put it in the storage room for the houses and outside the flat for the flats, so people do not interact with it (2.3.1.2.1) (2.3.1.3.1.1) (2.3.2.1)	Co-63
					Inhabitants' limited understanding of the influence of monitoring their PV systems individually on using energy efficiently in their homes		2.3.1.1.2	• Some poor choices were made. The inverter was placed in a cupboard under the stairs, which is difficult to get to … because actually, when I walked into my house, I was surprised the location of some the things. We never talked about the location of the PV parts through the design stage until I saw them. I would have liked to have influence over where they (author: PV appliances) would be placed. It was too late … the inverter is hidden and in low position so I can't see the display easily … I would prefer to put it a little bit higher so I could read the display … Yes, it has stopped my interaction with the inverter. So, if it is higher, I will interact with it more …There is an interesting displayer on the inverter, but it is quite low which makes it difficult to read … Also, the location of the Inverter inside the storage room, as I said before, it would be better if they had put it higher on the wall (2.3.1.3.1.1) (2.3.1.1.2.1) (2.3.2.1)	Co-64/70/98/101/103/17/22
				PV affordance and system design problems (2.3.1.2)	The small size of the display screen		2.3.1.2.1		
					Incompatible energy monitoring device with PV systems		2.3.1.2.2		
					Insufficient provision of Wi-Fi connectivity in the PV appliances		2.3.1.2.3		
				PV context problems (2.3.1.3)	Macro context (2.3.1.3.1)	Invisible PV appliances (inverter)	2.3.1.3.1.1	• The meter was in the hallway in not very good place … Just because it could be put in somewhere more aesthetically pleasing and out of the way… they have put the PV parts in the wrong places such as the generation meter and the isolating switch, a very poor place. It should be in a cupboard somewhere … Just the location of the meter, consumer box and PV emergency switching. It would be much better if they had put it in the storage room beside the inverter … Just to keep it out of the way, yes (2.3.1.3.1.2) (2.3.2.2)	Co-64/65/9720/21
						Location - Poor aesthetic appeal	2.3.1.3.1.2		
						Inaccessible PV appliances (PV panels)	2.3.1.3.1.3		
					Micro context (2.3.1.3.2)	Poor position of the appliances on the wall (inverter)	2.3.1.3.2.1	• What I understood from you, is that you just have a problem with the location of your meter in the house and the location of your inverter in the storage room. The other problem is the dis-connectivity between the interfaces and your computer, which disables you from understanding how much you are generating and consuming energy at different times and conditions? Participant: Yes. (2.3.1.3.1.1) (2.3.1.2.3) (2.3.2.3)	Co-24
		Effect of problem	2.3.2	Discouraged inhabitants to interact with PV appliances			2.3.2.1		
				Inhabitants' changing the visual appearance of PV appliances			2.3.2.2	• We have an obligation to use smart energy monitoring; we have got energy monitors from the electricity company, which shows the electricity generation and use in your house, but they don't work because they don't interact with our PV system … It is not calibrated to work with PV. So, it does not work … Yes, the smart meter. We all realise that the smart meters don't work … I mean the energy monitor that was provided by the electricity company. All of us have disconnected them and we are not using them any more… I have tried to use this (author: the energy generation monitor) to	Co-67/68/80/81 6/7/10/15
				Less control on energy management process			2.3.2.3		
				Occupants unable to clean their PV panels – the panels were cleaned by a professional cleaner			2.3.2.4		

					Stopped inhabitants to interact with their PV appliances (PV meter)	2.3.2.5	see the generation level … This is the energy monitor and we have got one for every house, Now, this works perfect, but the problem is when the PV starts generating, the energy number goes down …Yes, but all have disconnected for the same reason … We have got a grant, which says you must monitor your energy (2.3.1.2.2) (2.3.2.3)	
							• I would also have chosen an inverter and meter with Wi-Fi capability. So, we could download the data somewhere by using 3G connectivity yes. The ones we have got do not have Wi-Fi … It could be useful if we could download the readings. I only get a snapshot of today, but I need the whole thing … I'm looking now to add Wi-Fi connectivity to my inverter, so I could see all the data on my laptop at any time … But for the problem of connectivity, I did not make any change. Why you did not make any change despite the problem? I think the cost of doing the change, I could by a wireless smart meter or inverter but the cost will be prohibitive for me (2.3.1.2.3) (2.3.2.3)	Co-72/94/104/26
							• One issue has come up is - we were unsure about how often we need to clean them "the solar PV" and how to clean them if needed; We can't get a definitive answer … We also have a solar thermal engineer who goes once a year anyway, so he could look at PV panels also and clean them if needed (2.3.1.1.1)	Co-83/84
							• Why are LILAC members, or particularly, the maintenance team are not cleaning the solar PV? Because it is difficult to get up there as there is no stairs there… Where there any issues relating to the maintenance of your PV system? No, I mean it is just cleaning the PV on the roof once a year (2.3.1.3.1.3) (2.3.2.4)	Co-30/29
							• I think the energy monitor is interesting, but it does not really fundamentally change your behaviour, people in LILAC are already low consumers… Really, once you have monitored your inverter for a little amount of time, it is boring, it stops being interesting, it is not interesting anymore. Within a month, you know roughly how much energy you have used in your house … I used to look at the screen, but I have lived here for a year now, so I know roughly how much energy I have produced a year and how much I have used. It will not tell me anything new. Because every year will be the same roughly, within a 5-10% change (2.3.1.1.2) (2.3.2.5)	Co-69/12/18
	PV changes through practice (2.4)	Type of change	2.4.1	Practice change (2.4.1.1)	Energy usage practice change	2.4.1.1.1	• The only behavior change that I consciously do is we have the PV on the roof of the common house, which provides electricity for washing machines; we run the washing machine when it was sunny. It is really good … All the washing machines are located in the common house and so we encourage residents to set the washing machine for daylight and sunny period…it's a win-win situation if you change your behaviour. You get paid to generate electricity, and you do not have to buy it from the grid if you also use it while you generate (2.4.1.1.1) (2.4.2.1.1) (2.4.3.1)	Co-87/104 Documents (p.126)
				Technical change (2.4.1.2)	Changing the visual appearance of the PV appliances	2.4.1.2.1		
		Reason for change	2.4.2	Adaptive (2.4.2.1)	To adapt the overall energy consumption patterns to the individual PV energy generation patterns	2.4.2.1.1		
					To adapt to inhabitants' aesthetic value	2.4.2.1.2	• So, we put the meter in a box, because as I said it is just terribly in the way. Do you mean Aesthetically? Yes, yes. It is in the wrong place … I have just covered the meter and the consumer box with a small box (2.4.1.2.1) (2.4.2.1.2)	Co-4/25
		Change outcome	2.4.3	Positive/ Financially and environmentally		2.4.3.1		
		Change restrictions	Free-4	Cost		Free-4.1	• I'm looking now to add Wi-Fi connectivity to my inverter, so I could see all the data on my laptop at any time… But for the problem of connectivity, I did not make any change. Why you did not make any change despite the problem? I think the cost of doing the change, I could by a wireless smart meter or inverter but the cost will be prohibitive for me… you know it could cost me £400 for just the smart meter. I'm not going to do that, as it will cost me lots of money with a little money back (Free-4.1)	Co-104/26
				Generating green energy		Free-4.2	• I'm aware that I'm generating a lot of energy. I'm happy to still use the energy as well. I feel less guilty about using energy because I'm already generating it (Free-4.2)	Co-86
	Inhabitants' conflicts		Free-5				• I mean there might be some interesting information about the generated electricity at a specific moment … it is still quite interesting to make some observation of using energy, such as how much do you use energy to boil a kettle … Really, once you have monitored your inverter for a little amount of time, it is boring, it stops being interesting, it is not interesting anymore. Within a month, you know roughly how much energy you have used in your house … It would be nice to output the data every day, so you could see over the year exactly	Co-63/69/12/35

						• I think the energy monitor is interesting, but it does not really fundamentally change your behaviour, people in LILAC are already low consumers … Actually, just now there is a desire to have a meeting to look at our energy use and discuss ideas about how we could reduce it further • The inverter was placed in a cupboard under the stairs, which is difficult to get to … the inverter is hidden and in low position so I can't see the display easily … I think it is not too bad by putting it in the cupboard, because it makes a lot of noise … Are you satisfied with putting it in the cupboard? I think yes … And as you know the inverter is here and that is fine as we use this space for storage … Just the location of the meter, consumer box and PV emergency switching. It would be much better if they have putted it in the storage room beside the inverter (Noise/aesthetic to visibility) • Were you ever introduced to the PV system and how to use it before you moved into the house? Yes, they gave us a brief guide to show where the things were working in the house, but it was not very much to see … for the PV it was enough, because there is not much to interact with … A better explanation of the system when we move into the house? Do you mean that the explanation of your PV system was not good enough? Yes.	Co-69/76 Co-64/98/101/16/20/ Co-56/57/110/111
	Good practices	2.5				• I would say to maximise the amount of PV on the roof. Do not save money on the roof.	Co-112
	Inhabitants' recommendations	2.6	Adding Wi-Fi connectivity to the PV appliances to download the PV generation data		2.6.1	• It could be useful if we could download the readings from the inverter … Exactly yes, but I think if we bought a meter now, we will decide to have a Wi-Fi enable … Yes again, it will be nice to have Wi-Fi connectivity in the meter/inverter, so we could download the data. If we had a smart meter, we could download the readings … I would get the one with Wi-Fi enabled and integrated with consumption data … What new features do you think are important to add to the system in your home to improve it or your interaction with it? The Wi-Fi connectivity … I think a smart meter will be more useful way, so you could transfer the data literally … I can say by having a Wi-Fi capability. That will be great…have a single dashboard (on your laptop for example) to monitor energy use and energy consumption … No…really, I would have a smart meter to connect everything together and Wi-Fi connectivity for the inverter (2.6.1)	Co-94/73/108/109/107/13/34/22A
			Professional PV induction process to inhabitants when moving to their houses		2.6.2	• A better explanation of the system when we move into the house… Very clear and detailed hand-over processes when residents move into their homes is crucial. We are now exploring a home inhabitant energy guide so that members can start to interact with their homes from a more informed perspective (2.6.2)	Co-110/ Documents (p.130)
	The influence of living in community housing on PV system	Free-6	Positive (Free- 4.1)	Comparing information and sharing and Better understanding of energy performance	Free- 6.1.1	• Every three months we logged the amount of kilowatt used for each house. So, we had a record of all the kilowatts generated and used and we could compare the energy efficiency … Actually, just now there is a desire to have a meeting to look at our energy use and discuss ideas about how we could reduce it further. I think it is useful for sharing ideas …But I mean because we are low energy users anyway, I think we have understood how much energy we have used and how much energy we have generated and that is quite useful. (Free- 6.1.1/2) • Were there any group discussions about PV interaction that highlighted problems … Yes, the smart meter. We all realise that the smart meters don't work (Free- 6.1.4) • The washing machines are located in the common house and so we encourage residents to set the washing machine for daylight and sunny period (Free- 6.1.3)	Co-75/76/78 Co-80 Documents (p.126)
				Sharing idea	Free- 6.1.2		
				Encouraging behavioural change	Free- 6.1.3		
				Understanding problems	Free- 6.1.4		
	General remarks					• Black text: Interview codes • Red text: video tour codes • Blue text: Documents codes (Low Impact Living: A field guide to ecological, affordable community building (Paul Chatterton, 2015)	

Appendix 11: Detailed recommendations

Policy recommendations

1. A 'light-touch' version of the government endorsed Soft Landings package needs to be developed for domestic projects with a scheme developed by the policy makers (e.g. indirect carbon taxation) to payback the extra cost resulting from the use of the SL actor in the housing construction network.
2. New policies are needed to encourage closer collaboration between building and energy efficiency professionals and organisations, and research, in relation to developing resilient energy communities with less reliance on the national grid and to provide valuable education for community members regarding the technical and behavioural aspects of energy management in close collaboration with the design team.
3. More detailed PV and energy efficiency information should be made available at a national level for inhabitants who are particularly interested in reducing their energy use by using their PV energy efficiently. This information is also useful for the architects and contractors who are contractually obligated to install PV systems.
4. Effective training for clients, contract managers, architects, PV installers, maintenance staff, and inhabitants needs to be developed to ensure that critical details are not ignored by the provision team during all the provisioning stages. This will help to improve their general understanding of PV systems in relation to inhabitants' interaction with their PV appliances, and to understand the different influences the provisioning team governance can have on inhabitants' practices.
5. Grant bodies should specify PV monitoring requirements that encourage inhabitants to load match directly, through their consultants, as part of their grant requirements. Grant body consultants also need to be more engaged with the actual delivery of the installations in practice to ensure that all installation requirements are covered during the building construction process via appropriate guidance and provisioning PV champions.
6. New policies need to be formulated by the UK Co-housing network describing the detailed role and agency of the Provisioning Inhabitants (PIs) and their association with the other construction team and inhabitants. This role in the PC contracts needs be clearly acknowledged as a contractual role rather than a voluntary role,

to ensure their commitment to the role assigned to them and for the construction team to function properly.

Contractual recommendations

1. The early consultation of a SSM in PC projects should also be clearly defined in the contract due to the latter actor developing the PI/Client inhabitant knowledge of what the appropriate requirements are for their home technologies at the preparation stage (briefing stage), which might not be at all familiar.
2. Design and Build (DB) contracts need to be clearly worded to include the client and architect involvement beyond the preparation stage of PV provisioning process, kept advised of what is happening and consulted for their views. This is to ensure that PV installers and the main contractors do not make any mistakes at any stage of the contract process, which works against the design intention of the development in order to give PV installation, the best chance to succeed.
3. The Site Sustainable Manager (SSM), as a specialist trained in managing environmental performance, should be contractually involved in the provisioning of home technologies (e.g. PV system) from the briefing stage of the project, and directly employed by the client to ensure his/her independency during the construction works.
4. A new co-ordination role of the project manager in relation to the provisioning of home technologies should be clearly written in the contract by the client to ensure their actual engagement in this process, rather than just checking if the technologies were installed on time, which is often not happening in the presented case studies in this thesis. It is also important for either the client or contractor to employ an independent PV champion to ensure co-ordination and completion of energy specifications as per the contract.
5. Where there is no Project Manager or SSM in the building construction network of a housing project, the architect of a DB project should be contractually involved in the network after the completion of all the detailed drawings, to perform the co-ordination role between the various actors in relation to achieving the environmental targets. In the SBC contracts, the architect is already responsible to perform this role, however, this also need to be clearly worded in the contract to ensure that the latter actor do not withdraw him/herself from the home technologies provision process.

6. PV supply actors need to be integrated with the other design team in situ, and with inhabitants during operation. The former integration helps to optimise the system design and to supply the PV appliances on time, while the later integration helps to receive feedbacks from inhabitants in relation to the system design and affordance.

Practice recommendations: provisioning and occupancy

Building professionals

1. The home demonstrator should adequately discuss all the PV aspects with PV installers prior to meeting the inhabitants in their homes and should be appropriately trained to explain the affordances provided in the PV controls as one client recommended: “A better education of the staff that educating the residents to get the highest benefit of it” (Client representative- E6). Energy saving potentials and practices should be emphasised by the demonstrator during the home induction process and not assuming that inhabitants are aware of that, as one PV professional commented: “we were not really that interested in sitting down with the consumer and saying: Actually, did you know if you put your appliances on the daytime rather than running them at night it then cost you nothing” (E6).

1. Considerable design and installation team attention should be given to avoiding possible overshadowing and collection of dirt when locating the PV panels on the roof in order to achieve the designed performance.
2. Careful consideration and discussion, as a requirement, should be given by building professionals to the specifications when choosing the PV appliances in terms of the affordances offered to inhabitants to match their energy loads (e.g. Wi-Fi, feedbacks). Inhabitants cannot improve their PV affordances without replacing the old PV appliances with new ones with cost implication.
3. All PV feedback devices should be located in clearly accessible and visible locations.
4. PV systems should also include a new appliance to allow the system to be isolated from the main grid when a power cut occurs. This is to increase the resilience of the PV systems.
5. Provide inhabitants with simple guidelines (e.g. HUG) rather than a huge amount of very complex information. People always prefer to go to the point directly, and if it is interesting, they go and find out more.

6. When installing automatic monitoring systems to be managed by housing managers in NPC housing developments, it is vital that residents are also able and encouraged to engage with the monitoring in order to be able to energy load match.

Provisioning Inhabitants (PI)

1- Community members need to carefully choose a PI to represent their interest and define their role in the whole governance network. A PI can change his/her role as a representative of the inhabitants (intermediary) to a more governing role (mediator), thus representing their own interest rather than the community interest.

2- Maximising the size of PV system as recommended by one PI: “I would really recommend maximizing the size of any PV system, especially in countries where there is a FIT” (PI-A3)

3- PV integration into homes should be a part of the design process of PV system. As one PI stated: “I would have liked to have influence over where they (author: PV appliances) would be placed” (PI-A3)

Inhabitants

1. All inhabitants should be encouraged to directly monitor their PV and energy performance, rather than relying on others in order to achieve effective load matching practices.

2. PV panels must be made accessible for checking whether they need cleaning or not. All inhabitants should be appropriately educated on how to clean their panels and clearly written in the Home User Guide (HUG) as a significant maintenance issue, to ensure designed performance.

3. Where there are no collective graphs, particularly in the NPC projects, it is vital that all PV interfaces that show the performance of an individual PV system (e.g. inverter screen) are accessible for other inhabitants to see and compare the performance of their system with the performance of the other identical systems.

4. PV inhabitants should be informed by the PV demonstrator from the outset of any tariffs benefits available, if the full benefit is to be exploited.

5. Inhabitants should be informed about the significance of keeping the inverter well ventilated when working in terms of increasing the performance of the PV system. This significant technical knowledge needs to be communicated with the POs

during the PV provision process in the PC projects and with the inhabitants when handing over the houses in the NPC projects.

PV design recommendations

1. PV system should be able to be isolated from the main grid when the power cut occurs. This is to increase the system resilience to infrastructure fluctuations.
2. All PV controls, particularly the inverter, need to be sufficiently labelled to avoid inhabitants' misunderstanding when interpreting the data provided in their controls.

Other detailed recommendations made by PC and NPC inhabitants are summarized in figures A (PC inhabitants) and B (NPC inhabitants)

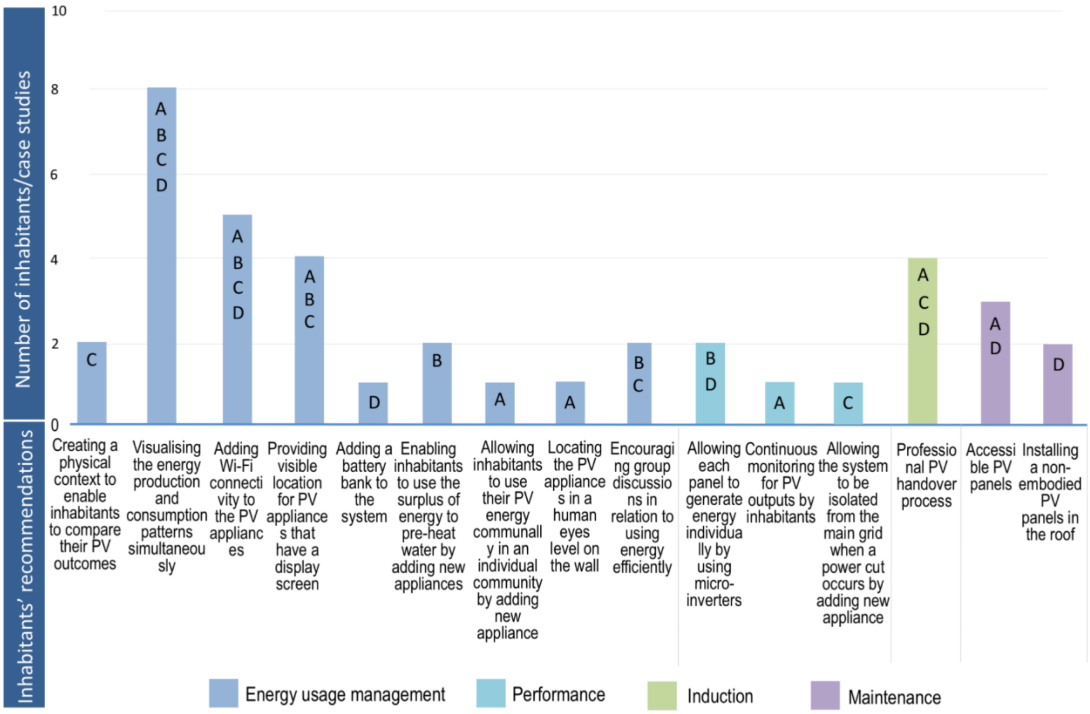

Figure A: Inhabitants' recommendations (PC case studies)

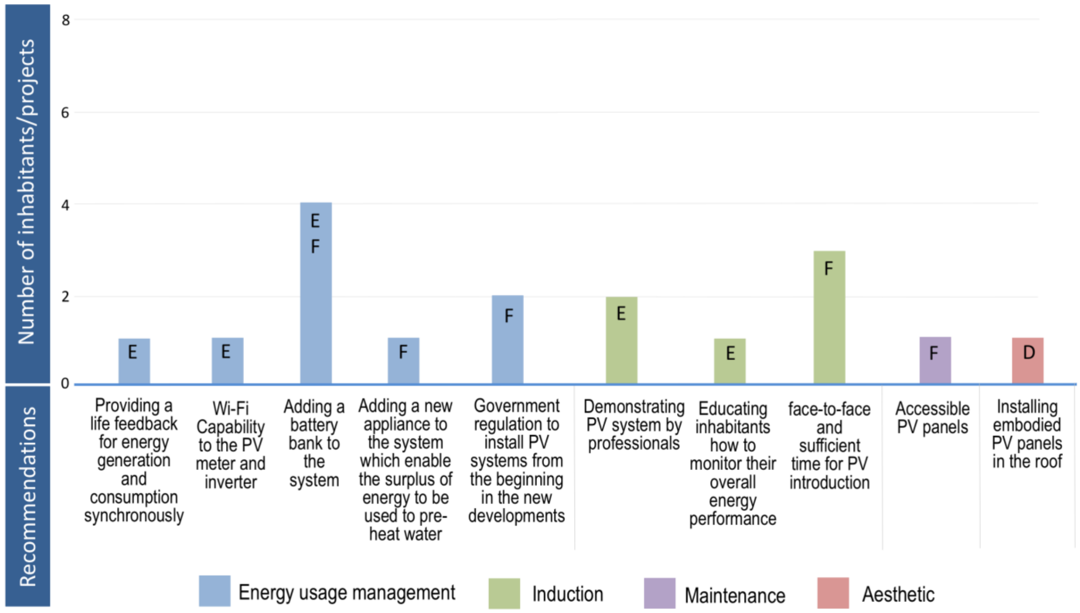

Figure B: Inhabitants' recommendation (NPC case studies)

Appendix 12: Interview coding process – Participant A3 (both for inhabitant and provisioning inhabitant (PI))

INTERVIEW GUIDE – INHABITANT/PROVISIONING INHABITANT (PI)

Thank you very much for giving up your time to take part in this discussion today.

My name is Ziyad Frances, and I would like to begin by describing how the interview will work. The interview questions will be related to your interaction with solar PV system in your home. I am also interested in the role you may have played during the installation process, to understand if there are any problems. This will help with the design and development of more efficient solar energy technology systems for existing and future housing developments.

The interview will last for 45 minutes and take the form of short open questions covering your views. During the interview, you can talk as freely as you wish on any issues you feel are relevant. You don't have to talk about anything you don't want to and you may end the interview at any time.

All the information you offer will be kept entirely anonymous and will only be shared with research team members in The University of Sheffield. With your agreement, I will be recording the discussion, to catch all your comments. I will also produce a transcript of the recording, and take photographs if needed. You will then be able to review the transcript, and only after you have done so and agreed to it, will we be able to use it in our project. The recording itself, the transcript and any notes taken during the interview will be destroyed after the completion of the research. I could only retain and use the record and transcript in future research up to five years if you give an express consent in Consent form.

Before we move on, is there anything you would like to ask at this stage? Are you happy with everything?
Okay, let's start with some simple information.

The demographic information

Development address: **Lilac Grove, Victoria Park Avenue, LEEDS LS5 3AG**
Company/Organisation name: **LILAC MHOS Ltd.**
Role of the Participant:
House number:
Participant's name:
Number of people in household: **4 (Two adults and two children)**
Age:
18-24 25-34 **35-44** 45-54 Over 55

Gender:
ID: **A3**

1

Interview questions

Section 1: General questions

1- Are you the:
Owner – Tenant - Others/What?
Participant: Owner

2- When did you move into this home?
Participant: March-2013

3- What is the type of your previous home?
Participant: A house

4- Are there any environmental, social or economic influences in your life that have affected your energy use?

Participant: Yes, Yes.
Author: What?
Participant: I would say ahhh; my concern is about climate change. So, I would say my desire is to reduce carbon emission from our environment.
Author: Do you mean that you have an environmental influence?
Participant: Yes.

5- How often are you in your home?
Participant: For me: evening and weekends, but for my family: most of the time

PV actors, network and changes (PV provisioning stage)

1- What were the reasons behind installing the PV system in your homes?

Participant: It is financial definitely and definitely environmental.
Author: Are there others?
Participant: I think, the others would be a kind of image or publicity. Our image is as a project, for which it is important we had a PV.
Author: Could you explain that a bit more?
Participant: Because we are a land mark project, it is important that we support that kind of technology.

2- What position do you hold in your community? Do you have any specific role or responsibility in your community?

Participant: I was the secretary of the LILAC company for the last five years and now I have just stopped been a secretary.
Author: Now, you are just a resident?
Participant: Yes
Author: What was your responsibility when you were a secretary in relation to the PV provisioning?
Participant: So, during the development phase, I was responsible for helping make all the decisions about the infrastructure, like the solar PV. So, how many and that kind of things. So, I was responsible for making choices about the environmental features like solar PV and solar thermal unit.

2

Comment [ZF1]: Co-1

Comment [ZJ2]: Co-2

Comment [ZJ3]: Co-3

Comment [ZJ4]: Co-4

Comment [ZF5]: Co-5

Comment [ZF6]: Co-6

Comment [ZJ7]: Co-7

3- Have you been involved in the meetings with other people (agents) when discussing issues related to the provisioning of PV system for this housing project, or you have just informed by a person about the decisions from these meetings and why these decisions have been made?

Participant: Yes, I was involved in the monthly project meetings with other people. Particularly, with the contractor when we made the decisions.
Author: In Which phase of provisioning process "design stage, installation stage, others"?
Participant: In 2009, we contracted a company to write an energy report for us. The energy report outlined the options we could implement.
Author: Ok, and what is the name of that company?
Participant: B (author: name is anonymised). They based in Spain, but it managed by a friend of mine called 'C' (author: name is anonymised). I could send you the report, because in that report he outlined some options to us and I think that Magda has already got it. Now, in that report we decided to…it did not directly cover the PV, because PV was not a part of our heating strategy, so the report was covered how we are going to heat our homes. And in that report, we decided on the MVHR, gas and central heating with solar thermal. We always wanted to buy as many PV panels as we could, because we were aware that the Feed-in-Tariff was decreasing in the UK directly during this period. So, the quicker we could finish the project, the more money we can get. Because the FIT was about 5p kw/h generated and then during this period it was decreasing and decreasing. When we involved in contract with 'D' (author: name is anonymised), it was a bout 15p Kw/h. So, it was frustrating we did not get as much, but the financial reason was very important for us, because it still generated a lot of money about £4000/year

4- What position do you hold in relation to this provisioning process?
Participant: To make decisions.

5- Who was involved in the process of your PV provisioning?

Participant: So, there was the LILAC project team, and we met every month with the contractor to make those decisions.
Author: Were there meetings with the architect?
Participant: Well, the kind of contract we had, the architect worked for the contractor. We had design and build contract. The architect works for the contractor. But, yes there were meetings with the architect but not directly for the PV system; It was with the contractor and our project manager. So, in our project team meetings, there was the project manager (author: A5, name is anonymised). He worked with us for four years from the beginning.
Author: was he a LILAC member at that time?
Participant: No, he was not a LILAC member. We were paying for him, but he also participated in decision-making for the project.
Author: Who made the decisions, 'A5' or LILAC project team?
Participant: He gave us an advice, but we (LILAC team) made the decisions.
Author: Were there any meetings with PV installer?
Participant: No, they just did what we asked for. The contractor had a subsidiary company called 'X' (author: name is anonymised) and they did the PV installation.

6- Whom did you have the most meetings with in relation to PV provisioning process?
Participant: The contractor, all through the contractor.

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Comment [ZJ11]: Co-11
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Comment [ZJ14]: Co-14
Comment [ZJ15]: Co-15
Comment [ZJ16]: Co-16
Comment [ZF17]: Co-17
Comment [ZF18]: Co-18
Comment [ZJ19]: Co-19
Comment [ZJ20]: Co-20
Comment [ZF21]: Co-21
Comment [ZJ22]: Co-22
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Comment [ZF25]: Co-25

Author: Were there meetings with a specific person?
Participant: Well, the chair of the project team meeting was 'A5', but every month, there was a representative of the contractor. Our meetings were with a various people. The contractor had a design team, a site management team, others…several people would be there. In addition, there was a meeting with our quantity surveyor at a company called 'Z' (author: name is anonymised). He would be at the meetings and he would also give us advice in terms of money. Because, he was always telling us we can afford that and we cannot afford that. And finally, there was a meeting with the electrical installer - "the subcontractor" who was doing the electrical installations.
Author: Who was the person?
Participant: He was called 'Y' (author: name is anonymised).
Author: Is it a company?
Participant: yes, the contractor contracted him. They know as an X (author: name is anonymised). They were doing the mechanical and electrical installations. So, they installed all the heat and electrical equipment. They worked with X (authors comment: this was the roofing subcontractor). X put the solar PV on the roof, and then Y (author comment: this was the M&E subcontractor) did all the inverters, meters and all the wiring system.
I have a spreadsheet I can send you, which shows the Kilowatts and the amount of Feed-in-Tariff on the Kilowatts.

7- In terms of the people involved in the PV design and provisioning process, who had the authority "power" to make decisions and in which stage?

Participant: Ultimately, LILAC made all the decisions. All those people gave us the information and we made the decisions.

8- What form did this discussion take between you and the other participants? Is it like group discussions or paired discussions or others?
Participant: We had a monthly meeting with the members where we presented information and we choose as a group.
Author: You mean group discussions?
Participant: Yes
Author: Sorry, I meant the discussions with other agent not with the LILAC members.
Participant: It was mainly with the contractor.
Author: Do you mean- paired discussions?
Participant: If we consider the LILAC development team as one, and the contractor as one, yes. But it was a group meeting when 'A5' has participated.

9- Who set the agenda for the meeting? Who is structuring the conversation in your meetings? Why?
Participant: We called it "the project development group", so LILAC has a number of task teams… the project development group was tasking to liaise to make contact with the contractor. LILAC task team was set the agenda.
Author: Do you mean that LILAC task teams led the conversation?
Participant: Yes. Sometimes, we asked 'A5' to come to our meetings to give us expert information, but he did not lead the meetings, he just gave us information.

10- Which form of discussion was the most effective in relation to decision-making about specific issues?

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Comment [ZJ27]: Co-27
Comment [ZJ28]: Co-28
Comment [ZF29]: Co-29
Comment [ZF30]: Co-30
Comment [ZJ31]: Co-31
Comment [ZF32]: Co-32
Comment [ZF33]: Co-33
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Comment [ZF39]: Co-39

Participant: LILAC member discussions were the most effective in relation to decision-making. We discussed proposals, and everybody's opinion is taken into consideration.
Author: But 'A5' as you said before, has participated with LILAC members in some meetings.
Participant: Yes, but just for giving advice.
Author: Do you think that he had an influence in making a specific decision about the PV system?
Participant: About the PV system, I don't remember, but in general as an expert yes.

11- If the meeting was held as a paired discussion, who did you have the most discussion with during the PV provisioning process? When "which phase"? Why?
Participant: Most of our meetings were group discussions. There might be some smaller meetings to clarify some points, but the group always made the decisions.
Author: With other people?
Participant: The contractor.

12- How often were your meetings have held?
Participant: The LILAC internal meetings, we would meet every two weeks, but with others every month.

13- Have any changes been made in the PV system through these discussions in your meetings?
Participant: Yes. We increased the number of Kilowatts on each house.
Author: You have increased the number of solar panels for each house?
Participant: Yes. This is because, they (author: the contractor) came to us and they said that most of the money is going to the inverter and the wiring. There was 0.75KW on each house and they said to us, we just want to give the option that you could add an extra 0.5KW for a small amount of money. So, we took the decision at pre-construction stage to do that and it was great, because it means we have got more 29KW of electricity with a small amount of money.
Author: Were there any other changes?
Participant: No, just that one and it was very good.
Author: Were there any change in the inverter, the meter, the wiring system or others?
Participant: No, there was some debate about whether we should have a very big inverter for just one block to reduce the number of appliances, but we reject this idea because we will exceed the 4KW limit and it means that the FIT will be reduced because, you will be considered as a commercial installation.

14- Who asked for this change(s)?
Participant: Actually, the contractor has offered this change and we (LILAC group) agreed.
Author: Why?
Participant: Financial. It was just to increase the FIT and get more pay back.

15- Who had the most influence in making decisions in your provisioning team in relation to deciding on any change?
Participant: The LILAC membership had the most influence in making decisions in relation to deciding on any change. We always wanted to buy as many PV panels as we could afford.

16- Did the group have any expectations about the performance of the PV system as a result of the changes agreed?
Participant: Yes, because, we had an accurate estimate of the annual income from the PV and the expectation at that time was positive and it worked out very well.

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Comment [ZF43]: Co-43
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Comment [ZJ46]: Co-46
Comment [ZF47]: Co-47
Comment [ZF48]: Co-48
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Comment [ZF50]: Co-50
Comment [ZJ51]: Co-51
Comment [ZF52]: Co-52
Comment [ZF53]: Co-53

17- Would you engage with user participation in the provisioning stage for future housing schemes involving PV system?
Participant: Yes, mainly to understand about the finances. So, how much money is it going to generate? Where will that money get spent? I would say, yes, it is positive.

Comment [ZF54]: Co-54

18- Who had the most influence in making decision in your community group in relation to PV provisioning process?
Participant: The all group meeting.
Author: Did anyone have more power?
Participant: No.

Comment [ZJ55]: Co-55

19- Were you ever introduced to the PV system and how to use it before you moved into the house?
Participant: Yes, they (author: Y subcontractor) gave us a brief guide to show where the things were working in the house, but it was not very much to see.
Author: You mean when you moved to this house?
Participant: Yes.
Author: Was it enough to understand how the system is working and how to get the best benefit from the system?
Participant: Ahhhhh, for the PV it was enough, because there is not much to interact with.
Author: Did you have any previous experience in using the PV system?
Participant: No.
Author: Could I see and review your previous meeting reports in relation to your PV system?
Participant: There were not specific meetings on PV. It is just a little bit everywhere. So, it is very difficult.
Author: Well, let's move now to section three which is about the design intention.
Participant: Ok, great.

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Comment [ZF57]: Co-57

Comment [ZF58]: Co-58

The design intention

20- What type of PV system was selected for this scheme by your provisioning team?
Participant: Occupants could not interact with all the PV parts.
Author: Do you mean that occupants are not allowed to interact with some part?
Participant: We could read the meter.
Author: But this is a kind of interaction?
Participant: Yes. We have to do that every three months, every resident has to give us their meter reading to get the FIT.
Author: Any other interaction with other parts, such as an interaction with inverter, consumer box or isolation switches?
Participant: No… in the inverter there is a display, it gives information but often residents did not interact with it. I did, sometime in the beginning.
Author: Why do you expect that other residents in your community are not interacting with the inverter?
Participant: I mean there might be some interesting information about the generated electricity at a specific moment, but it is quite a small display screen, and they have put it in a hidden location, in the storage room for the houses and outside the flats, for the flats, so people do not interact with it.

Comment [ZF59]: Co-59

Comment [ZJ60]: Co-60

Comment [ZJ61]: Co-61

Comment [ZF62]: Co-62

Comment [ZF63]: Co-63

21- Did you provide all the means that enable occupants to interact with these parts easily and safely?

Participant: Well, we were not involved in the choices of where things were placed in the house, and some poor choices were made. The inverter was placed in a cupboard under the stairs, which is difficult to get to; the meter was in the hallway, in not a very good place.
Author: Why?
Participant: Just because it could be put somewhere more aesthetically pleasing and out of the way.
Author: You are referring to aesthetical aspects, not about the performance?
Participant: Exactly, yes. And we have an obligation to use smart energy monitoring, we don't have smart meters, but we have an obligation to use smart energy monitoring, we have got energy monitors from the electricity company which shows the electricity generation and use in your house, but they don't work because they don't interact with our PV system.
Author: Why?
Participant: I don't know. It is like a technical fault because, when the sunshine and the PV go on (the inverter turns on), the monitor's reading goes down. It is not calibrated to work with PV. So, it does not work.
Author: Do you think it would be useful for you, as a resident if the provided energy monitor worked with your PV system properly?
Participant: I think the energy monitor is interesting, but it does not really fundamentally change your behaviour, people in LILAC are already low consumers. But, it is still quite interesting to make some observations of using energy, such as how much do you use energy to boil a kettle.

Comment [ZF64]: Co-64
Comment [ZF65]: Co-65
Comment [ZF66]: Co-66
Comment [ZF67]: Co-67
Comment [ZJ68]: Co-68
Comment [ZF69]: Co-69

22- Did you remove some of these means through your PV provisioning meetings?
Participant: No, because actually when I walked into my house, I was surprised the location of some the things. We never talked about the location of the PV parts through the design stage until I saw them. I would have liked to have influence over where they (author: PV appliances) would be placed. It was too late. They never told us, they have never been a part of the design process of PV system.
Author: If you were informed about the location of PV parts before installation, would you make changes?
Participant: Yes. I would say look, do not put this here…etc.
Participant: I would also have chosen an inverter and meter with Wi-Fi capability. So, we could download the data somewhere by using 3G connectivity. The ones we have got do not have Wi-Fi.
Author: But it might be cheaper?
Participant: Exactly yes, but I think if we bought a meter now, we will decide to have a Wi-Fi enable.
Author: Even if it cost you more money?
Participant: Yes.

Comment [ZF70]: Co-70
Comment [ZF71]: Co-71
Comment [ZF72]: Co-72
Comment [ZF73]: Co-73
Comment [ZF74]: Co-74

23- Are there any comments would you like to make?
Participant: No thing, we have covered everything.

24- What new features do you think are important to add to the system in your home to improve it or your interaction with it?
Participant: We discussed the previously
Author: Now we will move to another section, which is about living in Co-housing scheme.

Actors and network: PV occupation stage

1- What is the role of your community/neighbours now in developing your knowledge in relation to your interaction with your PV system or how to make the best benefit from it during your occupation of the home?
Participant: Every three months we logged the amount of kilowatt used for each house. So, we had a record of all the kilowatts generated and used and we could compare the energy efficiency.
Author: And how does this affect your behaviour of using energy in your house?
Participant: Actually, just now there is a desire to have a meeting to look at our energy use and discuss ideas about how we could reduce it further. I think it is useful for sharing ideas. . But I mean because we are low energy users anyway, I think we have understood how much energy we have used and how much energy we have generated and that is quite useful.
Author: Are you happy with your energy consumption in relation to your energy generation from your PV system and why?
Participant: Yes, Absolutely yes, because each house generates just a little bit less than uses. It is pretty good actually as expected. I have got the figures in my house.

2- Were there any group discussions about PV interaction that highlighted problems?
Participant: Yes, the smart meter. We all realise that the smart meters don't work.
Author: But you do not have a smart meter in you PV system?
Participant: Yes, but I mean the energy monitor that was provided by the electric company. All of us have disconnected them and we are not using them anymore.
Author: Did this happen when you moved into your house or just now?
Participant: In the beginning, when we moved into our homes in 2013.
Author: Were there any group discussions now?
Participant: One issue that has come up is - we were unsure about how often we need to clean them (author: PV panels) and how to clean them if needed; We can't get a definitive answer. So, what we will probably do is going into the roof and decides if they need to clean.
Author: How can you get access to the roof?
Participant: By using a ladder. We also have a solar thermal engineer who goes once a year anyway, so he could look at PV panels also and clean them if needed.

3- Are there any negative issues from living in a community housing in relation to your PV system for both "provisioning" and "occupation" stage including maintenance?
Participant: Ammm, no, I don't think so.
Author: Is there anything else you want to say in relation to being a member of the community group and having use of a PV system?
Participant: No. Basically, the main thing is fantastic that we have a £4000 a year. We have free money from the sun.
Author: Now let us move to the next section, which relates to your practice of using PV system.

Comment [ZF75]: Co-75
Comment [ZF76]: Co-76
Comment [ZF77]: Co-78
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Comment [ZF79]: Co-80
Comment [ZF80]: Co-81
Comment [ZF81]: Co-82
Comment [ZF82]: Co-83
Comment [ZF83]: Co-84
Comment [ZJ84]: Co-85

PV practices, problems and changes

4- Have you changed your way of using energy after the installation of your PV system in your home?

Participant: Not really, No. Because I'm quite a low-user of energy but also, I'm aware that I'm generating a lot of energy. I'm happy to still use the energy as well. I feel less guilty about using energy because I'm already generating it. The only behavior change that I consciously do is we have the PV on the roof of the common house, which provides electricity for washing machines; we run the washing machine when it was sunny. It is really good.

5- Did you have any experience of using PV systems before you lived here?
Participant: No

6- Are you aware of what type of PV system do you have?
Participant: Ammm, yes, but I can't remember. I have got some technical sheets somewhere, but I don't remember.
Author: Could you send me this technical sheet by email?
Participant: Yes. On each unit, there are 5 of 0.25kw panels, which is 1.25kw for each house.

7- What are the parts that you could interact with in your PV system?
Participant: The generation meter - "reading the meter" as a kind of observation and that is all.
Author: Is there any interaction with the inverter?
Participant: very little in the beginning, but it gives you like daily generation readings.
Author: It just gives you information as percentages?
Participant: It does have numbers. It is like amount of Kilowatt generated now and in the last 24 hours.
Author: Do you think it is useful or not?
Participant: it could be useful if we could download the readings from the inverter. I only get a snapshot of today, but I need the whole thing.

8- Has this interaction had any effect on your energy bills?
Participant: yes, it helps to make your bills cheaper, yes. For a 4-bedroom house, I'm just paying £250 a year, which is very cheap comparing with other houses.

9- Did your interaction with your PV system meet your expectation "the intention design" in relation to:
Participant: Oh yes.
Author: How?
Participant: The money thing, the money. Because each house generates just a little bit less than it uses. It is pretty good - actually as expected. I have got the figures in my house …from what I calculated for my house from April 2013 to April 2014, for one year, the PV system generated 1040kW, and from what I calculated from my bills, I used 1307kW. Basically, I just used about 250kW more than what I have produced, which is great

10- Are there any specific problems in your PV system or your daily interaction with any parts?
Participant: As I mentioned before, they have put the PV parts in the wrong places such as the generation meter and the isolator switch, a very poor place. It should be in a cupboard somewhere.

Comment [ZF85]: Co-86
Comment [ZJ86]: Co-87
Comment [ZJ87]: Co-88
Comment [ZF88]: Co-89
Comment [ZF89]: Co-90
Comment [ZF90]: Co-91
Comment [ZF91]: Co-92
Comment [ZJ92]: Co-93
Comment [ZF93]: Co-94
Comment [ZF94]: Co-95
Comment [ZF95]: Co-96
Comment [ZJ96]: Co-97

Author: But they might intend to do that. For example, to draw your attention about its presence. Do you think?
Participant: May be yes. The other way around, the inverter is hidden and in low position so I can't see the display easily.
Author: Is it in the same place as 'A2'?
Participant: Yes, the same. It is difficult to see it.
Author: Another member of LILAC has said that the inverter is generating heat through operation; do you think that putting it in the cupboard with less ventilation might decrease its performance?
Participant: Oh, I do not know. Do inverters generates heat?
I think it is not too bad by putting it in the cupboard, because it makes a lot of noise.
Author: Are you satisfied with putting it in the cupboard?
Participant: I think yes, I would prefer to put it a little bit higher so I could read the display.
Author: What about the isolated switches?
Participant: I have never touched them.

Comment [ZF97]: Co-98
Comment [ZF98]: Co-99
Comment [ZJ99]: Co-100
Comment [ZF100]: Co-101
Comment [ZJ101]: Co-102

11- Did these problems affect your use or interaction with the system?
Participant: Yes, it has stopped my interaction with the inverter. So, if it is higher, I will interact with it more. I'm looking now to add Wi-Fi connectivity to my inverter, so I could see all the data on my laptop at any time.
Author: Is it possible to do that without changing the inverter?
Participant: Not sure, I don't know.

Comment [ZJ102]: Co-103
Comment [ZJ103]: Co-104

12- Did you make any change in your PV system or how you interact with the system to increase the performance?
Participant: In my house?
Author: Yes.
Participant: No. There is nothing to change.

13- Are there any unintended consequences from having a PV system in your home?
Participant: Yes, just the energy monitor does not work.
Author: Is it a negative, positives or normal consequence?
Participant: Of course, negative.

Comment [ZF104]: Co-105
Comment [ZF105]: Co-106

14- What new features do you think are important to add to the system in your home to improve it or your interaction with it?

Participant: Ahhh…The Wi-Fi connectivity.
Author: anything about your meter?
Participant: Yes again, it will be nice to have Wi-Fi connectivity in the meter/inverter, so we could download the data. If we had a smart meter, we could download the readings.

Comment [ZJ106]: Co-107
Comment [ZF107]: Co-108

Key lessons and recommendations

15- Would you use this PV system again?
Participant: Oh no, because I would get the one with Wi-Fi enabled and integrated with consumption data.

Comment [ZJ108]: Co-109

16- What good practice "interaction" in relation to the different part of your PV system should be used again?
Participant: A better explanation of the system when we move into the house.

Comment [ZJ109]: Co-110

Author: Do you mean that the explanation of your PV system was not good enough?
Participant: Yes.
Author: Oh, sorry for misunderstanding, I'm saying here the good practice in relation to the different part of your PV system should be used again?
Participant: Haaa, I would say to maximise the amount of PV on the roof. Do not save money on the roof.

Comment [ZF110]: Co-111

Comment [ZJ111]: Co-112

17- Are there any other comments would you like to make?
Participant: No, very comprehensive.

I'll be analysing the information you have given me, and preparing a draft report. I will send you a copy to review at that time.

Thank you again for your participation

Appendix 13: Video tour coding process – Participant A3 (Inhabitant)

VIDEO TOUR GUIDE – INHABITANT A3

Thank you very much for being willing to take part in this video tour discussion.

I would like to begin by describing how the video tour will work. The video tour questions will be related to your interaction with PV parts in your home. This will help us to understand which PV parts in your home enable you to interact with them and to highlight if there are any problems. It will also help to identify any changes you may have made in your PV system through interacting with it.

The video tour will last for 30 minutes. With your agreement, we will walk through your home visiting your PV system. I will video each part of your PV system using a video camera, ask questions and take notes. I will also ask you to show me each parts of your PV system if possible while I ask questions and make a video. I will produce a transcript of the video recording. I want to assure you that no records of the video tour will be kept with your name on them. The video tour record and transcript will be destroyed once the report is complete. I will only retain and use the record and transcript in future research if you give an express consent in consent form.

Before we move on, is there anything you would like to ask at this stage? Are you happy with everything?

The demographic information

Development address: **Lilac Grove, Victoria Park Avenue, LEEDS LS5 3AG**
House number:
Participant's name:
Number of people in household: **4 (Two adults and two children)**
Age:
18-24 25-34 **35-44** 45-54 Over 55

Gender: **Male**
ID: **A3**

1

Video tour questions

1- What parts does your PV system have? Where?
Prompts:
Solar panels? **Participant:** Yes
Inverter? **Participant:** Yes
Meter? **Participant:** Yes
Author: Meter for what
Participant: For electricity generation from the system.
AC and DC isolator switch/ What? **Participant:** Yes, I have that.
Others/What? **Participant:** Nothing.

2- Which part(s) of your PV system do you have an interaction with in your home?

How? (R= regular), (W= where needed), (N= NO interaction)

Solar panels? **Participant:** No

Inverter? **Participant:** Where needed

Meter? **Participant:** R

AC and DC isolator switch? **Participant:** No

Others/What? **Participant:** No

Author: Did you use the AC and DC isolator switch before?
Participant: No -
but presumbly, in the future when I need to do that.

3- Is there any particular part in your PV system you want to draw my attention to at the start of our tour?
Participant: Ah, no.
Author: Do you want to start with your meter?
Participant: Yes. So, we put the meter in a box, because as I said it is just terribly in the way.
Author: Do you mean Aesthetically?
Participant: Yes, yes. It is in the wrong place.
This is the PV meter and it is very easy to read. The display comes up now.
Author: Could you read the numbers easily?
Participant: Oh yes. 1925 yes. It's great, I mean- when that red-light flashes in the meter, it means the system is generating electricity.
I did connect this device to it to try to see if I could solve the problem with the energy monitor, but it did not work. I have tried to use this to see the generation level.
Author: How can you know that from this device?
Participant: By providing us an energy monitor from the energy company. They said: try adding one of these, but it did not work so I have now stopped trying to solve the problem.
Author: Is it the problem that you said before in the interview?

Comment [ZF1]: Co-1

Comment [ZF2]: Co-2

Comment [ZF3]: Co-3

Comment [ZF4]: Co-4

Comment [ZF5]: Co-5

Comment [ZJ6]: Co-6

Participant: Yes. I will show you the energy monitor… This is the energy monitor and we have got one for every house. Now, this works perfect, but the problem is when the PV starts generating, the energy number goes down. I do not know what it does, because it conflicts with the wiring system. So, I called the company who make the monitor; they said try adding this device, but it still does not work. I think there is a solution but it is very complicated, so I have left it for now.
Author: What kind of solution?
Participant: I do not know exactly. I need to find somebody knows this.
Author: All the residents have this monitor?
Participant: Yes, but all have disconnected for the same reason.
Author: No one has shown me this monitor or referred to the problem.
Participant: They have probably forgotten, because we don't use them anymore.
Author: And why you are trying to use the monitor?
Participant: because it was a requirement of our grant to monitor the energy.
Author: And how does this affect your energy use?
Participant: Really, once you have monitored your inverter for a little amount of time, it is boring, it stops being interesting…it is not interesting anymore. Within a month, you know roughly how much energy you have used in your house.
Author: Do you mean that this monitor is not useful even if it works properly?
Participant: I think a smart meter will be more useful way, so you could transfer the data literally.
Author: Which meter would you want to be a smart meter, the one inside or outside?
Participant: Both of them, because I could interface all. But now, they all are disconnected.
Author: Did the energy supplier provide you with this monitor for free?
Participant: We just paid £20 each.
Author: Should this monitor be provided by your PV supplier?
Participant: It wasn't a requirement of PV our supplier. We have got a grant, which says you must monitor your energy. So, we just got these for £20. And as you know the inverter is here and that is fine as we use this space for storage. We have got another isolating switch here, AC/DC isolating switches. There is an interesting display screen in the inverter, but it is quite low which makes it difficult to read.
Author: Do you have an interaction with the inverter?
Participant: Not now. Sometimes in the beginning when I moved here. I used to look at the screen, but I have lived here for a year now, so I know roughly how much energy I have produced a year and how much I have used. It will not tell me anything new. Because every year will be the same roughly, within a 5-10% change. So, from what I calculated for my house from April-2013 to April-2014, for one year, the PV cells generated 1040kw, and from what I calculated from my bills, I used 1307kW. Basically, I just used about 250Kw more than what I have produced, which is great. So, the annual bill for that period was £240. The money generated here actually went to LILAC. So, in a way that bill would be zero, but the money went to LILAC not to me.
Author: Can I ask you some more questions?
Participant: Yes.
Author: Are there any specific aspects in relation to your interaction with the part of your PV system you would like to highlight?

Comment [ZF7]: Co-7
Comment [ZF8]: Co-8
Comment [ZF9]: Co-9
Comment [ZF10]: Co-10
Comment [ZJ11]: Co-11
Comment [ZJ12]: Co-12
Comment [ZJ13]: Co-13
Comment [ZF14]: Co-14
Comment [ZJ15]: Co-15
Comment [ZJ16]: Co-16
Comment [ZJ17]: Co-17
Comment [ZF18]: Co-18
Comment [ZF19]: Co-19

3

Participant: Just the location of the meter, consumer box and PV emergency switching. It would be much better if they had put it in the storage room.
Author: Why?
Participant: Just to keep it out of the way, yes.
Also, the location of the Inverter inside the storage room, as I said, it would be better if they had put it higher on the wall.
Author: Anything in relation to:
- Size? **Participant:** No.
- Colour? **Participant:** No
- The use of other technology? **Participant:** No… really, I would have had a smart meter to connect everything together and Wi-Fi connectivity for the inverter.
- Safety requirement? **Participant:** No
- Maintenance or replacement cost? **Participant:** No maintenance at the moment.
Author: Not just for the equipment inside you home, but for solar Panels also?
Participant: No.
Author: What I understood from you, is that you just have a problem with the location of your meter in the house and the location of your inverter in the storage room. The other problem is the dis-connectivity between the interfaces and your computer, which disables you from understanding how much you are generating and consuming energy at different times and conditions?
Participant: Yes.

4- Did this problem affect the efficiency of the system's energy generation or how to make the best use of energy produced by the system?
Participant: No.

5- How did you deal with these problems?
Participant: The problem is not so big, and there are not any structural problems. So, I have not made a big change. I have just covered the meter and the consumer box with a small box. But for the problem of connectivity, I did not make any change.

6- Why you did not make any change despite the problem?
Participant: I think the cost of doing the change, I could buy a wireless smart meter or inverter, but the cost will be prohibitive for me. You know it could cost me £400 for just the smart meter. I'm not going to do that, as it will cost me lots of money with a little money back.
Author: Are you allowed to make any change individually without going to the management team?
Participant: Yes, because you will be doing an upgrade for your house, you will be doing an addition for your house.

7- How usable are your PV features in this home?
Participant: It is great… it is easy to use.

8- Were there any issues relating to the maintenance of your PV system?
Participant: No, I mean it is just cleaning the PV on the roof once a year.
Author: Just that one?
Participant: Yes.
Author: And as you said before, the heating engineer has done it for free?
Participant: Yes.

Comment [ZF20]: Co-20
Comment [ZJ21]: Co-21
Comment [ZJ22]: Co-22
Comment [ZF23]: Co-22A
Comment [ZF24]: Co-23
Comment [ZF25]: Co-24
Comment [ZJ26]: Co-25
Comment [ZF27]: Co-26
Comment [ZF28]: Co-27
Comment [ZF29]: Co-28
Comment [ZF30]: Co-29

4

Author: Why are LILAC members, or particularly, the maintenance team not cleaning the solar PV?
Participant: Because it is difficult to get up there as there is no stairs there.
Author: Why you did not put safe stairs there for each block for doing general maintenance?
Participant: Because it would cost more money to add a thing like that. It is not necessary for a big cost. We only have to go there once a year.
Author: Did you discuss this point before with other procurement team? Which stage?
Participant: Yes, at the design stage, because there is no point to do that, we could not justify the cost because, we are only going up once a year. We could use a ladder for that.
Author: How can you cover the safety requirement by using a ladder?
Participant: We have a working at a high agreement, so we use a ladder and the responsible person.

9- What improvements could be made to your PV system or your interaction with it?
Participant: I can say by having a Wi-Fi capability. That will be great… have a single dashboard (on your laptop for example) to monitor energy use and energy consumption.
Author: Anything in relation to your meter?
Participant: It would be nice to output the data every day, so you could see over the year exactly.

10- Are there any other comments you would like to make in relation to this system?
Participant: No.

I'll be analysing the information you and others gave me, and preparing a draft report. I will send you a copy to review at that time.

Thank you again for your participation

Comment [ZJ31]: Co-30

Comment [ZJ32]: Co-31

Comment [ZJ33]: Co-32

Comment [ZF34]: Co-33

Comment [ZJ35]: Co-34

Comment [ZJ36]: Co-35