Sustainable development in the UK car industry using bio-based materials as an example: an analysis of EU automotive legislation.

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Abstract

The European automotive sector faces a number of sustainability challenges including the consumption of significant amounts of raw materials. The use of bio-based materials, i.e. those made from living organisms, as opposed to metals or plastics from non-renewable fossil fuels, has been hailed as one mode of addressing this challenge due to their lightweight structure and renewable supply. The increased adoption of biomaterials is however shaped and constrained by existing legislative frameworks. Of particular note are the EU's emissions regulation, (EC, 2009) governing car emissions, the End of life vehicle directive (EC, 2000) covering car disposal and the Circular Economy (CE) package (EC, 2014) which seeks to encourage reuse and recycling rather than disposal.

This thesis analyses EU policies and their application and effect at the UK level to establish if and how they facilitate or block the uptake of biomaterials within the European automotive sector. The thesis draws upon expert interviews and documentary analysis to make an empirical and methodological contribution to broader sustainability transitions theory by examining the impact of extant legislation upon sustainable innovation. The thesis suggests that the multi-level perspective, which has been used to explain the adoption of new sustainable technologies, should be amended to take the legislative regime more explicitly into account.

Specifically the analysis shows that whilst emissions legislation has been largely neutral in its effects, the ELV and CE packages present potential barriers to the increased adoption of biomaterials in this sector. There are also inconsistencies between the legislation which hamper their effective implementation. The analysis implies that the promotion of sustainable material innovation in the car industry requires particular attention at the supranational legislative level to prevent unsustainable path dependency and permit legislators to strategically manage the regime of automotive legislation.

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Authors Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

1 Introduction

1.1 Introduction

This thesis investigates the prospects for the uptake of biomaterials in the automotive sector in Europe. It critically engages with transitions theory by explicitly considering the role of legislation in shaping the adoption of biomaterials by the sector. Empirical analysis of three central pieces of EU automotive legislation reveals both obstacles and opportunities to the adoption of bio-based materials but also the importance of the national political context. The thesis thereby makes both an empirical and theoretical contribution to the wider field of transition studies by asserting the importance of the political context in both the formulation and implementation of legislation. By focussing on legislation, it shifts attention to a neglected aspect of the literature and repositions regulatory authorities as important actors within the transitions process. This chapter provides an introduction to the later discussion by providing some background on sustainable innovation, the automotive sector and the adoption of biomaterials. It also briefly introduces the case studies and the research questions which frame the study.

1.2 Sustainable Innovation in the Automotive Sector

Society faces the challenge of sustained economic development at a time of increased environmental pressure and declining resources. Mobility is acknowledged as a key driver of economic growth (Eddington, 2006; Stern, 2006) facilitated by relatively accessible fossil fuels to contribute to higher living standards over the last century (Smil, 1994). But whilst petroleum's concentrated energy permits global supply chains and international trade, the transport sector is a major contributor to greenhouse gas (GHG) emissions with the automotive sector predominantly responsible (Sims and Schaeffer, 2014; Chapman, 2007). GHG emissions from this sector have also increased at a faster rate than any other energy end-use sector despite efficiency improvements (Sim and Schaeffer, 2014), particularly within Europe, where transport emissions continue to rise (EEA, 2015). These emissions generated throughout the life-cycle of the car, but particularly in manufacture and use, are linked to global warming as well as contributing to wider air and land pollution (EEA, 2015). The mass car industry is also a major consumer of finite raw materials, including steel, rubber, petro-chemicals and petroleum-derived plastics with resource extraction also negatively impacting the environment (Berners-Lee and Clarke, 2010).

Unruh (2000) refers to the "carbon lock-in" which describes how established investment, prevailing patterns of usage, legislation, institutions, and even patterns of thought support the existing *status quo*. Alternative energy and material sources must also break into an established market without a significant price advantage (Porter and Van der Linde, 1995a). Established industries such as steel and plastics, which benefitted from exploitation of "cheap oil" have also shaped the applicable legislation so that more sustainable products, practices and materials are disadvantaged (Geels, 2013;Walker, 2000). There is thus an urgent need to understand both how existing industrial sectors might rapidly innovate and how legislation can adjust to reflect and facilitate this transition.

This is particularly true of the automotive sector since the basic design of a car is little changed in over a century: an internal combustion engine running on petrol with a metal body on top (Wells and Nieuwenhuis, 2012; Wells, 2010). Dominated by large trans-national firms at the apex of a complex supply chain of much smaller firms and heavily capitalised with large, sunk investment in manufacturing plant, financial and legislative barriers to market entry are high (Wells, 2010). Intense cost-competition has created complex international supply chains but encouraging this chain to innovate is difficult given the embedded capital investment and since limited information may be shared along its often multi-national length (Sturgeon and Van Biesebroeck, 2009). Innovation in this sector is therefore often focussed on gradual, incremental technological improvements rather than radical redesign (Wells *et al.,* 2012). Despite environmental concerns, as a financially successful sector there has been little incentive to change and the sector's importance has meant that national governments are often reluctant to challenge or legislate significantly against the industry. Radically different cars, with reduced environmental impact, such as electric vehicles (Steinhilber *et al*., 2013) or concept cars made of bio-materials such as the Biofore (UPM, 2015) or Rasa (Wells, 2016) are limited in production, expensive and have not yet gained widespread acceptability.

1.3 The problem

The European Union (EU) has taken a lead in initiating legislation to encourage automotive firms to mitigate the environmental impact of cars (Wurzel and Connelly, 2011). Whilst the legislation seeks to create a common market with shared environmental standards, these shared standards also benefit car makers, reducing costs through economies of scale. EU legislation, such as EC443/2009 (European Commission (EC), 2009) has required manufacturers to reduce carbon emissions in the use phase by designing improved fuel economy cars. Car manufacturers must ensure that cars are produced with average fleet carbon dioxide (CO_2) emissions of 130 grams per km (g per km) by 2015 and 90g per km by 2020 (EC443/2009). The End of Life Vehicle Directive (ELV) (EC 2000/53/EC) charges EC manufacturers with a 95% recovery and 85% recycling target by 2015 to reduce vehicle waste. However whilst current legislation focuses on the use phase of car, efforts to de-carbonise energy supplies and concerns over resource shortages and waste, encourage consideration of the material, manufacturing and disposal phases.

Theories on alternatives to current material production and consumption patterns suggest the need for a variety of solutions, including improved management techniques to handle material supplies and recycling (Allwood *et al.*, 2011) and material choice and behavioural-driven demand reductions (Chapman, 2007). Car manufacturers have primarily focussed on incremental technological solutions to improve performance, but continued improvement requires more radical innovation. However this may be constrained or facilitated by the legislative framework.

Recently it has become increasingly recognised that a significant sustainability improvement is possible through mass reduction (Cabrera Serrenho and Allwood, 2016): a lighter vehicle generally requires less material, but also produces fewer emissions in use. Light-weighting may be achieved by improved design and smaller size but also through the use of lighter materials, including polymers and plastics, rather than metals. Steel has traditionally made up approximately 70% of a typical vehicle mass, offering strength and reparability, and satisfying safety standards, which were often developed with metal in mind (Ryntz, 2006). This unconscious bias means that many new materials may struggle to satisfy existing standards. Steel is energy-intensive to produce, but relatively easy to recycle with established processes (Cooper and Allwood, 2012). Improved understanding of vehicle stresses may render this strength unnecessary in some parts of the vehicle however. Thus whilst highly recyclable, steel's mass and energy production costs mean that it contributes significantly to higher GHG emissions in both the use and manufacture phase.

Increasingly car manufacturers are utilising plastics and polymers due to their lightweight/strength ratio (Akampumuzu *et al*., 2016; Ryntz, 2006): quantifying the extent of this uptake is challenging however given commercial confidentiality. However these materials are derived from petro-carbons meaning their environmental impact and long-term sustainability is problematic. Moreover as they are usually landfilled or incinerated at end of life rather than recycled or reused (Pimenta and Pinho, 2011) this constrains their use in the European automotive sector due to the ELV. This means that the environmental impact and sustainability of their increasing usage is questionable.

Biomaterials are derived from "material of biological origin excluding material embedded in geological formations and/or fossilised" (EC, 2010) with a standard developed EN16575 in 2014 (CEN 2014). Increasingly these materials are seen as an attractive basis for various plastics and composites for the automotive sector although there are a number of technological challenges to their further development. Whilst oil price volatility makes hydrocarbon plastics pricing unpredictable, biologically-based feedstocks such as sucrose may offer a reliable, long-term supply solution (Chadha, 2010). Their usage offers an additional income stream for the agricultural sector and development has been supported by the EU. As they are potentially biodegradeable (Mohanty *et al.*, 2000), there is also growing interest in their use from a sustainability viewpoint (Monteiro *et al.*, 2009). Biopolymers or plastics are therefore a small but growing part of the automotive sector (Akampumuzu *et al.*, 2016; Hill *et al.*, 2012; Alves *et al.*, 2010; Carus and Gahle, 2008) and offer an opportunity for European industry to secure an innovative sustainable solution to further industrial and economic development.

However, the introduction of any new material into the complex automotive supply chain is challenging given the structure of the industry (Wells *et al*., 2012). The industrial inertia to change, the cost of development and the safety requirements and testing procedures around materials may act as a brake to their adoption. These may be considered as examples of "carbon lock –in" (Unruh, 2000).

Yet whilst there is a significant and predominantly academic literature on bio-materials development, (Andresen *et al.*, 2012, Vandermeulen *et al.*, 2012) there has been limited analysis of the relationship between the automotive legislative framework and their adoption in this sector. This thesis seeks to fill this gap by engaging with the sustainability transitions literature to which we turn in the next section.

1.4 Theoretical and Analytical Frameworks

There are a number of theories that seek to understand how transitions to more sustainable societies can be encouraged including Technology Studies (Bergek *et al.*, 2008a), Strategic Niche Management (SNM) (Kemp *et al*., 1998; Hoogma *et al*., 2002) and the Multi-Level Perspective (MLP) (Geels, 2014; 2005a; 2002) which may be grouped as Sustainability Transitions (Markard *et al*., 2012). SNM originated as a normative policy process to encourage innovative sustainable development of new technologies in competition with existing industries, recognising the problem of embedded carbon lock-in (Unruh, 2000) and institutional interests. Research suggested that these technologies might develop in protected niches before integrating into society as a whole (Hoogma *et al.*, 2002; Kemp *et al.*, 1998). Theory emphasised the importance of managing stakeholders expectations; of building social networks and learning; of understanding the institutional structures, legislative, cultural and economic factors which may affect the introduction of a sustainable innovation. MLP theorists postulated that an innovation cannot succeed in wider society unless it can access these institutions to generate wider acceptability. The MLP has been used to analyse the introduction of new sustainable technologies in a number of sectors such as aviation (Nakamura *et al.*, 2013), biofuels in Europe (Bos *et al.*, 2008; van der Laak *et al.*, 2007) and the transport sector in general (Geels, 2012; Whitmarsh, 2012).

Whilst the framework has drawn criticism on a number of grounds (*inter alia* Geels 2014; 2011; Lawhon and Murphy, 2012), it offers insights and tools to understand how innovation occurs and the processes by which new products and processes can become integrated more fully into society. These literatures therefore offer a useful and appropriate framework for assessment of the potential for biomaterials as their use expands in the mass automotive market.

1.5 Aims and objectives.

This research aims to critically engage with and further develop sustainability transitions studies. It does this by exploring sustainable innovation in the automotive manufacturing sector with a focus on the growing use of bio-materials and in particular, how EU legislation effects their development. To bound the case, discussion is limited to their application within the UK. There are two theoretical contributions. Firstly, by critically engaging with transitions theory, the thesis identifies difficulties with this approach but utilises some of its insights to examine how the legislation may act as a barrier or driver to development of a particular technology. Secondly, by explicit study of the role of legislation, it develops transitions theory to more fully reflect its potential role in shaping sustainable innovation, specifically in the EU automotive sector. Thirdly it identifies gaps in the EU legislative framework that require amending to allow a “closed loop” product cycle to emerge.

The principal research questions that the thesis seeks to address are:

RQ1: How has European legislation affected the development of more sustainable innovation in the automotive sector?

RQ2: What are the barriers and drivers to the use of bio-based materials in the UK automotive sector?

RQ3: Are there legislative barriers to the use of bio-based materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

RQ4: How could EU legislation be modified to support sustainable technologies in this sector?

In order to critically engage with and further develop sustainable transitions theory and answer the over-riding research aim:

> How can transitions theory to foster sustainable innovation be improved by the study of legislation?

The thesis does not therefore attempt to answer if and to what extent bio-based materials are sustainable *per se* in the car industry, but to understand how existing legislation shapes and constrains their development. Study at the sector level may thus have implications for legislation in other sectors.

1.6 Thesis structure

The thesis proceeds via a classic structure from a literature review, to a consideration of methods, to a presentation of three case studies. Hence, Chapter 2 provides a literature review considering the development of technology studies and innovation with a particular focus on the automotive industry. It introduces the theoretical framework of the sustainability transitions field outlining its development and exploring the lack of studies related to legislation and those conducted at a sector or intra-national/European level. Chapter 3 outlines and justifies the analytical framework and methods used in the research, and chapters 4 to 6 cover the case studies of emissions regulation, end of life vehicles directive, and the Circular Economy package. Chapter 7 summarises and provides a concise cross-comparison of the empirical and analytical findings, explicitly answers the research questions and concludes with a summary arguing that the importance of legislation in shaping transitions has been underestimated and requires further scrutiny to facilitate a timely transition to more sustainable industrial innovation.

2 Literature Review

2.1 Introduction

This chapter reviews the literature on sustainability transitions or the multi-level perspective (MLP) (Geels, 2014; 2007; 2004; Kern, 2012; Markard *et al.,* 2012). Kemp *et al.,* (1998) provided an early study of the transport sector in which they introduce the concept of Strategic Niche Management (SNM) to explain the difficulty of producing more "environmentally benign vehicles" (Kemp, *et al.,* 1998, 175). In doing so, Kemp *et al.,* (1998) identified an urgent need for academic frameworks to assist in the analysis of, and transition to, more sustainable innovation in the automotive sector. Following initial promise however, SNM has been largely subsumed within the "sustainability transitions" and "Multi-level Perspective" (MLP) literatures (Geels, 2014; Kern, 2012; Markard *et al.,* 2012) but, it is argued, has continued relevance due to the normative priority it assigns to policymakers and its heuristic framework of the landscape, regime and the niche. This framework offers a way of understanding how innovative, potentially more sustainable materials such as biomaterials (Hill *et al*., 2012; Koronis 2013) are blocked or incentivised by current legislation. Figure 2.1 provides a visual representation of the major literatures drawn upon in this review.

The chapter starts by briefly setting the background for the following discussion by defining innovation and sustainability. Consideration then switches to development of the sustainability transitions literature from its roots in SNM and its use in theory and practice. Gaps in the literature pertaining to the centrality of political processes and the nature of regimes are identified. The next section considers the automotive industry in terms of innovation and sustainability then reviews studies on the sector, within the MLP or related fields.

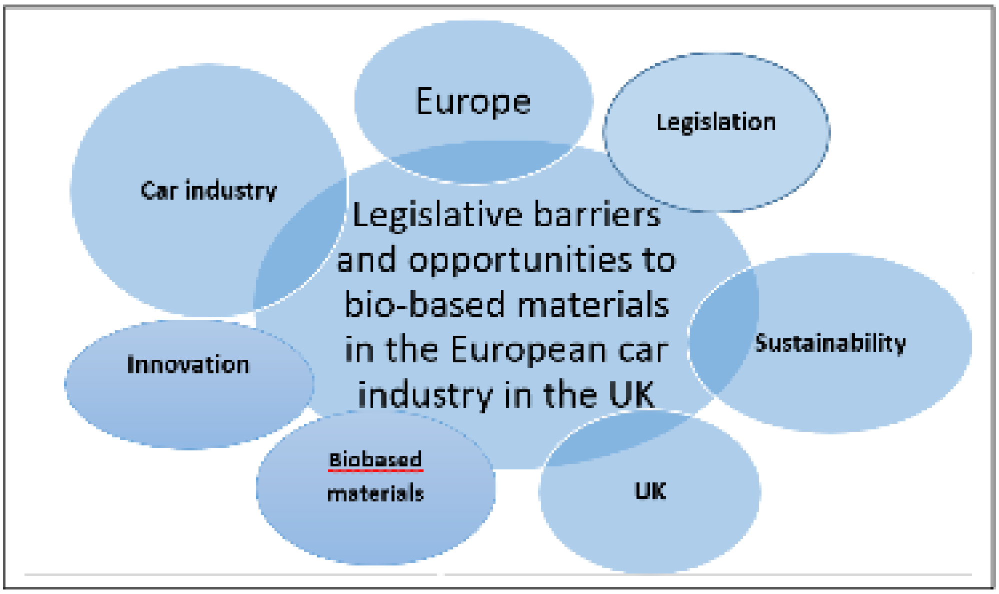

Figure 2.1. Visual overview of literature

It is argued that the current literature fails to address explicitly the importance of legislation in changing the existing regime nor is there, as yet, a detailed analysis of how the automotive regime specifically must change in order to foster more radical, but also, sustainable innovation.

2.2 Innovation

Innovation, here defined as the introduction of new methods, technologies or changes in existing practices, has been a fundamental concern for firms and nation states since at least the 1920s (Schumpeter, 1934; Becheikh *et al.*, 2006; Fagerberg and Verspagen, 2009). New products and associated practices have a key role in maintaining competitiveness, profitability and growth and a number of research areas have developed to study innovation at varying scales. Management studies, for instance focused on the firm or company level and considered how new products might most successfully be developed and established in the market (Drucker, 1954). Economists have prioritised innovation to boost employment, promote economic growth and compete with other nations (Fagerberg and Verspagen, 2009; Schumpeter, 1934). Technology and innovation studies examined innovation at the sector level to understand how new industries develop (Aldrich and Fiol, 1994). In general, these theories have tended to take a narrow, technological viewpoint focused particularly on the initial invention of a technology and its incremental improvement, rather than considering the wider influence of public adoption and usage (Shove and Walker, 2007).

In contrast, a more holistic viewpoint was gradually adopted which recognised the importance of the politics, culture and society in the fostering of new technological and industrial developments (Fagerberg and Verspagen, 2009; Smith and Marx, 1994). Research began to recognise that innovation must counter an existing dominant technological paradigm which sees innovation produced from a relatively narrow, pre-chosen, “ex-ante” path (Silverberg *et al.*,1988, p. 1036). Thus rather than emerging at random, in an almost Darwinian evolutionary model, innovation tends towards incremental improvements which fit into the prevailing paradigm. The introduction of more radical, disruptive (and potentially more profitable) innovations is therefore hampered for a number of inter-twined reasons: the lack of a competitive price and market niche; that incumbent firms and industries find these new changes difficult to initiate because they are so enmeshed in the existing paradigm; and because incremental improvements are easier to manage and organise.

Management studies, focused at the firm level, therefore sought to understand how companies might best internally develop processes to foster innovation and change, noting the importance of the firm’s culture and learning processes and how users and demand factors stimulate innovation (Thomke and von Hippel, 2002). Simultaneously, there was greater recognition of the importance of institutions at the national level and their role in supporting innovation (North, 1990) and the tendency towards stability through gradual improvements (Aldrich and Fiol, 1994). This stability and/or inertia provides predictability, but locks society, including both producers and consumers, into long-standing patterns of behaviour as institutions and politics come to be dominated by established players (Walker and Shove, 2007; Berkhout, 2002; Walker, 2000). Hence these studies take a systems perspective, acknowledging the role of both demand and supply factors but also wider political, sociological and historical trends in technological development rather than the technical knowledge, invention and artefacts alone.

The early choice of a technology however, whilst seemingly accidental and minor, might push technology choices down a self-reinforcing path: the danger of path-dependency (Rip, 1995). The QWERTY design keyboard for instance was adopted and became standardised at an early point in the development of manual typewriters (David, 1985). Initially to ensure that the most commonly used keys were at the centre of the keyboard, to be used by the strongest fingers, the design became standardised in part because of early economies of scale, but also through generic training, a wider societal factor. The relative inefficiency of the design has been maintained however despite advances in technology and awareness of its obsolescence. Similarly, chemical, rather than integrated pest control management became the more dominant method, despite environmental concerns, because initial developments were comparatively cheaper, easier to introduce and more acceptable (Cowan and Gunby, 1996).

Therefore early adoption of a particular winner, pushed by economies of scale, but also by government intervention, in the form of legislation, fiscal policy, grant or any other support, means that technology choices may become narrowed at an early point to only one winner. Any public support must therefore be carefully calibrated to prevent early “closure” of options and retain a flexible range of competing mature technologies, with varying potentialities and sustainability implications.

2.3 Climate change and sustainability

Around the millennium, a number of factors began to impact these fields, particularly a growing awareness of the effects of greenhouse gas emissions (GHGs) on the climate and the economy (Stern 2006), with the accompanying recognition of the risk these emissions pose to populations and the need for governments to take urgent action (IPCC, 2014). There is broad agreement of the urgent need to restrain GHG emissions including atmospheric CO_2 to below 350 parts per million. Processes for achieving this change however or meeting the more moderate 2°C limit agreed at Paris COP21 (UNFCC, 2015) are lacking. Without change, it is expected that significant environmental threats to the ecosystem including rising sea levels, degraded water and air quality, and changing weather patterns are likely and will impact large populations worldwide (IPCC, 2014). The longer that change is resisted, the more radical the required solutions. In the meantime, it seems inevitable that there will be increased competition for material resources and that the most environmentally at risk areas will increase in size, impacting the poorest most (McMeekin and Southerton, 2012**).**

Whilst the market might provide technological solutions to mitigate these effects, the prevailing pattern of economic development and incremental change means that it is increasingly unlikely that these market responses will be appropriate or rapid enough to produce significant results. Existing business will use state institutions to distort the market, preventing new market entrants and innovations (Anastasiadis, 2014; North, 1990). Firms, particularly large multi-nationals, will lobby to influence governments and shape future legislation to protect the status quo and maintain profits (Coen, 1998) particularly in developing economies, where a "capture economy" (Hellman *et al.*, 2003, p. 770) may emerge in which dominant actors embed their advantages in law and regulation.

The state or government is bound to be an important actor in addressing these problems (Giddens, 2009). At a quantitative level alone, this influence is felt due to the public sector's size as both a consumer and purchaser of commodities; as an employer and contributor to economic growth; its unique legislative power; but also because of societal expectations (Hellman *et al.*, 2003). Whilst the exact meaning of "sustainability" and the role of the government in its implementation may be contested, (Boehner-Christiansen, 2002), the United Nations has defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UNWCED, 1987, p.43). The need to address the dangers of a rapidly changing environment and sustainability therefore underlies many international agreements such as the Kyoto Protocol (UNFCC, 1997) and UK Climate Change Act (H.M. Government, 2008), requiring states to address this issue proactively, rather than simply accepting and protecting the status quo. Importantly, government has a role in "editing choice" (Giddens, 2009, p.109), or shaping societal behaviour through legislation or other means to promote long-term goals such as sustainability.

Governments possess a range of tools to influen9ce the behaviour of industry, which may be broadly categorised into market-based instruments which affect prices (such as taxes or subsidies) and legislation or regulation. These tools have had limited success in fostering innovation however. Regulation in particular was generally criticised as crudely hampering innovation, although the constraints imposed might in certain cases paradoxically encourage innovative solutions (Porter and van der Linde, 1995a). Market- based tools in general were seen as insufficient and more suited to incremental technological improvement. The radical change required on many levels to shift industry to innovate to reduce carbon emissions whilst simultaneously retaining acceptable living standards for most of its population is thus a complex, "wicked" (Rittel and Webber, 1973) and systemic problem which requires innovative solutions at many levels (Foxon *et al.,* 2013). But states have a particular responsibility to shape and manage this transition due to their democratic accountability.

Recognising these issues, academics (Kemp and Rotmans, 2004; Berkhout, 2002; Kemp *et al.,*1998) and states such as the Netherlands sought a more wide-ranging understanding of how they might affect a transition towards a more sustainable future by supporting innovative technology, recognising the problem of embedded carbon lock-in (Unruh, 2000) and institutional interests. This initiative informed the development of strategic niche management theory (SNM), and the roots of the sustainability transitions and multi-level perspective frameworks (*inter alia* Markard *et al.,* 2012; Smith *et al.,* 2010; Geels, 2002).

2.4 Sustainability Transitions

Sustainability transitions studies is an encompassing term to cover a range of analytical frameworks which aim to understand the processes under which sustainable innovation might be encouraged in order to address a range of environmental, societal and economic issues. In a seminal review, Markard *et al.,* (2012) reviews the literature and outlines four key approaches: Strategic Niche Management (SNM), Transition Management (TM), the Multi-Level Perspective (MLP) and Technological Innovation Systems (TIS) that share the framework of sustainability as a desired outcome. The coinciding of terms may reflect the theory-driven and somewhat academic, rather than applied, empirically based roots of this research. For the purposes of this review, the literatures might be grouped in terms of emphasis as illustrated in figure 2.2 below.

While all four frameworks owe a debt to Technology Studies (Dosi, 1982; Nelson and Winter, 1977), TM and SNM share a common theme of governance and deliberate shaping of outcomes, often prioritizing the actor of the state or government in supporting the development of sustainable innovation. TM and SNM differ however in terms of scale, with TM often considering the regional and national policy context (Rotmans *et al*., 2001) whilst SNM has been more focused on small-scale, often local developments (e.g. Kemp *et al*.,1998.) The MLP tends to take a more long-term, historical and theoretical perspective (e.g. Geels, 2002). Technology Innovation Studies were originally more focused on technology and systemic theories, including institutional structures (Raven, 2002) but now often take an interest in radical sustainable technologies and their system-transforming effects (e.g. Bergek *et al.*, 2008b). In contrast to SNM or TM, TIS often downplays the role of the state, taking a more market-based approach which emphasises the role of entrepreneurs, markets and technology.

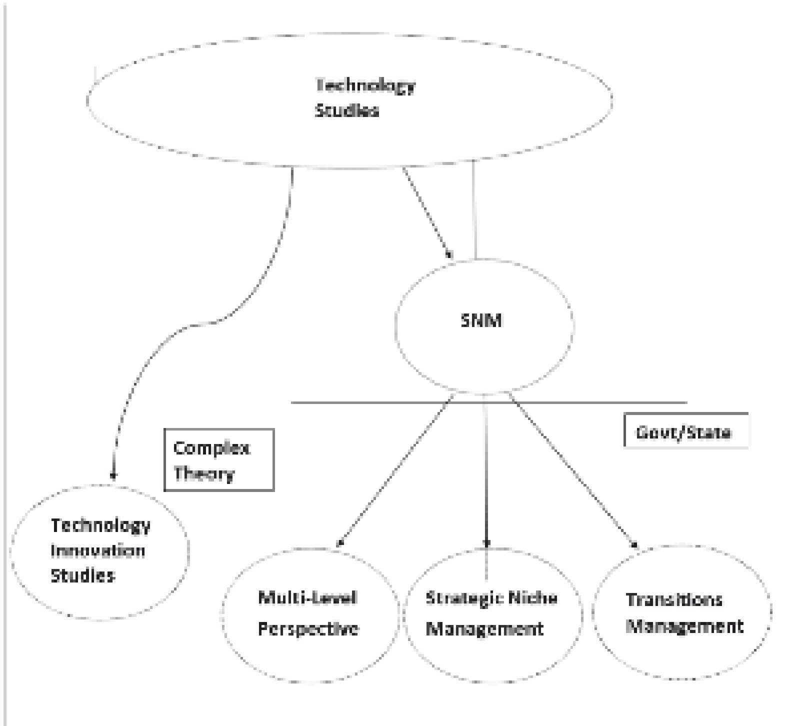

Figure 2.2. Diagram illustrating the development of the Sustainability transitions literature (Authors own).

2.4.1 Theoretical framework: the Landscape, Regime and Niche

Sustainability transitions rely on a heuristic model of society consisting of a socio-technical system, in which technology and society interact over three levels, the landscape, the regime and the niche (*inter alia* Kern, 2012; Markard *et al*., 2012; Geels, 2010, 2005b; Raven, 2002; Kemp *et al.*, 1998). These levels function over differing, but poorly defined, time scales with the landscape considered the most long-term and the niche, the most immediate.

The "socio-technical system" supplies a societal need, such as transport and includes the artefacts, together with the economics, culture, beliefs, and user preferences etc which make up that system (Geels, 2004; Rip, 1995). For example, in the case of the automotive regime, this means not only the car itself, but also those supporting institutions and systems which make the car "work" in society (Geels, 2005a). The system therefore includes laws applicable to manufacturers such as emissions standards or parking fees for drivers; production systems, including car manufacturers and suppliers; road infrastructure such as roads and traffic lights; car insurance companies and repair garages; but also the markets and user practices surrounding cars, such as motorway networks, tax regimes or driver preferences for private rather than public transport (Geels, 2005a).

The "landscape" is the external environment, which consists of long-term, gradual historical processes such as climate change which are beyond the influence of individual actors (Markard *et al.*, 2012; Geels, 2010, 2004;). These processes also include long-term demographic and cultural changes such as socio-economic and political developments (Kern, 2012; Avelino and Rotmans, 2009). Examples of these forces in the transport sector might include changing societal expectations of work which facilitated the introduction of the car (Geels, 2005a).

The "regime" is the "dominant configuration of certain technological artefacts, institutions, networks, user practices, market structures, regulatory frameworks, cultural meanings and scientific knowledge" (Kern, 2012, p299). The regime is the existing present, which is assumed to be stable and provides the predictability and security which allows innovation to develop incrementally.

"Niches" are often referred to as the "protected spaces" (Kern, 2012; Kemp *et al.*, 1998) where innovation can occur, the micro-level which interacts with the regime and landscape to produce change. Niches are different in some way to what prevails in the regime, perhaps a new technology, such as an electric car or a new process or way of doing things, such as car leasing rather than purchase. Niche developments are often small-scale, used in a particular specialist market or area and require shielding from the regime because they are not yet proven, cannot compete in the open market without protection and lack wider societal acceptance. Whilst "niches" were considered inherently short-term and unstable, regimes and landscapes were defined by their more permanent characteristics.

Figure 2.3 (Genus and Coles, 2008 from Geels, 2004) outlines this model showing how niches were thought to interact with regimes in multiple ways across time with the over-arching landscape shaping all. The model formed the basis of the multi-level perspective or MLP and has become a key construct in the "transitions" literature (Markard *et al.,* 2012; Kern, 2012; Geels, 2004; Kemp *et al.,* 2000).

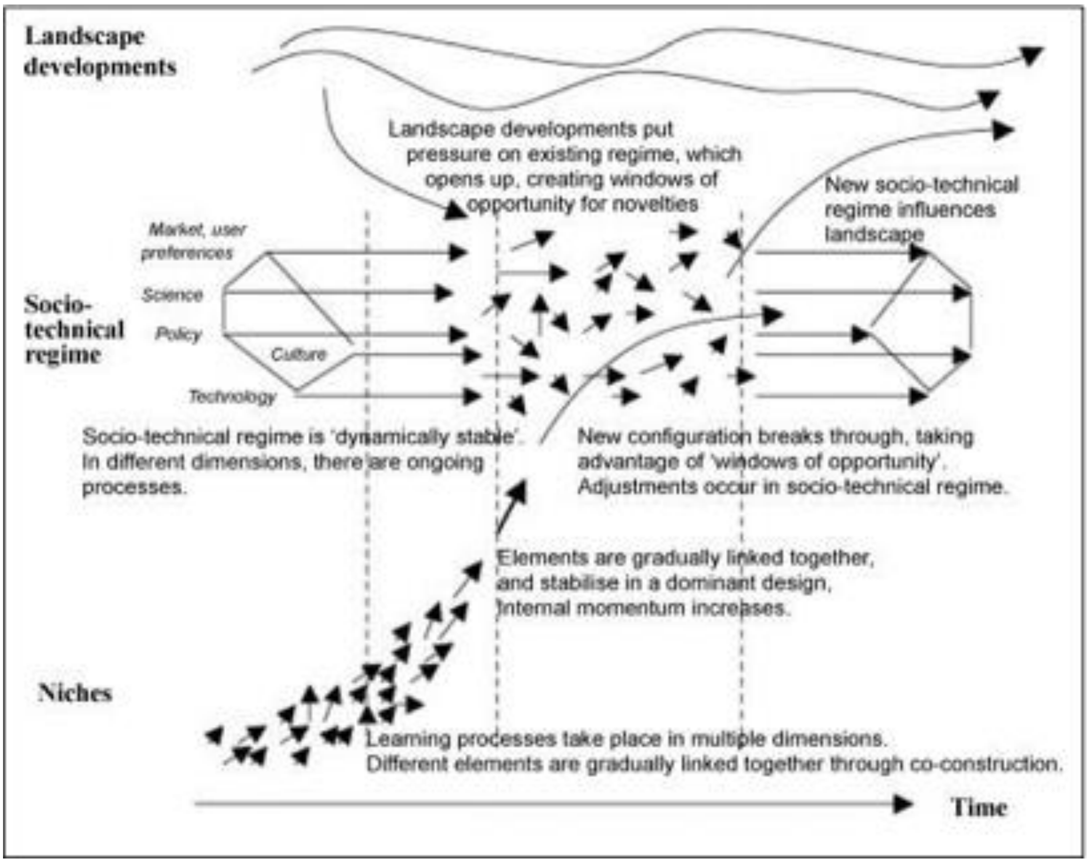

Figure 2.3. A dynamic multi-level perspective on systems innovation from Genus and Cole(2008) adapted from Geels (2004).

Innovation was conceptualised as initiating in the "niches", a concept from technology studies, i.e. small-scale, specialised arenas outside the mainstream. Change was theorised as endogenous, initiated within the niches at a small, usually local level and spread through key learning processes which include learning, networking and the articulation of expectations (Budde *et al.*, 2012; Kemp *et al.*, 1998). Following state fostering, niche innovations might be learnt from and replicated elsewhere to survive and alter the regime. Shielded from market forces by the public sector in the short term, innovation could then be steered into long-term sustainability options, to benefit all sections of society rather than focusing on finding a current market fit (Smith *et al.*,2010; Rotmans *et al*., 2001; Schot *et al.*, 1994).

The next section considers SNM in more detail given its importance in the development of the MLP and its specific focus on the early stages of innovation.

2.4.2 Strategic Niche Management

Strategic Niche Management (SNM) is a systemic theory which seeks to understand how sustainable innovations might best be facilitated, given institutional and market barriers to their more widespread adoption (Kemp *et al.,* 2000b; 1998). Rather than relying purely on market-based tools or legislation, sustainability transitions could be promoted by governments through a range of measures which would support innovative technologies to gain wider acceptance and facilitate a transition towards more sustainable living (Kemp *et al*., 2000b). SNM fills an academic space drawing on insights from technology studies, history, sociology and institutional theory, with qualitative methodologies frequently employed (Schot and Geels, 2008). Schot and Rip (1997) defined SNM as "the orchestration of the development and introduction of new technologies through setting up a series of experimental settings (niches) in which actors learn about the design, user needs, cultural and political acceptability" (p 261) of these technologies. Later, SNM is characterised as a more calculated initiative, "the deliberate creation and support of such niches" (Markard *et al.,* 2012, p 958), the change of emphasis perhaps reflecting the field's development. Early work acknowledged and drew directly on technology studies (*inter alia* Silverberg *et al.,* 1988; Nelson and Winter, 1977) accepting the systemic viewpoint that change to sustainable innovation required change on multiple societal levels, but with a focus on networks, actors and institutions (Kemp *et al.,*1998; Schot and Rip, 1997).

SNM differed from earlier technological studies approaches in two key ways. First, there was a specific focus on the problem of sustainable innovation, rather than innovation per se. New sustainable technologies are often initially unable to compete with existing ones due to their higher cost, lack of supporting infrastructure and lack of market demand for them. SNM tended to ignore this aspect of economic/market viability, and focus on other support, assuming that as sustainable technologies became more societally acceptable, markets would be found. Second, government or state actors were seen as crucial facilitators in consciously creating and managing this process, (Kemp *et al.,* 1998) because of the need for "a range of integrated systems of technologies and social practices" (Kemp *et al.,* 2000b), encompassing technology-push and market-demand pull which might frequently be beyond an individual firms' capabilities. Rather than focusing on legislation or market-led instruments alone therefore, states might assist the development of these innovative new technologies through a more subtle range of integrated measures. These policies might include the fostering of networks of contacts and learning with institutions in order to overcome the institutional and market barriers to their development. Whilst Weber (1997) argued that the focus on barriers, (drawn largely from innovation studies), reinforced an implicit assumption that "technical solutions" and positive actions (rather than changes in demand or political choices) were more important, SNM shifted study to an early, very specific stage of innovative technological interaction with society.

SNM's aims were to understand how development could be enhanced through "three internal niche processes": learning, networking and the articulation of expectations (Kemp *et al.,* 1998). The learning process involves adjusting the technical and the social so that they fit together well, for example, understanding how the technology will be used, and users preferences. Networking involves bringing new stakeholders in, to increase acceptability of the technology and provide a wider base for action and learning, increasing the acceptability of an innovation and allowing other sectors to adjust and accommodate the technology. Sharing expectations is considered key in attracting attention, giving direction to future developments, and building acceptability into existing institutions and frameworks. SNM therefore calls for examination and enhancement of processes that might be considered inherently political, i.e. building a wide network of stakeholders, seeking acceptability and legitimacy, and network formation in order to facilitate the speedier introduction of sustainable innovation.

From its earliest stages, SNM had a practical governance and policy-development strand (Rotman *et al.,* 2001) with early research sponsored by the EU (e.g Kemp *et al.,* 2000a) and adoption by the Dutch government, for example, the Fourth Dutch Environmental Policy Plan in 2001. Experimentation was acknowledged as a necessary part of this process, since predicting which technologies might be most appropriate and successful at an early stage in development is not possible and to avoid the problem of path-dependence mentioned earlier (Loorbach and Rotmans, 2010). Controlled abandonment of "failures" was therefore as necessary as continued support for successful technologies.

Methodologically, early SNM research often took a qualitative case study approach, using historical documentation and semi-structured interviews with stakeholders. Analysis was structured in terms of the three key processes: learning, networking and articulation of expectations (Kemp *et al.,*1998; Caniels *et al.,* 2007). Van der Laak *et al.,* (2007) for instance considered biofuel pilot projects in the Netherlands, explaining their success in terms of a wider range of stakeholders becoming involved, and dealers "learning" to accept maintenance warranties on converted trucks when no problems arose. Some rather generic policy advice was generated; for example, "Develop a clear vision" but "Prevent visions from becoming rigid". (van der Laak *et al.,* 2007). By looking back therefore, research sought to develop suggestions for future policy tools. Research was frequently focused on Europe, particularly the Netherlands (Bos *et al.,* 2008, van der Brugge *et al.,* (2005), which is acknowledged to have been a key leader in the implementation of sustainable policies, however this geographic focus has opened up the theory to criticisms of Western bias (Geels, 2011). Transitions theory was built up inductively from limited case studies, often focused at the national level, meaning its universality was likely to be spatially and culturally restricted. As theoretical work predominated, policy recommendations lacked credibility and claims for an empirical basis appeared tenuous. Further empirical case studies, particularly at levels other than the national, such as the supra-national, might address this shortcoming.

Many transitions studies aim to address sustainable innovations but the grounds for selection of one technology or innovation is rarely made explicit and there is no agreed basis for doing so. Ulmanen *et al.,* (2008) for instance considers biofuels in Sweden and the Netherlands and van Eijck and Romijn (2008) and Caniels *et al.,* (2007) the development of Jatropha-based biofuels in East Africa without explicit justification for their "sustainability". Using the SNM approach to study a particular technology is in some ways therefore a political choice, implying that the technology is small-scale, local, but sustainable and worthy of support. Study of the "niche" may also attract academic attention because of its novelty, whilst the "ongoing processes" at the other levels are ignored (Geels, 2002, p1261, Wells and Niewenhuis, 2012). Whitmarsh (2012) suggests that "niche" can now be used to refer to almost any technology that is not mainstream, indicating how far in some senses the field has strayed from its sustainability roots.

Critically, an underlying assumption, which has not been sufficiently interrogated is that the learning processes which occur in one niche can be easily categorised, copied and repeated in others. There is an assumption too that these niches can link together in such a way as to achieve a critical mass, which challenges the regime**.** Ignoring for a moment the cultural assumptions around the sharing of knowledge, this supposition re linking fails to recognise commercial and company sensitivities around patenting and copyright. Raven (2002), in a prescient work, also argued that niche interactions with the regime must be studied. We may therefore need to re-evaluate dominant assumptions such as the idea that incumbent actors always favour the existing regime whilst newcomers search for a new one (Farla *et al.*, 2012).

However practical implementation and diffusion of these experiments proved challenging. Rather than niche experiments being replicated or linking into other niches to scale up and gradually replace the regime, experiments remained detached and isolated and failed to develop, meaning that early work had been "over-optimistic" (Hoogma *et al.,* 2002, p 195). Rather than limiting support to single projects therefore, policymakers should aim to actively support projects at a niche level, moving SNM from a retrospective analysis to a more ex- ante policymaking tool (Mourik and Raven, 2006). Theoretically therefore, attention broadened out from the niche to a wider consideration of the interaction of the three theoretical constructs of the niche, regime and landscape.

2.4.3 The Multi Level Perspective

The MLP is a systemic theory which sees sustainability transitions as "complex and long-term processes comprising multiple actors" (Geels, 2011, p24) with change occurring at particular "windows of opportunity" due to interactions between the three levels i.e not just at the niche level. The MLP perspective builds on the same theoretical framework as the SNM but takes a much wider viewpoint on the connections between technology, innovation and society than the SNM focus on the "niche", the "protected space" where innovation might occur and challenge the regime (Kern, 2012; Whitmarsh, 2012).

Geels and Kemp (2007) proposed four main types of systemic transition pathways: transformation, where landscape, exogamous pressures push the regime to adapt but with little influence from niche innovations; reconfiguration, where landscape pressures force the regime to utilize niche innovations; technological substitution, where well-developed niche innovations can replace the regime, due to internal regime pressures and de-alignment where landscape pressures cause disintegration of regimes which are then replaced by a variety of niche innovations, with one eventually leading to a new regime. Roeggma *et al.,* (2012) views change as incremental; through a transition or through a transformation. Transitions differ to incremental changes in being a long-term, but radical shift, involving multiple actors and numerous changes in societal systems.

Destabilisation of the regime therefore, due to either landscape or niche pressure (Geels, 2012), is necessary to allow change, but particularly sustainable innovation which may lack a compelling cost advantage (Porter and van der Linde, 1995b). Radical change however triggers maximum resistance from the regime (Grin *et al*, 2010) so that small adjustments towards an end goal are most successful (Grin *et al*, 2010). Studying biofuels and LED lighting in the Netherlands, Smink *et al.,* (2015) also demonstrate how incumbent industries can block innovation, and limit sustainable innovation. Rather than policies which foster the niche therefore, this implies active policy attention towards "creative destruction" of the regime (Kivimaa and Kern, 2016; Turnheim and Geels, 2013). Disruption of the regime rules, reduced support for dominant technologies, replacement of key actors in policy advisory bodies or the formation of new networks and "control" policies, (at their most extreme, bans), are examples of barriers which can be placed at the regime level to shift the regime towards a more sustainable configuration.

The wider focus of MLP means that more exogenous factors are included, making use of complementary literatures. For example, Caniels and Romijn (2008) attempted to address the failure of isolated SNM experiments to connect and infiltrate the regime by drawing in the management of radical innovation at the firm level (such as O'Connor and McDermott, 2004) and state protection of industry, particularly in East Asian countries (Chang and Cheema, 2001). Parallels between the two are apparent. Business teams are thought to innovate best when drawn from a varied base of skills and share a common vision. States can protect nascent industries by grants, regulations or tolls for example, with a clear vision of success so that the state here shields incipient industries, like a protected niche, from foreign competition.

Recognition of the difficulties of scaling up from niches to the regime has therefore seen attention switch away from niches themselves to the transition zone between the niche and regime and the regime itself (Geels, 2014; Smith, 2007). There is greater scepticism over the ability of the **r**egime to accommodate sustainable transitions and thus a greater understanding of how the niche interacts with the regime is required (Geels, 2014; 2011). Better understanding of these processes might shed light on how new sustainable technologies can move into the mainstream.

A review of the practical implementation of transition management also concluded that most focus had been on the “predevelopment stage of transitions” – i.e. the niche, but that now change is moving to “ an acceleration phase in which a structural regime transformation takes place” (Loorbach and Rotmans, 2010, p245). An enhanced “empowerment” of early adopters and “a minimally regulated space” may consequently be necessary, implying that regulatory authorities should act as a shield not only financially but in terms of regulatory protection, which has important implications for legislative design.

Smith and Raven (2012) also argued that whilst early SNM focused on niches as “protective spaces” where new technologies might be shielded and nurtured, there was now a need to consider empowerment to explain how they could develop. This development may in part be because sustainable technologies have matured to reach such a point of interaction, but also because the significance of the political aspect was not fully appreciated earlier (Avelino and Rotmans, 2009). Later input has also highlighted a certain political naivety (Lawhon and Murphy, 2012). Narratives are key evidence in this process and illustrate where “niche actors are seeking a fit-and-conform pattern or a stretch-and-transform pattern” (Smith and Raven, 2012), i.e. seeking to change the regime to fit with the niche or adapt themselves to fit with the regime**.**

SNM research had drawn significant criticism for often setting the research boundary at the national level which meant that the regime was frequently conflated with the state or the national and the niche with the local (Markard *et al.,* 2012; Raven *et al.,* 2012). This analytical fusion may have occurred because of the impact of national legislation and institutions, but these boundaries are not necessarily appropriate. Products such as mobile phones or cars, for instance, rely on international supply chains meaning that it is possible, both in theory and practice, for there to be global niches (Romijn and Caniels, 2011). Electric cars for instance may be regarded as a niche product, but they are not restricted to one particular state or area, presenting a further practical challenge to sustainable governance for states or supra national organisations such as the European Union. Later MLP analysis therefore often addresses the regional or international level as increasingly appropriate given the globalized market for many recent technologies.

Since the MLP takes a wider perspective than SNM, researchers often draw on a broader range of methodologies and sources, such as secondary documentary data, including newspaper reports and surveys. Penna and Geels (2015) for instance examine long-term changes in US car manufacturers approaches to climate change from 1979-2012, by examining documentary congressional records and linking these to patent applications, concluding that a slow adjustment is taking place. MLP theorists also often use historical case studies to develop policies for the future, seeking to understand the right combination of conditions within the landscape, regime and niche that might make transition possible (Geels and Kemp, 2007; Geels, 2010). Bree *et al.*, (2010) for example use the MLP to construct alternative scenarios to understand how hydrogen and battery-electric cars might be introduced. The wider perspective and increased attention to politics also means that the MLP has increasingly made visible the different players and stakeholders in sustainable transitions, opening out consideration of different pathways and providing a framework for analysis (Whitmarsh, 2012).

Kern (2012) offers a slightly different example by using the MLP for an analysis of policy, rather than for policy (his emphasis). Using three key examples of the MLP (Geels and Kemp, 2007; Shackley and Green, 2007 and Verbong and Geel 2007), he operationalizes the MLP to provide an analytical framework to examine how the work of the UK Carbon Trust contributes to a low carbon energy transition. Building on this work, Moore *et al*., (2014) uses the MLP to analyse zero emission housing standards from five states to develop 17 criteria of what a zero emissions housing policy might look like, concluding that for governance, long-term visions, pathways and links to wider policies are particularly important for a successful transition.

The MLP has been used to study a wide variety of transitions including aviation (Nakamura *et al.,* 2013); electricity systems (Hofman and Elzen, 2010); clean water (Fuenfschilling and Trufferr, 2014; Nastar, 2014); transport, (Whitmarsh, 2012, Schwanen, 2013) and energy (Tambach *et al.,* 2010). These studies continue to draw on the key SNM processes of learning, networking and visions and expectations, for example in fuel cell and hydrogen cars (Budde *et al.,* 2012) or bioenergy (Levidow *et al.,* 2014).

2.4.4 Conclusions on the sustainability transitions literature.

From the review, a number of points emerge. First, that there is an increasing need to understand the power and political relationships between regime and niche actors (Lawhon and Murphy, 2012; Foxon *et al.,* 2013; Meadowcroft, 2011; 2016). Second, there is little consideration of the inevitable losers in this process and how one shifts away from older technologies and regimes. Third, the focus on ”fostering” in the niche requires a shift towards study of how the regime responds to calls for sustainable innovation and how the regime might adjust “the rules of the game”, both informally, in terms of practices and formally in terms of legislation (Geels, 2011, 2014).

The emphasis on case studies within national state boundaries has obscured the importance of legislation, because legislative boundaries become conflated with geographical ones and accepted as immutable. Regarding legislation as a fixed part of the regime however ignores the rich tensions and deliberations which go into the development and amendment of legislation. The sustainability transitions literature as a whole does not seem to explicitly consider the way in which environmental legislation is shaped so that states or intra-national authorities in particular might proactively shape the new “regime.” As such developments in the MLP literature which increasingly bring in the normative aspect of SNM which sees governments as those ultimately bearing responsibility for a failure of action; the positive insights gained from previous SNM research and the methodology developed. SNM retains a normative appeal because it urges a shaping of the future, it has a constructive policy focus and it recognises that the market alone cannot provide a timely solution. SNM also clearly places government as a central actor, rather than firms or technology. Insights include greater understanding of how existing rules and norms block and divert new sustainable niches and the framework provides an analytical tool for comparison.

If we shift perspective to the space between niches and regimes then, there is a greater need to understand the politics and power of the transitions process (Lawhon and Murphy, 2012; Smith *et al*., 2010) to include consideration of a wider range of actors beyond firms and governments, and the importance of scales other than the national, such as the local and regional. Legislation's role in protecting the status quo and presenting barriers or incentives to sustainable niche developments is a key arena in which the transitions process can be observed.

The MLP methodology offers a framework to analyse this process and has been used in a variety of contexts, evidencing the frameworks flexibility and utility. Sustainability transitions in some senses are inherently political processes: by articulating expectations, development of networks and accommodation of varying societal expectations, the MLP explicitly calls attention to these processes. The research process also encourages incumbents both within and outside the regime to make visible the barriers, and consider new configurations for innovative change.

2.5 The automotive sector.

Cars (those designed for the mass market, rather than luxury supercars, Formula 1 racing or publicly provided motor transport) are a highly successful product and an established part of 21st century life, sometimes considered **"**the single greatest engine of economic growth in the world" (OICA, 2015)**.** Automotive firms such as Ford, General Motors, Nissan and Renault, for example, are international in scope, financially successful and major manufacturers. The sector employs circa 12 million in the EU, accounting for approximately 4% of EU GDP and is considered "a backbone of the European economy" (SMMT, 2014). In the UK, the automotive sector is valued as a major contributor to export income and a significant part of a declining manufacturing base, despite the lack of UK-owned automotive manufacturers (Automotive Council UK, 2013). The sector is therefore an important part of UK government attempts to “rebalance “ the UK economy, in this context taken to mean increasing the share of manufacturing, as opposed to services, in the generation of UK GDP (HM Government, 2013a).

Cars permit flexible individual mobility but require significant infrastructure, for example in terms of roads, fuelling stations and traffic lights which has grown up over the last century, often supported by favourable planning regulations and public sector finance. It can be argued however that this success was due to a happy agglomeration of particular factors at a certain time including for example, relatively cheap oil, cost-effective steel manufacturing, rising incomes, post-World War II conversion from military to consumer goods, and urban planning that failed to provide public transport but did provide a garage (Geels, 2005a). Cars therefore are a long-standing part of a dominant pattern of living, which includes transportation infrastructure and work patterns.

The industry is heavily capitalised and dominated by large firms operating in an almost oligopolistic manner (Sturgeon, *et al.*, 2009). At the apex of this value chain, car manufacturers (known as O.E.Ms or Original Equipment Manufacturers) are often supplied by other large multi-national firms, (known as Tier 1 firms), who co-ordinate a larger number of much smaller companies (Tier 2 firms)(Wells *et al.*, 2012). These firms may be scattered across the globe or clustered around the assembly plant (Rutherford and Holmes, 2008). Thus Ford for example, the O.E.M, may be supplied by Guest, Keen and Nettlefolds (GKN), a global Tier 1 firm with a drive train assembled or manufactured by other firms (Tier 2 companies). Vertical integration of firms to maximise profits, for example, Tata steel with Jaguar LandRover, consolidates the value chain, narrowing production and material choices.

2.5.1 The unsustainable nature of the automotive sector

The unsustainable nature of car production and its resistance to change have been frequently noted (Orsato and Wells, 2007a; Cohen, 2012; Wells *et al.*, 2012). The automotive sector has a significant environmental impact throughout its value chain in terms of energy consumed and raw materials required, with land transport-related GHG emissions increasing at a faster rate than any other energy end–use sector (Sims and Schaeffer, 2014). For example, from the earliest stages in the extractive industries as the raw materials, predominantly steel are produced; manufacture, (especially the paint process), assembly, and use-phase of the product itself, emissions are produced impacting air quality and causing GHG warming effects. The degree of unsustainability is also increasing for two reasons.

Firstly, the car market is growing at a significant rate (Sperling and Gordon, 2009). Current vehicle ownership levels of 800 million (Simms and Schaeffer, 2014) are expected to be over 2 billion cars by 2030 based on income, urbanisation and population density trends (Dargay *et al.*, 2007). Whilst the market in OECD countries is considered to have reached saturation point, curbed by the recent economic crisis and focused on replacement vehicles, there is significant potential for growth in non-OECD countries due to rising income levels and more liberalised markets (SMMT, 2014). Growth is particularly marked in Brazil, Russia, India and China (BRIC nations) with China having overtaken the US in 2009 to become the world's largest market for cars (OICA, 2015).

Second, current trends in car design are also hampering efforts towards sustainability. Despite improvements in vehicle efficiency, there has been a tendency for the size and weight of cars to increase. For example, the average US car is now some 20 % heavier than in 1989 (US EPA, 2009), requiring more raw materials, energy for manufacture and more fuel to move it and in consequence generating increased emissions. These design factors have been spurred in part by fashion but are also presented as safety features for passengers (Kemp and Pontoglio, 2011). Cars makers frequently emphasise the safety and privacy afforded by cars, meaning that the early promise of freedom offered by private cars has now been replaced by a desire for security (Wells and Xenias, 2015).

Increased vehicle mass however, whilst protecting its own occupants, makes cars more dangerous to other road users, those in lighter cars, pedestrians and cyclists. Recent research, particularly in the US, is beginning to reframe increased mass as a public safety issue, rather than an emissions/fuel problem alone (Anderson and Aufhammer, 2013). Whilst reductions in pedestrian casualties are due in part to better design to the front grill and improved driver visibility, societal and built environment improvements, such as improved driving standards, motorway design, lighting and enforcement of speed standards are at least as important (Retting *et al.*, 2003). These features, which may have incrementally improved over many years, have been largely paid from public funds, yet may be lacking in many BRIC countries, leading to significant potential future casualties (Rodrigues *et al*., 2014; Hazen and Ehiri, 2006). Increases in car emissions (directly related to greater mass) are already significantly impacting human health in some BRIC states where population density in cities may be particularly high (Wang and Hansson, 2013).

Adoption of any new technology by the mass automotive sector is particularly important therefore compared to other sectors both because of its size and influence (Orsato and Wells, 2007a), interconnections with other industrial sectors, impact here and abroad (Wells *et al.*, 2012), but also its environmental, health and social sustainability effects.

2.5.2 The automotive sector's attitude to innovation

The mass automotive sector, with its use of established technologies, particularly the internal combustion engine (ICE), capital-intensive infrastructure, mass-production focused on engineering standards and cost-control has achieved its success by ruthless focus on continuous improvement and cost-reduction (Choi and Hong, 2002). A complex product made by a complicated value chain, organisationally, it has a hierarchical structure, factors that limit its ability to undertake rapid and radical innovation (Zapata and Nieuwenhuis, 2010).

Incremental technological improvement rather than radical change characterises the industry, with the basic design of the internal combustion engine (ICE) unchanged in more than a century (Geels, 2005a). The all-steel body, rather than the ICE, however is an overlooked, but major determinant of current automotive production, locking manufacturers into significant capital investment (Nieuwenhuis and Wells, 2007). Mass automotive manufacturers concentrate on integrating many outsourced components by reducing car design to a modular level, outsourcing design and production then managing the process of integrating these parts into cars. The modularity process also outsources innovation (Morris and Donnelly, 2006) pushing the supply chain to compete to innovate, but also means that suppliers are then tied to the component level, because of confidentiality requirements: they cannot question the material, other technical specifications or necessity for that part. The increased focus on cost-reduction also means that geographic clusters that traditionally innovated such as Canada, (Rutherford and Holmes, 2008) have tended to be replaced by cheaper production sites abroad. The hierarchical organisational structure therefore ties overall design and control to the firms' design headquarters. These factors are particularly significant for the UK because it lacks both UK ownership of car firms and UK design centres. If factories are simply assembly plants, but not really embedded in that location because both the design and component manufacture takes place elsewhere, they are more vulnerable to outsourcing (Automotive Council UK, 2013).

Radical technological innovation is more often visible in specific market sectors or "niches" such as Formula 1 (F1) and the luxury car market, supporting the MLP approach. Many of these innovations are often discarded however on the grounds of cost rather than being further developed for the mass market where the advantages of economies of scale come into force (Genus and Coles, 2008). Whilst there are examples of innovative concept cars such as the Biofore, (UPM, 2015) with a cellulose/carbon fibre composite chassis, or the Rasa (Wells, 2016) with a lightweight carbon-fibre reinforced plastic structure, neither has been produced in association with any major automotive manufacturer, meaning that scaling up for the mass market is a significant issue.

Innovations such as electric vehicles or plug-in hybrid electric vehicles (PHEVs) are considered promising potentially sustainable innovations due to their non-reliance on petroleum, lack of toxic fumes or GHG gases and have attracted significant academic interest (Bakker *et al.*, 2012, Dijk *et al.*, 2013). Their development requires differing design characteristics, which might shake the dominant regime from within in a variety of ways. For instance, as the battery currently accounts for some 20- 25% of the weight of the car, redesign of the chassis is common in order to place the battery in the base of the vehicle to lower the centre of gravity and improve road handling. Replacing the ICE with the battery also changes the material characteristics needed in the engine area in terms of heat-tolerance and conductivity. Compensating for the battery's weight also increases interest in light-weighting and alternative materials. Moreover, these new technical requirements require an additional skills base. Such changes in both materials, skills and personnel may challenge traditional automotive engineering assumptions.

Electric car manufacturers have made several attempts to challenge the dominant petro- chemical and ICE pattern but with limited success. In the early history of car development, electric cars were a significant alternative to the ICE (Genus and Coles, 2008). In the 1970s, Californian and Dutch efforts to initiate an electric car market were thwarted despite “a bandwagon of initiatives” (Schot *et al.*, 1994, p.1065) including tax credits to customers and support for car charging. There is some recent evidence that the sector is currently developing to threaten the predominant paradigm because of concerns over air quality, peak oil and climate change, institutionalised through carbon dioxide (CO_2) emissions regulation (Dijk *et al.*, 2013). Increased sales of hybrid electric vehicles in the UK for instance, (those cars which use both an electric battery and a conventional ICE), are ascribed, in part, to incentives such as exemption from the London congestion charge and reduced company car tax rates (Milligan, 2015). It seems unlikely however that significant market presence from the current 5% market share can be achieved without corresponding changes in other sectors such as energy supply and legislative support, (Steinhilber *et al.*, 2013) re-iterating the presence of on-going, seemingly insurmountable, barriers (Hoogma *et al*., 2002).

To summarise, the sector is “dominated by a limited number of incumbent actors who have few incentives apart from government policies to accelerate the introduction of sustainable innovations, considering that the production and distribution of their current technologies are closely connected to existing, large-scale production systems and infrastructures” (Bergek and Berggren, 2014, p115).

2.6 Studies on the automotive sector and innovation.

This section describes the global automotive sector, outlining its customary approach to innovation and why it is suitable for a sustainability transitions study. The transitions literature on automotive sector is discussed together with other literatures that consider SNM themes in automotive innovation. The review concludes that one of the major forces for sustainable change in the automotive sector is legislation, which has not been explicitly addressed in the transitions literature.

2.6.1 Studies on the automotive sector within the sustainability transitions perspective.

The automotive sector was an early focus of interest for SNM/MLP scholars given its unsustainability (Schot *et al.,* 1994; Kemp *et al.,* 2000b; Hoogma *et al.,* 2002), building on earlier technology studies with an enhanced understanding of how society and the sector had co-evolved. Geels (2005a) for instance used a historical case study of the US transition from the horseless carriage to the car to argue that the internal combustion engine was initially competing with other technologies such as the electric tram. Cars gained pre- dominance through successful niche formation for particular early adopters such as medical Doctors making house calls and women living in the countryside who lacked access to public transport (Geels, 2005). Changes in regulation, such as relaxation of speed limits and societal habits (for example discouraging children from playing in the street but creating purpose-built playgrounds), supported automotive use and tied in with long-term societal patterns. In contrast, much of the research on climate change mitigation in transport is based on a positivist and quantitative approach to technology and justifies market-based mitigation strategies, particularly in the UK (Schwanen *et al*., (2011).

Comparatively little research has been undertaken on the automotive sector at the local or firm level (Markard *et al.,* 2012). A notable exception comes from Ieromanachou *et al.,* (2007, 2004) who modified SNM into Strategic Policy Niche Management to consider a scheme on road access charging in Durham and toll-charging in Norway. Sushandoyo and Magnusson, (2014) also reported how field tests and subsidies supported the development of a hybrid electric vehicle by Volvo, arguing that the firm itself needed to be convinced that a niche market had the potential to become a larger market and thus gain acceptance within the firm first. The lack of research at the firm level may in part be due to the automotive sectors sensitivity to commercial confidentiality, but also reflects the non-commercial nature of SNM projects and the lack of connection between private automotive firms and the public sector. The lack might also suggest that the concept of the niche may not be appropriate for a commercial multi-national sector such as the automotive.

Alternatively, this research gap may reflect that while automotive firms undervalue this type of learning, public or state actors may be unable to commit public funds to such developments at a time of public sector economic austerity, particularly in the UK. Geels (2013) for instance argues that investment in renewable energy, another sustainable technology, has been negatively impacted by a lack of public funding and wider political support, due in part to the economic crisis.

Later MLP research has tended to take a more long-term view, recognising how the automotive sector is resistant to change and part of a dominant regime, as discussed earlier (Geels, 2012). Orsato and Wells (2007a) provide a comprehensive review of the car sector noting how the complexity of the current value chain made change difficult and risky, reinforcing inertia. Vehicle manufacturers are seen as the primary cause of this inertia with the sector as a whole considered a "transition failure "(Wells and Nieuwenhuis, 2012, p.1681). Zapata and Nieuwehuis (2010) reiterated this point viewing the mind-set of "accountants rather than economists" together with the large initial capital cost as two primary barriers to change. In an important paper, Bakker *et al.,* (2012) argued that whilst there are various technological niches at the local level, economic forces and institutional pressures push for there to be only one dominant regime. This theme echoes with Smith and Raven (2012) who claimed that niches compete to become the global regime setter because the market will enforce one clear economic winner.

At the landscape level, in addressing wider societal factors, in particular user preferences, Kemp and van Lente (2011) observe that because cars are viewed as a right, unless there is a change in criteria, the future suggests more, heavier cars driven for longer, rather than a move to a more sustainable mobility. There is a lack of functional alternatives to cars although the car no longer serves the same needs (Cohen, 2012). Rather than being a symbol of modernity, it is just an ordinary piece of household equipment. Car makers are consciously changing the appeal of cars from that of "freedom" to one of "cocooning" (Wells and Xenias, 2015, p. 114) where consumers may take refuge from the stresses of public transport. Significant attention has focused on electric cars (Silvester, *et al.,* 2013). Widening analysis to the landscape level has also pushed transitions literature's methods with study of how US car manufacturers addressed climate change concerns for example analysed by using newspaper articles, congressional records and patents (Penna and Geels, 2015).

The next section widens the review to complementary literatures which draw on similar themes, recognising where the nomenclature differs but concepts overlap.

2.6.2 Studies on innovation in automotive sector outside the MLP.

Approaching the problem from a technology viewpoint, Tao *et al.,* (2010) examined the development of the automotive catalytic converter by Johnson Matthey in the US in the 1970s using a historical case study approach. In this case innovation was forced by new legislation, (1970 US EPA standards on emissions control) and is discussed in the context of extensive learning, network-building, and the need for the firm to take a more long-term strategy aided by proactive research and development, management and partnership strategies. These processes might seem contiguous with those highlighted in SNM theory. The firm started with a "niche application" but also developed a positive relationship with regulators, utilised a UK engineering consultancy Ricardo, and worked with VW and Rolls Royce for demonstrating and testing. Tao *et al.,* (2010) considers this combination of stakeholders crucial and quotes Schumpeter (1934) that "important innovations are the outcome of "new combinations" concluding that "The case shows that when regulators provide a framework reducing uncertainty in regulations and market demand, this encourages initiatives and collaborations. Private companies "when appropriately organised and managed" (their emphasis) can in these conditions initiate profitable innovations that benefit the natural environment" (Tao *et al.,* 2010, p 156). Therefore, successful innovation might only occur in particular firms, rather than all, a finding which resonates with Farla *et al.,* (2012) that industry incumbents within the regime may also be looking to change (i.e innovation does not just originate from new firms entering the market).

The car industry tends to be organised on hierarchical terms meaning that automotive firms predominantly co-operate with other automotive firms on patents, particularly for electric vehicles (i.e. not academics or government institutions) (Sarasini, 2014). This means that including new actors to widen discussion and break out of the technology/accountancy mind-set is more challenging than in other sectors. This pattern may be repeated along the supply chain meaning that without better integration and management auto firms will struggle to innovate even in the event of a regulatory push (Rothenberg and Ettlie, 2011).

Collaboration and trust are based on particular hierarchies and institutional structures, which have built up within the sector itself. These differ from firm to firm but significantly affect innovative success. Kastensson (2014) for instance, examined how Volvo and Saab approached the concept of a lightweight car based on an aluminium chassis and a monocoque glass fibre reinforced polyester shell. Whilst Saab tended to use multi-disciplinary teams, including suppliers and academia, Volvo focused on developing concepts that could be implemented sooner, concentrating on the component level and specialised engineering teams. Thus, whilst we might consider all car firms to be the same, differing cultures, management and implementation processes mean they are not a heterogeneous population. This implies that innovation processes and the tacit processes learnt at one firm may not necessarily be successfully replicated elsewhere (Polyani, 1967) confounding the core assumption of the MLP i.e. that lessons learnt in one "niche" can be replicated easily in another.

There is a significant literature within political geography, which also offers important contributions to study of the automotive industry, noting how multi-national ompanies (MNCs) cluster in certain geographic locations to access markets (Sturgeon and van Biesebroek, 2009; Rutherford and Holmes, 2008). Focus on state boundaries is also shared by businesses since a supply chain close to assembly and final market reduces logistic costs and risks, particularly for bulky items or those vulnerable to cosmetic damage (Davies *et al*., 2015).

The ability of the state to take a role in automotive development is also demonstrated. Villareal (2011) argued that state involvement in the development of the electric car by Renault/Peugot Citroen was crucial as the government could take a long-term view, offer financial support and draw in support from the nuclear power generation sector. By analysis of the French press he demonstrated how a process of legitimisation occurred which sought to "educate" French consumers to the benefits of the car through a sustainability strategy focused on "mobility" rather than high technology, appealing to patriotism and local employment narratives. The role of the state in diffusion of new innovation can also be seen in Brazil with biofuels and the USSR with natural gas (Freyssenet, 2011). Therefore a winning automotive technology might not be due to superior technical innovation or the most improved environmental performance but "energy geo-policies and firm profit strategies." (Freyssenet, 2011, p. 300). This protection can also be observed in the US where the auto sector was dubbed "Too big to fail, too big to bail" (Pearl, 2008), since its collapse would simply have too large an effect throughout the whole economy. General Motors (GM) enjoyed significant federal support in 2009 following the economic crisis (Sturgeon and van Biesebroeck, 2009) because of political sensitivity to concentrated local employment, but also because by supporting car firms this would create an economic stimulus throughout the economy through the multiplier effect. In summary, "Economic nationalism cannot be ignored in this sector "(Sturgeon and van Biesebroek, 2009, p 20).

The size of large automotive firms may also mean that they can access state aid for innovation more easily than smaller SMEs (Rutherford and Holmes, 2008). If long-term finance is crucial to maintain the resources for research and development, national government support can offer this protection. The entry of a large command and control economy is significant here. A state decree from China for instance, that all vehicles should be electric would be a significant regime shifter, giving an enormous boost to the international electric vehicle market.

States often encourage the siting of automotive assembly plants to boost GDP, employment opportunities and prestige. The UK government has been particularly keen to encourage this practice (Automotive Council, 2013) because of the potential to rebalance the economy away from finance and to improve the balance of payments (Tovey, 2015). The lack of a UK-owned automotive firm or Tier 1 supplier however means that it lacks the collaborative framework for information sharing to innovate or the complex back supply chain, which embeds an assembly plant in a particular location. This means it is vulnerable to assembly being transferred abroad (Davies *et al.*, 2015). More recently, the pivotal role of the central state as a transitions actor is recognized for instance in developing car transport in Sweden (Soderholm and Wihlborg, 2015).

2.6.3 Pressures to change

It is widely acknowledged that the automotive sector is in an era of unprecedented change (Orsato and Wells, 2007b). A stable/declining market in the west but an expanding market in BRIC nations means that new factories are more likely to be built there, offering the opportunity to redesign production. Specialist, luxury car makers such as Jaguar Land Rover are taking advantage of rising income levels to expand out of the luxury car market into mass market production, exporting particularly to the BRIC nations (SMMT, 2014).

New players are also entering the market, particularly from the internet sector such as Google cars, which lack the commitment to both steel and traditional manufacturing models and enjoy a different relationship with their customers (The Economist, 2012). Developments in information technology including computer aided design and 3D modelling improve the speed and reduce the cost of introducing new designs and materials. Integration of mobile phone technology into the car increases the weight and electronics within the vehicle but also facilitates the development of fully driverless cars. The computing and phone sectors typically also employ a different financing option to the automotive sector of renting and sharing rather than ownership, permitting frequent upgrades of products (Belk, 2014). Since cars may typically be in usage for only limited parts of a day, from a sustainability viewpoint, increased usage of a car is materially more efficient and sustainable (Cabrera Serrenho and Allwood, 2016).

Whilst these factors may encourage more diversity and mean that the sector is in transition, it is not clear that they are sufficient to challenge the status quo, or that any reconfiguration will be more sustainable. The sector has faced significant shocks previously such as the oil price rises of the 1970s and resisted change (Well *et al.*, 2012).

2.7 The role of legislation in the automotive sector

Tighter environmental legislation appears to be one of the few successful drivers of change to sustainable innovation in the automotive sector as discussed earlier by Tao *et al.*, (2010). The US Clean Air act and EU emissions reduction legislation are considered to have had numerous innovation effects on, for example, engine management systems/stop-start systems (Bergek and

Berggren, 2014, Lee *et al.*, 2011). From a policymaking perspective, it also seems easier to increase "stringency of standards" once the principle has been established rather than to raise taxation levels, because "standards are less visible to potential voters. " (Bergek, and Berggren, 2014, p.121). Costantini *et al.*, (2015) however warned in an analysis of biofuels that the impact of regulations depends on the maturity stage of the technology, with less mature technologies being particularly sensitive to price-based instruments. Yet without legislation, there appears to be little to destabilise the auto-regime and encourage it to adopt potentially more sustainable innovations (Wells *et al.,* 2012; Marletto, 2011) as in the analysis of the energy sector in Finland and the UK (Kivimaa and Kern, 2016).

Complying with legislative targets has been interpreted as a technological challenge, pushing manufacturers to innovate whilst maintaining the basic model as much as possible, as they do not wish to change users expectations, which they see as a given (Kemp and van Lente, 2011). Since size in particular is roughly equated with safety, retention of shape/size pushes improved design to reduce drag and encourages the development of lighter materials to reduce mass. Any mass-reductions also save fuel in the use phase benefitting the user and can be marketed as a value or money-saving measure (Lutsey, 2010). Car manufacturers also appear to be developing this technology more quickly than policymakers had expected, meaning that a significant method of reducing CO_2 emissions, and potential policy tool, was being overlooked (Lutsey, 2012).

Study of legislative formation also permits exploration of the development of innovations, since whilst regulation may stimulate the innovation (Porter and van der Linde, 1995b) the innovation may well precede and influence the regulation itself (Ambec *et al.,* 2013). If "the link between regulator and regulated is not unidirectional", (Kemp and Pontoglio, 2011, p34) the regulated in part may shape the formation of new legislation. Popp *et al.,* (2011) for instance argued that before regulation was introduced on reductions of chlorine use in the pulping industry, public pressure and industry concern drove innovation, so that the innovation preceded the regulation. Early applications of an innovation therefore may shape later legislative development. Perhaps ideally, sustainable policy and technological innovation might co-evolve in an optimal long-term system pattern (Foxon and Pearson, 2008). The design of legislation is significant since stringency, predictability and timing amongst other factors may shape acceptability, understanding and the success of implementation. Well-designed legislation draws on consultation with effected stakeholders, reducing implementation and enforcement costs whilst simultaneously improving the authority of the legislator.

Legislation may therefore be regarded as the crystallisation of expectations of a new technology and illustrate the success of interested parties networking, learning and expectations, i.e. key transition processes identified in the MLP (Geels, 2012; Markard *et al.* 2012). As such, it may reflect the dominance of the existing regime or the promise of the fledgling niche. Examining this process therefore answers the call for more in-depth studies of how regimes form and supersede one another (Markard *et al.,* 2012). The absence of legislation may also benefit certain parties and disaffect others. If legislation is an expression of the regime, then understanding its formation and effects may reflect how regimes can become unlocked (Geels and Kemp, 2007; Smith *et al.*, 2010).

The formation of new legislation is therefore a crucial nexus at which sustainability considerations might be brought to bear by national and supra-national governance. The initiation of new or amendment of existing legislation is a specific point where the rules are being changed. Within this arena it may be possible to examine how existing institutions and actors interact with the new, reflecting shifting power capabilities and showing how "incumbents" may work for or block change. Legislative formation may require, though does not necessarily need, more involvement from other parties and allows the issue to be brought to wider visibility through the media, enhancing debate and garnering legitimacy with the wider public.

2.8 Material changes – Bio-based materials.

As discussed, a significant sustainability improvement for cars is possible through reduction of mass: a lighter vehicle generally requires fewer material resources but also produces fewer emissions in use. This may be achieved by improved design and smaller size but also through the use of lighter materials, including polymers and plastics, rather than metals. Steel has traditionally made up approximately 70% of a typical vehicle mass, offering strength and reparability, and satisfying safety standards, which were often developed with metal in mind. Whilst energy-intensive to produce, there is the potential for recyclability with established recycling collection routes and processes (Ryntz, 2006; Cooper and Allwood, 2012). However, improved modelling techniques, computer-aided design (CAD) and understanding of vehicle stresses may render steel's strength unnecessary in some parts of the vehicle, whilst its mass significantly contributes to fuel requirements/emission production. Thus, whilst highly recyclable, steel's energy costs and mass mean that it contributes significantly to higher GHG emissions in both the use and manufacture phase (Jian, 2015).

Alternative materials such as polymers and plastics are increasingly used in car manufacture (Ryntz, 2006) due to their relative light-weight/strength ratio. Primarily in the car interior, these are increasingly utilised in the engine due to better understanding of the environmental pressures experienced here and improved blending and processing techniques; these may also provide cost-savings as compared to steel (Fuchs *et al.*, 2008). Derived primarily from oil however, these are ultimately unsustainable, whilst at end of life, most polymers are land-filled rather than recycled or re-used (Pimenta and Pinho, 2011). Oil price volatility also makes manufacturing profits unpredictable, encouraging firms to consider biologically-based feedstocks as a long-term supply solution (Chadha, 2010).

Biomaterials may be defined as products derived from "material of biological origin excluding material embedded in geological formations and/or fossilised" (European Commission, 2009). This definition includes biofuels, waste products from agriculture e.g. hemp, straw but also those derived from fermentation processes, bio-degradeable polymers and bio-plastics. A growing feedstock source is the bagasse waste, or left over matter from bio-fuel production (Bennett and Pearson, 2009).

Whilst bio-materials are considered carbon-neutral and renewable, their GHG mitigation effects are nullified if produced on virgin land. Rather than competing with food crops for land therefore, (Harvey and Pilgrim, 2011), bio-mass produced from waste agricultural products is both more efficient, carbon neutral and morally acceptable (Fargione *et al.*, 2008). There are also concerns that switching production from "crops for food" to "crops for energy/materials" may increase agricultural prices, impacting developing nations disproportionately (McDonald *et al.,* 2006). This research does not attempt to establish if bio-based materials are sustainable *per se* but to use them as an example of an innovative technology which is impacting on the automotive regime.

Bio-based materials offer a number of advantages to car-makers: their light- weight and strength to weight ratio mean that they are potentially substitutable for other materials in a variety of functions. For example, Toyota introduced a part-bio-based plastic derived from sugar for vehicle interiors (Toyota 2010). Volkswagen have recently begun using "EcoPaXX polyamide", which is 70% derived from castor beans, to replace aluminum in a crankshaft cover, benefiting from a 45% reduction in weight and system costs across the Audi, Seat, Škoda, and VW brands (DSM, 2017). Biobased feedstocks are potentially unlimited in comparison to oil. Theoretically they may offer the possibility of bio-degradability (Mohanty *et al.,* 2000) and there is growing interest in their usage, particularly for sustainability purposes (Monteiro *et al.,* 2009). Whilst conversion of bio- mass may require significant processing energy inputs, particularly to remove water content, the novel functionality of a "green" product attracts research interest and is attractive for corporate sustainability purposes. Biopolymers or plastics are therefore a small but growing part of the automotive sector (Hill *et al.,* 2012; Alves *et al.,* 2010; Carus and Gahle, 2008).

The introduction of a new material into the manufacturing supply chain of cars faces a number of difficulties however. There are extremely tight safety requirements and testing procedures, which can act as disincentives and a brake to innovation. The automotive supply chain is complex, with many manufacturers having limited knowledge and control over the supply chain. Cost minimisation is also crucial to retain market share, which acts as a disincentive to innovation, particularly at a time of recession. These difficulties may be construed as examples of the "lock-in" (Unruh, 2000) which act as barriers to the use of more innovative materials.

Consequently, whilst the use of biomaterials offers the potential to reduce CO_2 emissions at one stage of the automotive life-cycle, the use phase, and simultaneously reduce dependence on finite oil-derived polymer feedstocks, their increasing adoption is problematic on at least two grounds.

First, there are concerns over their their environmental and societal impact, such as in terms of competition with food crops and need for water. Second, there are significant barriers, in terms of cost, legislation and industrial inertia, to their deployment on a large scale. This research is concerned with the obstacles and drivers to innovation and in particular, their manifestation within key legislative instruments used to regulate the European automotive sector.

2.9 Applying the MLP to the analysis of legislative instruments in the automotive sector and biomaterials

The previous discussion has explained that the automotive sector faces a number of challenges, but the financial success and stability it enjoys means there has been comparatively little pressure, either internally or externally to innovate either sustainably or to significantly consider either environmentally sustainable technologies or alternative materials unless pushed by legislation (Bergek and Berggren, 2014).

The definitions of the landscape, regime and niche as discussed earlier, can be applied to the automotive industry and are appropriate as shown below. Here legislation at the EU level is seen as a key part of the regime as EU legislation plays both a significant role in the development of the international car market and is used by the EU to achieve its environmental leadership ambitions (Wurzel and Connelly, 2011).

Whilst the importance of legislation to push sustainable innovation in this sector is acknowledged, there has been limited study of the formation of automotive legislation itself at the intra-national or EC level specifically using a transitions or MLP approach (i.e. analysis of the three key processes of learning, networking and articulating expectations) or for the explicit normative purpose of sustainable innovation. More significantly, the shaping of future legislation or of how existing legislation might need to be adjusted to encourage sustainable innovation appears to have attracted very limited investigation.

2.10 Conclusions, research aims and questions

Strategic Niche Management was originally developed to bridge the gap between legislation and market-based tools in order to foster more sustainable innovation. Whilst early research had a normative goal in seeking ways to shelter "niche" technologies so that they might survive in the market, engage with and gradually transform the regime, there is increased appreciation within the MLP literature of how the regime might block or facilitate this process. Analysis of how these new technologies might establish themselves within the regime or of how existing regimes will also need to adapt is therefore timely and necessary.

The formation of legislation, the formal rules of the regime, does not appear to have been explicitly addressed within the sustainability transitions literature but would appear to be a critical point at which the contradictions, dissonances and differences between the established regime and the new niche are contested and made visible. As the political process significantly influences the formation of legislation, the field can be developed by more consideration of political processes and the effects of legislation, particularly if one of their stated aims is to develop sustainable innovation (Lawhon and Murphy, 2012). The inertia and success of the automotive regime suggests that endogenous change is unlikely and the current literature suggests that change is more likely to emerge from a top down imposition of legislation (Tao *et al.,* 2010; Bergek and Berggren, 2014). The effect of legislation may depend however in part on the character of the firm and its approach to innovation (Kesidou and Demirel, 2012).

The loose analytical framework of the MLP has utility in consideration of this dynamic problem. The automotive sector has an established body of study, is widely considered to be in an era of transition and has an urgent need to sustainably innovate. These factors make it a particularly suitable sector for study. This research also addresses the need for further empirical data at the sectoral level, which is under-represented in the literature (Markard *et al.,* 2012). By focusing on legislative formation at the EU level, the research will widen the scale from the national, which is both appropriate to this sector and permits a more nuanced consideration of the role of scale, politics and geography (Raven *et al.,* 2012). The study of legislation is also important because of its effectiveness compared to market-based instruments in encouraging eco-innovation (Kemp and Pontoglio, 2011). Study of a number of cases, rather than a single case, within the MLP framework also permits comparative and thematic analysis which contributes to methodological developments in the field (Geels, 2011).

This research therefore seeks to illuminate a neglected aspect of the sustainability transitions literature by more explicit analysis of existing automotive legislation, the processes whereby legislation forms and the ways in which it may act as an enabler or barrier to a particular innovation.

The overall research aim may be summarised as:

How can transitions theory to foster sustainable innovation be improved by the study of legislation?

To that end it addresses four research questions:

RQ1: How has European automotive legislation affected the development of more sustainable innovation in the automotive sector?

RQ2: What are the barriers and drivers to the use of biobased materials in the UK automotive sector?

RQ3: Are there legislative barriers to the use of biobased materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

RQ4: How could EU legislation be modified to support sustainable technologies in this sector?

The next chapter explains the research design used to address these questions and explains the selection of cases and methods utilised to do so.

3 Research Design and Methods

3.1 Introduction

As discussed in the literature review, this research utilises methods drawn from the transitions literature (Geels, 2014; 2012; Kern, 2012; Markard *et al*., 2012; Kemp *et al*., 1998) and technology studies (Bergek and Berggren, 2014*;* Bergek *et al.,* 2008a; Bergek *et al.,* 2008b*)*. The thesis analyses the impact of European legislation on sustainable innovation, in particular the adoption of biomaterials in the automotive sector. As such, it addresses a limitation of transitions theory, that is, its failure to explicitly address how national and international legislation may shape sustainable innovation.

The research also develops transitions theory by shifting focus to explicit examination of what transitions' theory calls "the regime" (Geels, 2014, 2012; Kern, 2012; Markard *et al*., 2012) and posits that legislative formation is a forum in which the inertia of the established regime and the first interactions of "the niche" can be seen. This research therefore uses more traditional political analysis to show how this occurs, together with consideration of those processes which transitions theory considers critical, in particular, knowledge, expectations formation, and network development (Geels, 2014; 2011; Kern, 2012; Geels and Kemp, 2007; Kemp *et al.,* 2000b*)*. The research therefore develops a more political studies approach (Meadowcroft, 2016; 2011; Lawhon and Murphy, 2012*)* in which to address the aims of transitions management to foster sustainable innovation.

The chapter is structured as follows. Following an outline of the research design and use of case studies, a brief description of the chosen pieces of European policy is given. The choice of data sources, including the use of "elite" interviews and a semi-structured interview protocol for primary data collection are specified and justified.

3.2 Research Design

As discussed in the literature review, transitions theory seeks to understand how sustainable innovation might best be promoted. The review identified a gap relating to the influence of legislation in the MLP framework. Research questions were developed to address this gap specifically in relation to the introduction of bio-based materials to the automotive sector.

A qualitative case study approach was adopted utilising data collected from “elite” interviewees, gathered by a semi-structured interview approach based on the topic guide developed from the research questions. In line with the semi-structured approach, the precise questions varied depending upon the expert interviewees, but remained in line with topic guide themes. This information was supplemented by secondary data from academic literature and industry sources. A comparative case study approach was implemented (Burnham, *et al.,* 2008; Yin, 2009) because it allowed for study of the impact of legislation throughout the life-cycle of the car.

An analytical framework based on Kern (2012) was used, operationalizing key parts of the MLP framework as shown below in table 3.1, to identify important elements for study..

Table 3-1. Analytical framework

Landscape	Macro-economic trends eg globalisation, climate change Macro-political developments eg changes in EU structure and rules Cultural patterns eg changes in consumer demand for cars	Gradual long-term change beyond the scope of individual actors
Regime	Rules eg guiding principles, relationships, regulations, policies	Incremental change based on existing knowledge, networks and expectations
Niche	Small-scale innovative technologies and changes in practices	Disruptive change based on differing expertise, new networks and expectations

The key processes of learning, networking and expectations of the MLP are observed to varying degrees at different levels (Kern, 2012; Markard *et al.*, 2012; Geels, 2011; Geels and Kemp, 2007).

Following analyses, the case studies were then written up in a narrative framework based around Europe, the UK, the car industry and the bio-based materials sector, before being cross-compared in the final discussion chapter to answer the research questions more directly.

3.3 Case studies

Gerring (2012) defines a case study as "an intensive study of a single unit with an aim to generalise across a larger set of units" (Gerring, 2012, p. 341) and suggests that this allows researchers to understand both the uniqueness of the unit studied and what it holds in common with other instances. Case studies also permit early empirical data gathering for the formation of theories (Eisenhardt and Graebner, 2007) and are usually detailed reports, often including descriptive and analytical sections. There is a particular need for more empirical data in the sustainability transitions literature to enrich theory and widen understanding (Markard *et al*., 2012) with a gap noted at the sector level. Case studies permit the study of a complex set of relationships and there may be an explicit normative endpoint. The current small scale of development of bio-based materials in the UK also makes this method appropriate.

Case studies lend themselves to consideration of present-day events and early exploratory investigation of "how" and "why" questions (Yin, 2009). They may permit exploration of real-life contexts and are often based on a range of data sources including interviews and documentation. The bounded nature of a case study permits a wide variety of factors to be evaluated to give a more complete description. This holistic and systemic viewpoint may permit a deeper understanding of issues, particularly appropriate in studying the development of innovative sustainable transitions which by their very nature may represent unprecedented, original change, and through their uniqueness, be inimical to study by more quantitative methodologies. Case studies are also an established methodology within the sustainability transitions literature (e.g water management, van der Brugge *et al*., 2005; biofuels, van der Laak *et al.*, 2007; electric cars, van Bree *et al*., 2010; aviation, Nakamura *et al*., 2013; bio-energy, Levidow *et al.*, 2014). Case studies thus provide an ideal way to address the research questions, which consider the particular ways that existing automotive legislation may affect sustainable innovation, especially in new materials.

In contrast, the predominant mode of study of the transport sector, when addressing sustainability for instance is rooted in quantitative metrics, such as life-cycle analysis (LCA) and material for selection studies (Schwanen *et al*., 2011; Mayyas *et al*., 2012). Whilst considered value-neutral, these methods fail to question common assumptions, accept the primacy of the car as a transport solution and ignore the political/power aspects of the car industry (Schwanen, 2013). Moreover, these modes of analysis reflect the industry as the innovation agent/hero in a streamlined narrative of innovation (Deuten and Rip, 2000) in which other actors are superfluous or act "irrationally". As this research posits that legislation is both an over-looked aspect of sustainable transitions and may have wide-ranging and long-term implications on the industry, it is important to understand the specifics around its formation. By doing so, it may help to explain the inertia which appears to hamper innovative sustainable transitions and how existing legislation facilitates the status quo and/or hampers/shapes the innovative. As the use of bio-based materials develops, it is increasingly important to understand how a specific technology and material application may be shaped by existing legislation.

3.4 Legislation

As the automotive sector operates at a transnational global scale in terms of both its supply chain and research and development, in trying to understand the role of legislation, it is important to move beyond a purely national level of analysis. Whilst most transitions studies examine a particular sustainable innovation at a range of governance levels encompassing the national and European, they may conflate the local, national and international with the niche, regime and landscape (Geels, 2010). Here the "regime" is explicitly defined as the legislation at the EU level. Explicit examination at the EU and national level affords the opportunity to examine the effects of these boundaries more clearly whilst recognising their reflexive and interconnecting influences. More specifically, the research addresses a limitation of transitions' theory, namely that it fails to take account of how national and international regulation interact to affect sustainable innovation and the activities of actors such as car manufacturers.

European automotive legislation was chosen for a number of reasons. First the EU has a history of seeking a role as a leader in environmental legislation (see *inter alia* Liefferink and Wurzel, 2016; Karlsson *et al.,* 2012; Wurzel and Connelly, 2011; Lenschow and Sprungk, 2010; Parker and Karlsson, 2010; Skodvin and Andresen, 2006). Second the EU is a major car manufacturer, accounting for 23% of global car production, (second only to China) and for 23.6 % of all new car registrations (ACEA, 2016). Third, the European car industry enjoys significant state support but at a time of economic austerity, there is increased questioning over the extent of this support and its relevance to the public interest (Grigolon *et al.,* 2012; Jullien and Pardi, 2011). Third, EU standards are frequently adopted by emerging states, such as China where manufacturing is increasingly located (Chen and Zhang, 2009), meaning that the European standard may have international implications (Sakai *et al.,* 2014). This last factor is particularly applicable to the automotive sector where economies of scale may mean that one standard becomes the de facto international standard. Fourth the researcher's location made the study of European legislation more practicable than, for example, the US or an Asian market. While the European Union has evolved over time and gone through several name changes, (e.g 1992, European Economic Community) this thesis refers to it throughout as the European Union (EU) to maintain consistency (Bomberg *et al.,* 2012). Similarly, the term European Commission (EC) is used to refer to the executive arm of the EU (European Union, 2016; Bomberg *et al.,* 2012).

EU decision-making is based around three key institutions: the Council which represents the governments of the 28 member states; the Parliament which is directly elected by eligible European citizens and the Commission which acts as a politically independent executive body to propose, manage and enforce EU law (European Union, 2016; Bomberg *et al.,* 2012). Where the EU has either the exclusive or shared right with member states to make law, such as on most environmental legislation, policies are usually proposed by the Commission, then jointly adopted by Council and Parliament on the principle of "Ordinary Legislative procedure" known as codecision (Burns *et al.*, 2013). The Council has a rotating presidency shared between the member states on a six-month basis (e.g. the Netherlands 1 June-30 June 2016); a Council President, currently Donald Tusk, who is elected by member states and a Commission President, currently Jean-Claude Juncker. The process by which decisions are jointly taken is considered a more deliberative than confrontational system as in the UK parliamentary system. Much of the Commission's work is now around updating and amending policy, rather than new initiatives. A case for amendment is based around gathering data, representations from Council, or from MEPS in the Parliament, meaning that one piece of legislation may be subsequently weakened, strengthened or amended by further legislative acts.

The effects of a particular piece of legislation on innovation will depend on a number of factors including how it is enforced, its timeframe and boundaries. Writing in the context of another emerging technology, nanotechnology, Stokes (2012) argues that, regardless of regulation content, applying or adapting existing legislation "involves the transmission of traditions and assumptions, inbuilt in the regulatory regime, about how those requirements should apply and to what ends" (Stokes, 2012, p.101). To study innovation in the automotive sector therefore, required understanding of the automotive industry; the policy and legislative instruments of European law; and their particular application in one state, the UK. Within European law, the promotion of a common market is key (EEC Treaty, 1957) and facilitated by article 114 on harmonisation, which gives the EU competence to legislate. This justifies funding for research and development to develop new manufacturing industries to generate jobs, products and profits equitably throughout the Eurozone. To sell into the single European market, car manufacturers must comply with European legislation, offering car manufacturers significant economies of scale.

As the detail and context around legislative implementation is critical, the UK was selected for a number of reasons. The UK regularly accounts for the second highest number of new car registrations in the EC area (EEA, 2015) and is the fourth largest manufacturer, with a diverse production mix of luxury and mass-market vehicles (SMMT, 2014). Since some 77% of these vehicles are exported representing approx. 10% by value of UK exports, the sector is viewed as an important part of the economy and symbolic of a manufacturing industry. Again, selection was shaped by the practical one of researcher access. Yet the UK differs in one important regard from many other European car manufacturing states in that it perhaps most embodies the international aspect of car manufacturing, in which components may travel over national boundaries multiple times during the production of a single car part. Moreover, in contrast to other states, such as the USA in its support of GM and Ford in 2008, (Lee *et al.*, 2011) or France in its support of Renault (Villareal, 2011), the UK government has been reluctant to commit overt state support to UK-based car manufacturing, particularly since the collapse of Rover (House of Commons, 2006). This lack of overt "economic nationalism" on the UK government's part potentially makes the UK car industry more exposed to both market pressures and EU legislation making it an ideal site for study.

3.5 Choice of Legislative Case Studies

The choice of policy instruments was shaped by a number of factors. There are many policy measures which affect the choice of materials in cars and their impact, but those chosen were considered: most influential by industry (see section 3.6.2 below), had been in effect over varying time periods, (allowing study of change processes) and addressed the sustainability of the car at a particular point in its life-cycle thereby permitting analysis of different parts of the car "regime". These policy measures therefore act as proxies for a particular part of the lifecycle of a car, but seek to cover the car LCA completely, since reductions in one part, will shift the life-cycle burden to another, for example from the in-use phase to the manufacturing stage (Carbon Trust, 2011).

The predominant environmental impact of a car is generally agreed to come from the use impact of the vehicle, at around 85%, with manufacturing accounting for approximately 10-15% of its lifetime impact and disposal approximately 5% (Mayas *et al.*, 2012).

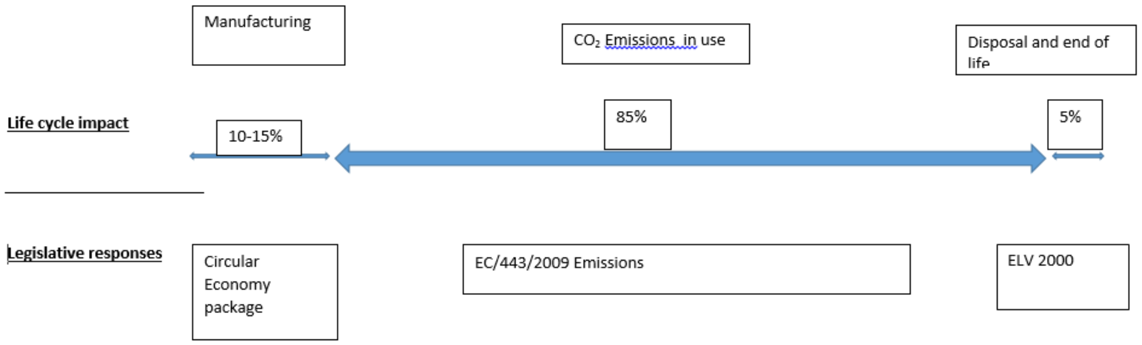

Figure 3.1 Life-Cycle Analysis of Car against Legislation

Figure 3.1 above maps this environmental impact against the legislative instruments thus suggesting that since the majority of the lifetime impact of a car comes from the use phase, predominantly regulated by Emissions regulations (EP, 2009), this might be considered the most important piece of legislation to consider from a sustainability viewpoint. The end of life of vehicles directive (EP, 2000) and the Circular Economy action plan (EC, 2015a) may be taken as attempts to address disposal and sourcing respectively.

Moreover, it is important that the legislative measures selected reflect all of the life-cycle of the car, not just the largest now,since efforts to reduce e.g CO_2 emissions in use and a move towards electric rather than petrol cars, means that embodied emissions, produced from the manufacturing and end of life phases, are estimated to become the dominant source of emissions from cars in the next 5-10 years (Carbon Trust, 2011).. Both the Emissions Regulations (EP, 2009) and the ELV directive (EP, 2000) are well-established and accepted parts of the legislative landscape and thus may be seen as part of the regime in transition terms. The third case study, the Circular Economy package (EC, 2015a) affords the opportunity to review proposed legislation that has the scope to affect material resources most directly Moreover, this last case offers the opportunity to explicitly address some of the key themes of transitions methods i.e. knowledge formation, network development and expectations (Geels, 2016; 2011; 2010; 2004; Kern, 2012; Markard *et al.*, 2012; Geels and Kemp, 2007) .Table 3.2 compares the three selected policy measures

Table 3.2. EU policy measures selected for case studies

Title	Purpose	Date	Type
EC 443/2009 Emissions Regulations	To reduce CO_2 emissions from cars in use	2009	Regulation
ELV (End of Life of Vehicles - 2000/53/EC	To ensure the environmentally safe disposal of cars at end of life	2000	Directive
Closing the loop: an EU action plan for the Circular Economy	To promote the Circular Economy, the sourcing and reuse of materials	2015	Package

Each case also acts as an exemplar of a particular way a car "problem" is conceptualized, which is relevant because it illustrates the differing ways in which networks, expectations and knowledge combine to shape the legislative solution offered. The cases also represent different levels of compliance. The long lead times associated with car regulation (Wells *et al.*, 2013) mean that whilst a longitudinal study was not possible within the timeframe of this research, the choice of different cases provides an opportunity to understand the influence of contrasting contextual factors over differing timeframes. These particular examples also show how the choice of legislative instrument shapes industry and national expectations around what is possible/permitted and as such offer the researcher the opportunity to examine the problem of implementation across Europe. The instrument chosen may reflect what is possible in terms of the marketplace and what is politically possible in contrasting time periods.

There are contradictions and tensions between these standards however. Steel has traditionally enjoyed high recyclability, satisfying ELV, but is heavier thus conflicting with reductions in CO_2 emissions. Because ELV is calculated on weight, this disadvantages more light-weight materials which may reduce emissions. These new materials may also lack a recycling infrastructure to support them, thus conflicting with the ELV and the proposed CE. More detail on the selected legislation is provided in the next section.

3.5.1 Emissions legislation

The Emissions Regulations (EP, 2009) apply to all cars sold in Europe and aims to reduce the amount of CO_2 emissions produced by cars in use. As such it is potentially a significant regime changer compared to previous voluntary efforts by industry to reduce car emissions. The legislation is directly credited with producing a reduction in CO_2 levels (Gibson *et al.,* 2015) a sustainability goal, and encouraging manufacturers to innovate. The structure of the legislation however suggests a narrowly technological view of innovation. For example, by applying the legislation to vehicle fleets as a whole, with heavier/more polluting cars permitted more emissions, the incentive to move away from heavier cars is blunted. Although material selection is a significant method for weight reduction it is largely ignored. The Directive seeks to reduce the amount of CO_2 emissions generated by cars in use, thus addressing sustainability issues by attempting to reduce the generation of GHG. As the legislation seeks to reduce emissions in use which can be directly addressed by light-weighting, it is relevant to bio-based materials which are a potential lightweight alternative to many established automotive materials. This case study forms chapter 4 of the thesis and directly addresses the first research question: How has EU legislation affected the development of sustainable innovation?

3.5.2 The ELV directive

The ELV Directive (EP, 2000) applies to the disposal of cars at their end of life and dates from 2000. It was transposed into UK law from 2003. Each car is considered individually and there is a particular emphasis on the safe disposal of materials harmful to the environment such as lead or battery acid. Safe disposal is evaluated in terms of material type and weight with a particular focus on metals, and an emphasis on recyclability. As such, the legislation is generally considered a success but its affects on material selection are problematic, since it indirectly favours heavier and more easily recyclable materials. As it seeks to remove the burden of waste disposal from future generations by reducing landfill dependence and the use of hazardous materials now it addresses a key goal of sustainability. It also affects material choices and is thus relevant to the increased use of bio-based materials.

The ELV directive was driven in part by concerns over landfill space filling up and was based on the principles of reduce, reuse and recycle. More subtly, the legislation sought to encourage manufacturers to reduce the amount of material used in design (long-term lightening the load) and to encourage design for easier disassembly. ELV is based on the principle of producer responsibility with the goal of recycling 85% of automotive material on a mass basis by 2015, with recovery of 95% (EP, 2000). The motivation was articulated in terms of human health and the environment and aims to ensure that materials should not cause any environmental hazard, for example the incorrect disposal of toxic battery fluid, lead or mercury. This legislation has also strongly influenced other states, particularly China (Chen and Zhang 2009), specifically in the area of resource recovery, recycling and design for sustainability. In addition, the Circular Economy package, the next case study, which aims to simplify a suite of waste legislation, includes the ELV. This case study forms chapter 5 of the thesis and also directly addresses the first research question: How has EU legislation affected the development of sustainable innovation?

3.5.3 The Circular Economy Package

This proposed package reviews existing legislation particularly on waste and addresses growing concern over resources and rising commodity prices. Moreover, as its formation was contemporaneous to the thesis research, in contrast to the other case studies, there was the opportunity to specifically investigate stakeholders expectations, knowledge and networks. Interviewees lacked the capacity for hindsight but gained the opportunity to articulate their expectations, which transition theorists regard as a particularly significant aspect of transitions management (Kern, 2012; Geels and Kemp, 2007; Kemp *et al.,* 1998). The case addresses a key sustainability issue, the shortage of resources and resource efficiency. This case study forms chapter 6 and particularly addresses the second research question: how might legislation be modified, particularly in relation to ELV.

3.6 Data sources

The research draws upon qualitative data from a mix of primary and secondary sources**.**

3.6.1 Primary interview data

Interviews are an important source of primary data for a number of reasons (Harding, 2013; Yin, 2009). First, they permit the gathering of contemporary views and perceptions, which might not be committed in writing or discovered by any other method (Weimer and Vining, 2011). This is particularly true of the tacit information, including industry assumptions, which is not normally committed to academic texts. Second, they may offer participants the opportunity to articulate their own motivations for behaviour (Herz and Imber, 1995). Third, interviews permit the articulation of expectations that may help to shape the future (Geels, 2010). Interview analysis may thereby expose values, blank spots and assumptions permitting interrogation and questioning of unfounded/irrational or biased futures (Byrne in Seale, 2010). Moreover, interview data sourced and recorded in the academic literature on the automotive sector are limited as previously noted in the literature review, in part due to commercial confidentiality requirements. This limitation has produced a significant gap in analysing the sector's development; the gap also obscures and diminishes the political aspects and elements of societal choice, rather than technological determinism, evident in this sector.

By interviewing key experts, particularly in relation to the relevant case studies, the researcher therefore sought to enrich the study of this sector. Expert opinion was gathered on the formation of the legislation and its effects in order to understand insiders' understanding of why the legislation had a particular effect. These data therefore permitted a more nuanced and political evaluation of how the legislation has shaped sustainable innovation, particularly in material choices, in the automotive sector.

3.6.2 Elite/expert interviews

"Elites" may be defined as a limited population with a specialist knowledge where the interviewees are not treated in a standardised way (Dexter 1970). Elite interviewing can be defined as that where the interviewee may be a "decision-maker" (Burnham *et al.,* 2008, p.231), with wider knowledge of the subject than the interviewer and where some interviewees are more important than others. Thus, rather than a similar population where quantity is the aim to ensure representativeness and validity, the elite-interviewing process accepts that some respondents are more influential than others. The relatively small population of decision-makers in automotive firms, EU and UK lobbyists and policy makers make elite interviews an appropriate tool for this research, particularly given that decision-making is so markedly hierarchical in the car industry as noted in the literature review (e.g. Wells *et al.,* 2013). Elite interviewing is often used to corroborate other data or particularly in a political context to understand how a set of events occurred (Tansey, 2007). Interviewees may offer insights to the motivations and perceptions of sections of the industry (Byrne in Seale, 2010). Since innovation is by definition a break from a norm, a representative population would also not necessarily shed light on this issue.

Selection of interviewees was based in part on availability, exposure to the issues and visibility in official documentation. Interviewees were often identified and accessed through industry events, which later afforded the opportunity to garner interviewees' analysis of industry presentations. "Chatham House" rules applied at these events, meaning the sources cannot be explicitly or implicitly identified, but attendance and discussion permitted the unofficial confirmation of information. Interviewees were also identified through freely available academic and official reports, and personal recommendation but also through visibility on social media, such as Twitter or EU websites. Selection of the latter group of interviewees seemed appropriate as the research sought to understand in part how innovation and new materials interacted with established industry and generated political contacts, networks and shaped expectations. Some snowballing of contacts also occurred. Whilst over 100 potential interviewees were identified and contacted, successful response was mostly limited to those met at industry events, resulting in 25 interviews.

Although the number of interviews is relatively small, and their views may not necessarily be representative, the range of views expressed is important because the research is explicitly bringing together disparate groups from different industrial sectors on a number of cases for the comparative analysis it affords. Moreover, the established hierarchical nature of the automotive industry, and its recognised carbon "lock-in" and inertia mean that a relatively small population enjoys a great deal of influence, whilst sharing a certain conformity of approach. The lack of prior research in this area also means that a relatively small number of interviews can generate rich data to shed light on a data-poor but important issue. Whilst Mason (2010) found a mean sample size of 31 interviewees in 561 qualitative PhD studies, he argues that a purely quantitative measure is inappropriate since it is the research questions and quality of the interviews themselves that are important. Nevertheless, in order to supplement and bolster the interviews, the evidence was triangulated against primary and secondary documentary sources, together with confirmation at industry events to validate findings (Cresswell, 2008; Prior, 2003).

Transitions theory suggests that stakeholders can be clearly identified and placed in the three sections of transitions theory, the landscape, the regime and the niche (Whitmarsh, 2012). However, applying this distinction in practice was not always clear-cut. A purposive sampling strategy was used and as the thesis focuses on the regime level, interviewees from the following groups were targeted: high-level car manufacturers, particularly those in charge of materials selection and their suppliers; legislative officials including EU MEPs; UK policymakers and civil servants. Interviews with academics and heads of relevant trade organisations also offered interesting insights and contributed to a wider understanding of the context and "landscape" of each case.

Semi-structured interviews were used, rather than strictly standardised questions, to take advantage of the range of interviewees and are also appropriate for elite interviewees, permitting the interviewee to shape the interview or to develop themes which might not have occurred to the interviewer (Smith *et al.*, 1995). Initial interviews often took a more unstructured approach as the researcher sought to understand key themes and industry concerns (Gillham, 2005). Of particular importance here was the early identification of a number of policy instruments which were identified by industry players as the most influential and significant in shaping their actions in materials choices together with an academic literature. The topic guide was then developed to address the research questions and the themes identified in the analytic framework from the academic literature (Byrne in Seale, 2010). The guide is grouped into three segments to cover the targeted groups of stakeholders: car manufacturers; policymakers and civil servants; and bio-based materials practitioners with particular reference to the identified policy measures. Other interested parties including NGOs, academics and trade association representatives were also interviewed, adapting the topics to their particular expertise because of their wider "landscape" experience of the contextual development of the legislation and particular expert knowledge.

The semi-structured format also offers the opportunity to more readily understand how and why questions (Cresswell, 2008). Given that new materials may challenge established protocols and knowledge, it is not always clear what the relevant factors are. This seemed appropriate since this research is concerned with how automakers and other stakeholders frame the problem and understand the barriers within the current legislative system, the regime. The question order was frequently varied and adjusted to suit the particular knowledge of the interviewee and circumstances in which the interview was obtained. Given time constraints with this group, one or two key questions were identified as priorities for each interview. The topic guide is shown overleaf in figure 3.2.

Due to the nature of information gathered, cross checking and confirmation were not always possible. Interview data however were sometimes tested by referring to their anonymised content with other interviewees (Hunter in Hertz and Imber, 1995). Questions were formulated to be open and non-leading as much as possible – though occasionally they were framed to provoke a reaction. Interview questions were developed in part from the literature and grouped around themes developed from the research questions to form prompts for discussion (Burnham, *et al.,* 2008).

Research questions

RQ1: How has European automotive legislation affected the development of more sustainable innovation in the automotive sector?

RQ 2: What are the barriers and drivers to the use of bio-based materials in the UK automotive sector?

RQ3: Are there legislative barriers to the use of biobased materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

RQ4: How could EU legislation be modified to support sustainable technologies in this sector?

Topic guide

Car industry

- Sustainability in the car sector
- Key knowledge and networks
- Influence of legislation vs other factors
- Improvements in sustainable innovation
- Factors affecting material choices
- Expectations for the future

Policymakers – UK and EU including Civil Servants

- Intentions of the legislation
- Factors influencing its development
- Effects of the legislation
- Issues in administering effectively

Bio-based industry

- Development of bio-based materials
- Sourcing, use and disposal
- Expectations of market development
- Importance of legislation
- Key knowledge and networks
- The car market

Key questions

- Do you think the legislation worked as intended? (expectations)
- What key issues do you think will affect the car market/bio-based sector over the next 10/15 years? (expectations)
- What knowledge gaps are there? (knowledge)
- Who are the key stakeholders in this sector? (networks)
- What is the role of legislation in these developments? (regime)

Figure 3.2. Research questions and topic guide

Due to the nature of information gathered, cross checking and confirmation were not always possible. Interview data however were sometimes tested by referring to their anonymised content with other interviewees (Hunter in Hertz and Imber, 1995). Questions were formulated to be open and non-leading as much as possible – though occasionally they were framed to provoke a reaction. Interview questions were developed in part from the literature and grouped around themes developed from the research questions to form prompts for discussion (Burnham, *et al.*, 2008).

Ethical approval was obtained from the University of York ethics committee before interviews commenced. This had to take account of commercial privacy considerations: in some instances non-disclosure forms were required which might have conflicted with possible future publication and required clearance by the University data management officer. Therefore prior to interview, a project information sheet, consent form and interview protocol were sent so that interviewees had full information and could provide informed consent (see appendices) and as recommended in good research practice (Ali and Kelly in Seale, 2010). These explained that data would be both anonymised and kept confidential, taking into account the Data Protection Act 2000Interviews lasted between fifteen to ninety minutes and where possible were recorded for accuracy and to enhance conversational flow, unless the interviewee specifically requested no recording in which case contemporaneous notes were taken. Ideally interviews should be undertaken within a short bounded timeframe but in practice due to the difficulties of recruiting interviewees and their limited availability, interviews were undertaken between 2013 and 2017, with an initial focus first on car manufacturers. Table 3.5 provides a full list of the twenty-five interviewees with dates and interview lengths.

Interviewees are indicated in the text by a numerical code inside brackets numbered 1-25 e.g. (1) or their position specifically advised e.g. ex EC MEP or Car manufacturer. The interviewees are numbered in sequence based on their first appearance in the text. Interviews took place in a variety of settings including factories, industry conferences, coffee shops and workplaces. Given that interviewees were often short of time and difficult to pin down, it was necessary to have key questions for answering. The assumption was made that a view expressed by an individual also represented the company stance unless otherwise stated (Anastasiadis, 2014).

Inevitably there were some challenges presented during data collection. The Volkswagen emissions scandal meant that car industry interviewees were particularly sensitive around any discussion of emissions legislation after 2015 (see Oroschakoff, 2015). In the run-up to and aftermath of the UK decision to leave the EU, interviewees at both the national and European level also noted a policy hiatus in UK government decision-making which also hampered discussion. Issues of commercial sensitivity over new materials and their life cycle assessment methods were frequently expressed, meaning that the interviewer balance between retaining access and assertive questioning was often challenging.

Table 3-2. Interviewee list

No. in text	**Description of Interviewee**	**Date**	**Length**
1	Retired VP of US car firm/academic	5/11/12	25 mins
2	Materials Manager, OEM, UK	16/1/13	55 mins
3	Senior Manager, OEM, UK	15/1/13	70 mins
4	MD – Tier 1 firm, UK	31/1/13	15 mins
5	Testing engineer – Tier 1 firm, UK	31/1/13	56 mins
6	Head of purchasing – Tier 1 firm, UK	14/2/13	28 mins
7	Senior Manager – Tier 1 firm, UK	2/3/13	58 mins
8	Academic with industry links	16/12/16	42 mins
9	Current UK MEP	9/1/16	43 mins
10	Member of House of Lords	18/1/16	52 mins
11	Ex-BIS Civil Servant	19/1/16	Approx. 1 hr
12	Head of sales at major UK OEM	22/1/16	37 mins
13	Ex UK MEP	1/2/16	1 hr
14	SME owner with innovative lightweighting product	8/3/16	80 mins
15	Trade association secretary	10/3/16	55 mins
16	Bio expert/Financier	19/4/16	Approx. 20 mins
17	Bio expert/Academic	4/5/16	50 mins
18	Academic with industry links	24/5/16	55 mins
19	Policy expert – Env NGO	6/6/16	44 mins
20	CEO Public/private research – ex JLR Director	7/6/16	15 mins
21	EC Cabinet member – Jobs, Growth, Investment and Competitiveness	9/6/16	35 mins
22	Composites manager	10/6/16	48 mins
23	Ex LA waste manager/Waste consultant	23/6/16	42 mins
24	Senior Civil servant - Defra	19/1/17	80 mins
25	Head of Bio-based materials association	21/2/17	53 mins

3.6.3 Secondary Data

Secondary data from a number of sources ranging from academic to industrial were collated to assist the analysis of the legislative case studies (Silverman, 2011). The wider media/general web were also used, despite their lack of research credibility because of the relative novelty of the subject, minimal academic research and to suggest experts and stakeholders for comment (Weimer and Vining, 2011). Moreover, as articulation of expectations is a key theoretical part of the MLP framework, this is an arena in which these can be seen and has been used by other academics in this field (e.g Penna and Geels, 2015). Documents were grouped from five main sources: those produced by academics; those produced by government organisations; reports by interest groups and NGOS, Company documents and the wider media/general web. Use of company reports is an established means of understanding innovation processes within firms (Sarasini *et al.*, 2014).

Prior (2003) makes the point that documents act in a number of ways: as the product of a particular process; as holders of instructions, and as actors themselves in their effects. This means they are not simply the neutral initiators of processes but the result of negotiations, expectations and political processes and necessarily the product of a particular configuration of bias. Much of the MLP literature accepts documentary sources with little examination of the motives for their creation, although historical research points out the fallacies of this approach. The provenance of the secondary data was therefore considered in order to identify potential biases and provide a relative weighting with regard to relevance and significance. Historians for instance commonly accept that all documents are biased but adopt rules of thumb to address this. These include 1. time and place i.e the closer to the original time and place of creation, the more accurate the document; 2. The reasons for the creation of the document, including its intended audience. 3. Comparing it against other documents, validated in a similar way. This is of even greater importance given the quantity and quality of information available on the internet. Whilst this evaluation can never be an exact science, particularly since interpretation is also subject to the researchers own bias, the process permits a reliable account to be built up.

The legislative document itself also formed a source of inference for assumptions about the car industry (Platt 1981a) supported by other independent information. General familiarity with other EC documents was therefore important to understand what was different about these particular documents and to find the “dissonance” (Platt 1981b).

Secondary data aided the robustness of the research in a number of ways. First, because the research was reframing a problem in a slightly different way i.e. how legislation itself might act as a barrier to a particular innovation, less conventional sources of information, such as grey media, were drawn upon. Second, the difficulty of obtaining primary interview data from the automotive sector due to industry sensitivity and commercial confidentiality underscored the importance of additional sources. The use of secondary sources also helped to identify potential interviewees who were either established figures, representing the regime in the broadest sense or niche actors attempting to break into the regime. Third examples of implementation of innovative sustainable material choices were limited and often restricted to trade press. Fourth, evidence from non-academic sources such as the media might be seen as evidence of increased public awareness and changes in the wider landscape (Penna and Geels, 2015). Since transitions theory highlights the importance of knowledge and networking this seemed particularly appropriate. Fifth, by using varied evidence sources this improves the robustness of the analysis whilst recognising that the research is multi-disciplinary and encompasses a wide range of knowledge’s and literatures (Luker, 2008). Analysis of the gaps in secondary literature also informed the necessity of obtaining primary data and pushed the researcher to use interview questions to gain information that couldn’t be obtained elsewhere.

3.7 Analysis

After each interview, contemporary notes were written up to reflect on the interview practice, of what had gone well/poorly and to record first impressions so that gradually a standardised expression emerged (Silverman, 2011). Harding (2013) recommends one page summaries of each interview to aid comparison and to assist with the recording of initial impressions and insights. Interviews were not transcribed completely verbatim as this level of detail was unnecessary but recordings were listened to repeatedly to immerse the researcher in the data (Prior, 2003). Numerical codes were then allocated to each interview to preserve anonymity and aid analysis, taking account of the interviewees' position in both the automotive value chain and the regime. Initial coding of the data was done by hand given the limited number, then supplemented by inputting into Excel for sorting so that both a narrative case structure and later MLP comparative framework could be produced.

Coding involves the classifying of text or parts of interview transcripts into groups which seem to represent the same idea or concept (Gibbs 2007). Given the exploratory nature of the research open codes were first generated to allow the data to drive the theory and to attempt to avoid bias. This required clear definition of the initial codes so that they could be applied in a consistent way and the development of the themes and thinking could be traced in an analytic manner (Saldaña 2009). By recording data codes and the development of the analysis, interpretation is made more transparent and valid, minimising researcher bias (Smith *et al*., 1995). Some of these codes were named after phrases used by participants themselves, *in vivo* code, as defined by Glaser and Strauss (Charmaz 2006). For example, an early interview with a car manufacturing materials expert discussed how data inputted into the International Materials Database (IMDS) was sometimes untrustworthy, being tainted by "Jokers and Wildcards" who sought to hide information or simply lacked it. "Jokers and wildcards" therefore formed an early *in vivo* code, was later grouped with other codes and categorised into the theme of "Knowledge".

The process of grouping the codes into categories, necessitated repeated and detailed consideration of some parts of text and summaries of others, particularly secondary data sources (Harding, 2013; Ritchie *et al.*, 2003;). Themes were then developed from the categories which were related back to the literature and analytical framework to aid analysis. To assist the repeated sorting, the data with codes were input into Excel, to permit filtering and organising. Applying this coding, category and thematic structure across a variety of empirical data i.e interviews and secondary data enhances comparisons between cases (Flick 2009) and permitted the cross-comparison which is described in terms of the MLP, the landscape, regime and niche in the final discussion chapter.

The themes and categories were grouped into a narrative framework for the case study write-up of Europe, the UK, car manufacturers, and bio-based materials before the data were finally re-sorted for comparison into the MLP analytical framework and to answer the research questions. Whilst the open data obtained may challenge analysis in terms of tidy statistical coding, its "messiness" may reflect reality and offer rich insights (Yin, 2009). Triangulation, the process of using different sources of evidence to check, confirm and authenticate each other (Yin, 2009) was therefore particularly important to validate the research and improve the robustness of arguments and conclusions reached.

Analysis also considered how the legislation was the result of the representation of a problem (Bacchi, 2009), contrasting with more traditional policy analysis which presumes a positivist, neutral, rational approach to analysis: in contrast this considers the location of power and how a problem is presented, shaping the formulation of a policy-solution. Policy/legislation is therefore the product of this process but will favour particular groups, power groupings and ways of behaviour. This approach complements the sustainable transitions literature and the research questions formulated at the end of chapter 2 as it provides a way of uncovering the extent to which legislation is an outcome of the interaction of established industries, those in the regime, and those seeking to enter it, the niche; how the vision of the future is produced and what expectations and political alignments can be observed.

3.8 Summary

This chapter has explained the methodology behind this research. An analytical framework based on the sustainability transitions literature is used to analyse the three chosen pieces of legislation which address the sourcing, use and end of life phases of a car. Given the previously identified lack of research in the area of automotive legislation, an exploratory, qualitative, case study approach was taken using elite interviews with selected stakeholders supplemented by secondary data.

The next three chapters present the case studies in turn, beginning with the Emissions legislation, because the use phase of the car is considered the largest, then ELV, and concluding with the Circular Economy package.

4 EU Emissions Legislation EC443/2009

This chapter primarily addresses the first research question:

RQ1: How has European automotive legislation affected the development of more sustainable innovation in the automotive sector?

It therefore considers European emissions legislation, focusing on regulation EC 443/2009 which set the most recent targets to reduce CO_2 emissions from cars. This particular piece of legislation was selected because of its acknowledged importance both by industry interviewees and academic literature (Gibson *et al*., 2015; Mazur *et al*., 2015). As discussed in chapter two, a key advantage of bio-based materials is that they are often significantly lighter than traditional materials used to manufacture cars, such as steel (Akampumzu *et al.*, 2016; Ryntz, 2006). Moreover, there is an incentive for manufacturers to reduce the weight of vehicles: heavier cars emit more CO_2 emissions (Zervas and Lazarou, 2008). As the principal legal instrument governing car CO_2 emissions in Europe, it therefore acts as a potential driver for innovation if it provides incentives for manufacturers to use lighter materials. Hence the legislation is reviewed here in order to determine the extent to which it provides either barriers or drivers to the adoption of lighter materials in cars.

To answer the research question, if we use the MLP's theoretical framework and define (i) the landscape as being the "exogenous socio-technical landscape" (Geels, 2014 p23) i.e. factors beyond the control of actors and (ii) the regime as "the locus of established practices and associated rules that enable and constrain incumbent actors in relation to existing systems", (ibid, p 23) and if we assume that a regime includes existing legislation and institutions, we might conceptualise the EU policy context as the regime and the wider international background as the landscape. In terms of biobased materials, this chapter addresses their increased use in cars, rather than their disposal (Chapter 5) or sourcing (Chapter 6).

The chapter is structured as follows: first it explains the structures of decision-making in the EU to provide the context for subsequent discussion, it then outlines the problem, the development of the legislation and explains how the legislation is designed to work. The chapter then examines the UK's implementation of the regulation, and the effects of the policy on the automotive sector, including their approach to innovation. Finally the chapter considers the use of bio-based materials in the automotive sector then concludes with a summary.

4.1 The Problem

Policymakers have been attempting to restrict car emissions since at least the 1970s (Vogel *et al*., 2010) motivated initially by air quality and health concerns, and more recently by the contribution of CO_2 to global warming and climate change (IEA, 2009). Road transportation is a significant contributor to climate change (Unger *et al.*, 2010) with the Commission estimating that CO_2 emissions from cars account for 12% of total European CO_2 emissions (EC, 2015). In March 2007 the EU also committed to a 20% reduction in greenhouse gas emissions relative to 1990 (67224/1/07 EC), layering additional regime pressure onto this issue.

The exhaust gases produced on ignition of hydro-carbon cars include carbon dioxide, (CO_2), nitrogen oxide (NOx) and Nitrogen Dioxide (NO_2), particulate matter and carbon monoxide. Early European emissions' legislation such as Euro 1 (91/441/EC) and Euro 2 (94/12/EC) focussed primarily on controlling the most toxic, harmful to health exhaust gases, such as particulate matter and NOx because of their effect on air quality and human health. Diesel, because it is more energy dense than petrol, generally produces less CO_2 on burning but more NOx, which are currently restricted to 80mg/km (715/2007/EC).

Yet because diesel cars generally produce less CO_2, because of their energy-density, their use was often incentivised by tax schemes (Sullivan *et al.,* 2004) meaning that diesel vehicles accounted for approximately 50% of new car purchases in the UK in 2015 (SMMT, 2016). However diesel exhaust is a known carcinogen (WHO, 2012), particularly impacting the old and children. Incentives for their continued use are problematic and following the Volkswagen "cheat" scandal

(Bandivadekar *et al*., 2015) there are increasing "doubts" that they have "any role to play in the mobility of the future" (RE/1076529/EN – 2014-2019). If car firms are unable to make their CO_2 reductions through diesel emissions, this means that there is an increased need for other technologies to reduce the impact of $C0_2$ emissions. Simultaneously policy-makers can draw impetus from wider public concerns, a landscape effect, over car makers emissions cheating. As an ex-Member of the European Parliament (MEP) put it:

> *"there's nothing like a good scandal to force change, because politicians feel there's a reason for doing it*

The focus here is on CO_2 because of its contribution to greenhouse gases and long-term sustainability impact on global warming. In contrast to NO_X, CO_2 produces no immediate direct toxic effects to human health but is produced as exhaust in direct proportion to the amount of fuel used. The heavier the car, the more energy required to move it, and the more CO_2 emissions produced (Cuenot, 2009; Sims and Schaeffer, 2014). Crucially therefore, from a manufacturing and design viewpoint, the generation of CO_2 cannot be avoided by applying any sort of filter or added-on technique to the car such as a catalytic converter, but must be made by reducing the amount of fuel burned (Sims and Schaeffer, 2014; 2, 3, 4, 5).

Fuel use can be reduced by changes in driving behavior, for example, driving more slowly, or braking more gradually (Barkenbus, 2010) or changes in the fuel itself (Chapman, 2007; McLean *et al.,* 2004) but attention has focused on manufacturers and their technologies, rather than attempts to educate drivers or constrain consumer choice. Premium cars with more powerful engines tend to be heavier creating a knock-on effect throughout the car; the increased car weight and power for example requires more powerful braking and transmission systems, again increasing weight (Gibson *et al*., 2015) but also generating more particulates from non-exhaust emissions e.g. from tyres and brakes (Amato *et al*., 2014). Manufacturers can reduce fuel consumption and the generation of CO_2 by three basic strategies: improving design to make the car more streamlined, improving engine efficiency or making car components lighter (Kastensson, 2014). Car components also can be lightened through improved design and material changes (2, 5, 6, 7). Therefore any material which combines strength with reduced weight, is potentially attractive as this would reduce the power and fuel required to move the vehicle (2, 5, 8, 9). Lighter materials are particularly attractive to electric car makers as a key constraint of such vehicles is the weight of the battery: the greater the range of the car, the heavier the battery (Silvester *et al.*, 2013). The range capacity could be significantly enhanced if other materials used in the car are lighter (10, 11).

4.2 Development of the legislation.

Perhaps taking their lead from the California Air Resources Board (CARB), which initiated emissions standards testing in 1991, the 1992 EC Green Paper on the impact of transport on the environment also suggested that emissions restriction and “sustainable mobility” might be important for the future (EC, 1992). Although the early focus was on NOx, Euro 1 standard 91/441/EC also called for CO_2 reductions from passenger cars. Extensive negotiations followed before a voluntary agreement was reached in 1998/9 with the European association of carmakers, the Association des Constructeurs Européens d’Automobiles (ACEA), to restrict emissions to 140g/km by 2008 (Gibson *et al*., 2015). During these negotiations the Commission was handicapped by a lack of technical expertise and data (Keay-Bright, 2000). One option had been to consider purchase taxes to make more polluting cars unattractive but some member states, such as the UK, resisted this option, considering it a restriction of the market (8). Manufacturers argued however that national governments should provide a more harmonised fiscal policy so that consumer demand would shift, which Anastasiadis (2014) suggests is an approach fashioned to diffuse responsibility away from car manufacturers. Gradually 120 g/km was adopted as a target, a number seen as symbolically important (Deters, 2010). Yet since a consensus could not be reached, the Commission took up the voluntary offer from the ACEA of 140g/km.

It became increasingly apparent however that even this lower target would not be met. Car weights were increasing significantly, particularly because of the changing consumer preference, for larger sports utility vehicles (SUVs), which may be considered a landscape factor. Carmakers argued at this time that responsibility for the limits should be shared with other stakeholders including tyre manufacturers, fuel refineries and consumers, which might have widened the impact of the legislation and led to wider political support for it, but can also be interpreted as an attempt to diffuse responsibility (Anastasiadis, 2014).

As an ex-MEP put it:

> *the voluntary agreement set out in the late 1990s broke down very quickly because the car makers found they could make lots more money by investing in Chelsea tractors, four wheel drives, and the like (13).*

so that by 2005 negotiations to bring in binding targets were initiated. Deters (2010) claims the regulations were effectively shaped by Germany, Europe's largest car manufacturer but poorest performing country, because of lobbying activities by premium car manufacturers such as BMW and Daimler, who tend to make heavier cars.

Germany has a reputation as an environmentally aware EU member state (Dryzek *et al.*, 2002). Yet in contrast to Germany's earlier, more interventionist stance in the 1980s when for example it pushed for reductions in emissions through the adoption of unleaded petrol (Wurzel, 2002), at this time it appeared to take a more protectionist posture towards its car industry. Germany also held the European Presidency at this time, meaning it could fully exercise "structural" power (Liefferink and Wurzel, 2016) drawing on its dominant economic position in European car manufacturing. Thus whilst the French and Italians, who tended to represent Peugeot and Fiat, favoured one limit, Germany, influenced by domestic car manufacturers', was keener on a higher limit (Keating, 2012).

The car firms were unable to present a united front to oppose the legislation however. The long run-up to the legislation meant that each firm had a clear understanding of its strengths and capabilities, and this knowledge shaped their stance. An ex- MEP suggested that:

> *Each company would look at its figures and do its own sums and work out accordingly what was in its best interest. And obviously the ability to meet these standards without too many problems. Then whatever they say in public, they would privately have a word to us saying 'it's not too much of a problem for us'. (13).*

Daimler Chrysler, BMW and Volkswagen with Ford Europe wrote to EU president Barroso saying the proposed targets of 120g/km were "technically unrealisable" (Anastasiadis, 2014). In addition several manufacturers suggested or perhaps, threatened, that the limits might lead to car production in Europe being outsourced. The disagreements between manufacturers however meant that the industry could not present a united front to the EC (Anastasiadis, 2014).

The UK negotiating position was somewhere between France and Germany and characterised as "*supporting industry*" by "*pushing for realistic levels"* (8). Wurzel (2002) suggests that the UK Clean Air Acts of the 1950s meant that most UK industrial emissions had already been addressed and that car emissions were therefore really only brought to the fore by EU action. British lobbying created the "niche" derogation which meant manufacturers with production of under 10,000 cars per annum were not required to use the new emissions test cycle which may have meant the survival of Rolls Royce (Wurzel, 2002) and was certainly favoured by more premium, (and heavier) car makers such as Bentley. UK-based Jaguar LandRover also had "*too specialised*" a fleet to achieve the average targets across its car fleet and required a separate target (13). This stance was often articulated in UK government as a desire to reduce the administrative burden on smaller, innovative firms (12).

Eventually manufacturers obtained a lower target of 130g/km (rather than 140g/km) with "an integrated approach" adopted so that the missing 10% was made up by other measures such as the use of biofuels. This tactic proved an effective negotiating tool since it was felt a uniform value would have hurt one manufacturer or country too much and this permitted the load to be spread. Deters (2010) argues that throughout these negotiations, the Commission and Parliament were "greener" than the Council but that the fast-track manner used to handle the legislation was achieved at the cost of the Commission's influence. In Council, Germany could draw on Eastern European states where many factories are located to effectively block the legislation, which meant that it was not as ambitious. Deters (2010) also suggests that it was only the combination of the election of Barroso as Commissioner and climate talks at UNFCC 2006 which helped to create the climate for the legislation to pass. Burns *et al*., (2013) supplements and extends this argument, placing the negotiations in the context of the UN climate change talks in Dec 2008 and the conclusion of the French Presidency. The time period might then be considered " a window of opportunity" (Geels, 2014) in that a number of factors both in the regime, including multiple policy initiatives, together with wider public awareness, a landscape pressure, were evident.

An ex- MEP looking back considered*:*

> *In many ways, what with Al Gore and 2008, 2007-2008 were really the high water mark at the time for initiatives to combat global warming. So the need to address the emissions from cars, given that of all the industrial sectors transport was one area where emissions were continuing to grow, seemed important. (13).*

However, these discussions also took place against the backdrop of the emerging economic crisis in 2007/2008, which might be considered a landscape pressure (Geels, 2013). As car sales dropped, carmakers could argue they were under severe financial pressure, causing job losses throughout the wider economy through a multiplier effect as smaller suppliers were also impacted (Sturgeon and Biesebroeck, 2009). As the EC Directorate General for Climate Action (DG Clima) held the mandate at the time, the policy's terms of reference were climate, not fuel efficiency, but the economic crisis meant that DG Enterprise and DG Grow, usually considered particularly friendly to the car industry, had an influence in the policy. The US government bailout of GM and Ford provided a template for motor industry support, reflecting the sensitivity of national policymakers. Support was echoed in the EU where significant EU-wide and individual nation state support was provided in the form of subsidies, scrappage schemes and favourable loans (Grigolon *et al.*, 2012). These interventions pushed states, the EU and the car companies into an even closer symbiotic relationship, with increased regulation, economic output and employment intertwined.

There was limited discussion of alternative materials in debates. Interviewees mentioned significant lobbying activity from recycled metal manufacturers (9, 10, 13) and Alcan, the aluminum producers trade organisation, at both the European and UK level. These groups argued that recycled metals were an important part of creating a more environmentally sustainable industry and sought mechanisms to tie car-makers more closely to their businesses *(*Coates and Rahimivard, 2007*).* Aluminum is typically 30% lighter than steel but approx. 35% more expensive and often used in high-end cars (Cooper and Allwood, 2012).

4.3 Explanation of legislation

This section clarifies how the legislation EC443/2009 was designed to work. In particular, it relies on an earlier piece of legislation, which is briefly discussed. To sell a car within the EU, manufacturers must register and test a new vehicle under Whole Vehicle Type Approval legislation (EC, 2007) at an approved testing station (EC715/2007). Once approved at one testing station, the vehicle model is valid for sale throughout the EC, a significant advantage for European carmakers, as it minimises licencing requirements and creates “a level playing field” (13) At this point, manufacturers declare the CO_2 emissions produced by the car in use. However in contrast to other EU legislation on emissions (EC715/2007) the car does not have to reach a minimum standard in the test, (implying that all cars must reach this standard), but only produce the “best” result. This provision means that manufacturers can choose the “best” car to test and despite conformity or production rules, it is not necessarily guaranteed that all cars produced will reach this level (8, 18). Member states then collect this information annually on newly registered cars in their country and submit the data to the Directorate (Gibson *et al.*, 2015; ICCT, 2014).

The independence of the testing procedure however is problematic. Manufacturers can choose where the test is carried out; they can select the conditions under which the car is tested and will pay for the testing themselves. Member states through their national testing stations have the power to require a recall or ban the sale of any non-compliant cars but it is not clear if this power has ever been exercised, either in the UK or elsewhere (14, 9). A House of Commons report cited anecdotal evidence to suggest that not all testing is identical; for example, many vehicle tests are completed in Luxembourg despite this country lacking indigenous car manufacturing industry (House of Commons, 2016). National testing agencies therefore appear to be competing within the European market to supply a service to manufacturers, rather than considering the legislation.

The European Environment Agency (EEA) uses the data submitted by member states, which was collected from car manufacturers, to calculate a target for the manufacturer's fleet for that year based on the average of the weight of the vehicles tested and the size of the fleet. Regulation EC no 443/2009 therefore set a target of 130g/km CO_2 emissions for new cars by 2015 and 95g/km CO_2 by 2020 but the limit is not applied to each car or model individually, but to the manufacturer's fleet as an average (Gibson *et al.*, 2015; ICCT 2014). This system of calculation was designed so that heavier car manufacturers were not disadvantaged and was justified as supporting a varied consumer choice (Gibson *et al*., 2015; ICCT, 2014).

A particular distortion however lies in the "limit value curve" methodology which limits the impact of the legislation on the heaviest cars. The permitted CO_2 limits for each car model are calculated through a "limit value curve" which gives the values for each car model as a function of the "utility parameter" based on average weight. The limit value factor used of 0.0333, means that for every 100kg of additional car weight, 3.33g/km more CO_2 is allowed (ICCT, 2014; Mock *et al.*, 2012). The fleet average mass number of 2009 (1289kg) was amended in 2010 to 1372kg, a 6% increase. But the continuing increase in average car mass, discussed in more detail later in the chapter, means that a new mass average of 1392kg is estimated for 2016, an 8% increase on the original. By using the value curve however the goal of 130g/km can be retained, despite the ever-increasing average car weights (Mock *et al*., 2012). An attempt to adjust the base year from 2006 to 2009 proposed in 2012 which would have changed the curve and disadvantaged those manufacturers making heavier cars, particularly BMW, was blocked by Germany (Keating, 2012). Figure 4.1 shows the limit value curve for 2015 and demonstrates how the legislation accommodates those car companies with the highest average weight, particularly German firms such as BMW and Daimler, but also UK firms such as Jaguar Land Rover (JLR).

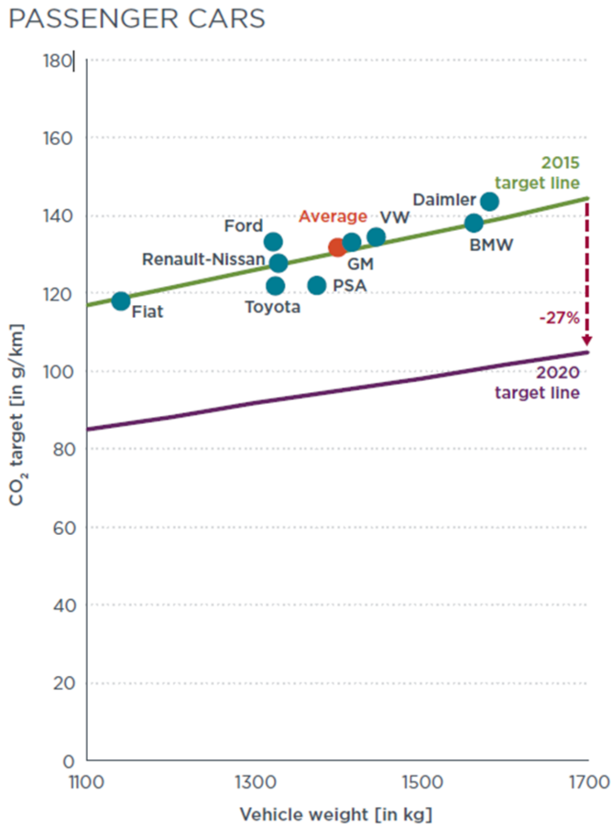

Figure 4.1. Car emissions limit value curve for 2015 (EEA, 2015).

The limit value curve is therefore shaped to allow heavier cars to emit more CO_2 than lighter cars. The provision means that manufacturers that generally made lighter cars, such as Fiat, might feel their early light-weighting efforts were not rewarded, but the difficulties of achieving the reduced CO_2 emissions for manufacturers of heavier cars were acknowledged (Keating, 2012). However, the design of this system means that a key advantage of bio-based materials, light-weighting, is not incentivised by the current testing regime. Moreover, retention of the limit value curve, means that there is limited impetus to reduce the weight of cars in the future so that achieving the 2020 target for CO_2 emission reduction is particularly challenging for these firms.

Mass was used as the assessment parameter because of its correlation with emissions, its data availability and unambiguous character. Alternatives to mass as the dominant parameter included assessment of the footprint of the car (i.e. taking account of the volume of the car as well as its mass). Alternative methodologies of well to wheel (WTW) calculation, and not tank to wheel (TTW) alone so as to include the carbon embedded both in energy production and manufacture might also have been considered. Using these methodologies might favour other technologies such as electric vehicles or light-weight plastics (Gibson *et al.,* 2015) although an exact comparison is heavily dependent on the exact technologies applied and case-by-case analysis (Schmidt *et al.,* 2004). The simplest method of only using mass to evaluate cars was apparently discarded at an early stage of discussions because of the built-in disadvantage this would have placed on premium, heavier, car manufacturers (Gibson *et al*, 2015, *2, 8).*

The time involved in collecting and verifying data creates a time-lag which complicates addressing the issues. This time-lag means that alignment of "windows of opportunity" (Geels, *et al.,* 2016) to affect sustainability goals through EU legislation is further complicated, since EU political attention will have moved on. When an issue arouses concern, this time-lag may weaken the impetus for rapid political action and provide an excuse for inaction when political consensus is difficult to achieve. As the design cycle for new car production may be 5-7 years, and the investment to alter the material, i.e. the earliest part of the manufacturing process, even longer, this time-lag is considered particularly problematic for the mass car market. The desire for stability is exacerbated at times of economic difficulty when policymakers' attention may be diverted to other issues. As the data-testing procedure is not directly comparable, it means that some manufacturers benefit more than others from failing to innovate to reduce CO_2 emissions. One interviewee (13) suggested that

> *"Whatever surveys you do, whatever analyses and economic studies emerge, the reality comes down to politics and horse-trading and what feels right and who you trust and who you don't."*

EC assessments were possible due to ex-car industry experts who'd perhaps retired and whilst still understanding the car industry and its capabilities well, were no longer directly tied to it. Increasing knowledge of the industry within the EU however meant there was a better understanding of the sector at the political regime level.

4.4 Further developments of EC 443/2009

This section considers further complementary legislation to EC 443/2009, especially the Eco-innovation regulation (EC725/2011) EC397/2013 which sought to tighten testing and regulation EC333/2014 which delayed the implementation of the original act. The EU adopts amendments via new legislative instruments to update laws. Much of the work in the Commission therefore is around gathering data, amending and improving existing legislation. Steinebach and Knill (2016) suggest there has been comparative "regulatory inactivity" since 2010 which they ascribe in part to the economic crisis of 2008/9. An ex-MEP (13) suggested that:

> *Talking about CO_2 in 2007 and 2008 was fine, but talking about CO_2 in 2013 and 2014 was not. No-one was interested. But clearly it's a time of economic … when everyone is concerned about jobs and growth, talking about CO_2 was not sy. The talk was all about "this could effect business" and "we can't afford to threaten any jobs"…*

which suggests that a landscape of wider public opinion attention significantly influences policy-makers' perceptions of the sustainability issue. Moreover, car makers lobbying activity, particularly through the ACEA and associated trade organisations, such as CLEPA, (the European Association of Automotive Suppliers) continued at both the national and EU level with a current EC MEP (9) advising:

> *I think all sectors that want to influence, shape or lobby on European legislation, realise that just lobbying your own government in your own country is insufficient. So if they lobby together through their association or through groupings at the EU level, they're much more likely to be effective.*

EC725/2011 develops article 11 of the original emissions legislation (EC443/2009) and permits manufacturers to claim a derogation of up to 7g of CO_2 towards their fleet target. It ties into type-approval of the car specifying how the CO_2 reduction must be measured. However the scope of this encouragement to innovation is limited as it focusses particularly on "innovative propulsion technologies" i.e. those associated with the engine and defines eligible technologies (3) as "only those…that are intrinsic to the transport function of the vehicle and contribute significantly to improving the overall energy consumption of the vehicle." Specific exemptions are outlined including tyres and air-conditioning, and the technology must "relate to items intrinsic to the efficient operation of the car." This would seem to specifically exclude any material substitution, or the particular use of bio-based, or any lightweight materials. In addition, Article 13 suggests that the Commission should "have the possibility to verify on an ad-hoc basis the certified savings" but how or who should be responsible for this is not specified. Sanctions for any misrepresented savings are also not discussed. Action to improve the independence of the testing regime and type approval of new cars have been proposed (EC, 2016) but as yet are resisted.

EC397/2013 tightens up monitoring to bring cars into line with light commercial vehicles testing. More data categories are required from member states including the type approval number for a new registration making it easier for all parties to trace through improvements and improve accuracy. A new field for any claimed innovative technology reduction is also included. However EC333/2014 is a significant adjustment to the original legislation, introducing a delayed phase-in for emissions reductions and reducing the associated financial penalties for non-compliance. Under the original legislation, manufacturers were liable to fines for exceeding the CO_2 targets from 2012 but EC333/2014 staggers this, so that in 2012 only the best performing 65% of the fleet is taken into account, then the best 80% in 2014 and finally 100% of the fleet from 2015-2019. This dilution of the original suggests successful lobbying for delay by car manufacturers (Politico, 2015). One interviewee suggested that presentation of the legislation as concerning climate change and the environment, rather than cost-savings for consumers, weakened its effectiveness (13). This legislation does however feature the first car-specific discussion of materials, with the preamble discussing the need for “A resource-efficient Europe” which might be seen as favourable to bio-based materials.

The initial 2009 niche derogation of 10,000 vehicles negotiated by the UK, which meant that smaller manufacturers had laxer targets, was also widened by EC333/2014 to include those firms producing between 10,000 – 300,000 vehicles per year. This derogation favours a number of smaller manufacturers including Volvo, Seat and Dacia but the biggest beneficiary is Jaguar Land Rover (131,530 registrations, EEA, 2014) with the highest average car mass of 2049 kg, and the highest emissions at 182 CO_2/km. Producers of less than 1000 cars a year also became exempt, reducing the administrative burden of compliance but also reflecting a view that smaller, particularly innovative racing cars firms, such as Westfield, McLaren and Aston Martin should not be effected.

Attempts have been made to widen the expert input on which the EU relies and address the issue of lack of expert knowledge which can affect decision-making (Keay-Bright, 2000) Decision C (2015) 6943 called for a new group of experts to make up the High Level Group on the Automotive industry, calling specifically for experts from “ICT associations, network operators and digital services associations active in area of connected vehicles” (EC, 2015). This development reflects the increased potential for connected and autonomous vehicles, but these technologies will add more mass to future vehicles, further enhancing the need for light-weighting and implying increased focus on new light-weight materials. The Commission therefore appears able to recognise the need for one kind of expert, in information technology, but not for materials experts, reinforcing the tendency to focus on the end-user and the market, rather than earlier points of the car life-cycle, at the manufacturing and commodity stage. The car industry is therefore increasingly aligning with the information technology sector which will increase weight and introduce more materials into cars, with implications for material usage, manufacturing, resource availability and safe disposal.

The car sector in general appears to continually delay efforts to improve fuel efficiency and reduce emissions. ACEA, the European carmakers association appealed to the Commission to permit a further 5 years for the proposed 2025 standard of 68-78 g/km to be reached on the grounds that they would be unable to meet the technical standards required by then (Shelton, 2015). The German and French governments also issued a statement in December 2014 arguing that the proposed 2025 standards should be pushed back to 2030. By contrast, some non-car producing states such as the Netherlands and Finland support the higher standards to meet climate change emissions reductions and to benefit consumers (Neslen, 2015). The car industry is therefore supporting a wider range of measures including driver training and building a wider stakeholder group (ACEA, 2015). Again, this proposal spreads responsibility for meeting lower emissions standards away from car manufacturers (Anastasiadis, 2014) but also means the case for investment in innovative materials is sapped.

In the USA meanwhile, an additional and significant legislative incentive to reduce emissions were the improved US CAFE (Corporate Average Fuel Economy) standards (Hermann *et al.*, 2011). This sets an overall fleet target of 54.5 mpg (equivalent to approx. 100g/km of CO_2) by 2025, a challenging target given the 2016 target of 34.5 mpg (approx. 158g/km) and more common fuel efficiency in US cars of approx. 28mpg (approx. 195g/km) in 2011. The new standard means that US cars must make an average 5% fuel economy saving each year up to 2025, an ambitious target requiring significant innovation efforts. Agreement was reached with most car makers (though not Volkswagen) with trade union support following the US government bail-out of the car industry (Freeman, 2011). The targets, for the first time, set a federal-wide, rather than state standard across the US, which makes for a more homogenous market, thereby increasing economies of scale.

Wider societal and landscape pressure on car manufacturers to reduce CO_2 emissions appears to have weakened since 2008, when there was "*peak concern on environmental issues*" (Penna and Geels, 2015) (13). The limited concern expressed over the poor evidence of CO_2 emission reduction in cars contrasts with the intense degree of inspection over Nox and particulates from VW *(*Oroschakoff, 2015*)* as current air quality concerns outweigh the more long-term sustainability impact of rising CO_2 levels.

4.5 UK Implementation

This section considers how the UK enforced and supported efforts to reduce CO_2 emissions. Analysis at the national level is justified for two reasons. First as discussed in the previous section, data for EC 443/2009 on the CO_2 emissions potential of new cars is collected at a member state level from the car firms manufacturing in that member state, and then forwarded to the EEA. Second, an EC regulation takes effect within an existing member state with its own presumptions, institutions and laws which means that the regulatory effects are contingent upon that infrastructure.

As EC443/2009 is a regulation, rather than directive, national implementing measures were not required by the UK. Compliance, monitoring and enforcement are at the European rather than Member state level meaning there was also limited scope for UK adjustment: the UK government was merely required to report on vehicle registrations to the EEA. Given the international nature of the car industry, the regulation was also primarily aimed at car manufacturers rather than states. Whilst most research on the implementation of EC policy has focused on transposition of directives, comparatively little has considered implementation of regulations (Treib, 2014). Skipping the transposition gap, (i.e. the way in which member states translate and implement European directives) which might offer the opportunity for EU states to adjust policy, might suggest that compliance with regulations is easier to assess. However, studying the implementation of regulations on a sector across member states is complicated by the need for collecting significant amounts of comparable data (Treib, 2014). Lack of data may also inhibit attempts to steer any sector towards more sustainable innovation.

The UK in comparison with other European states is considered to have a somewhat light-touch, *laissez faire* (10) attitude to business regulation, preferring not to burden firms with administrative costs, and to allow policy goals to be achieved by the market without overt regulation (Heritier and Knill, 2001; Dryzek *et al*., 2002). As part of its neo-liberal approach to regulation the designated UK type approval and testing authority, the Vehicle Certification Agency (VCA), is a semi-private company but acts as an executive agency for the Department of Transport. It provides testing facilities for the car industry in the UK and overseas, generating a profit of £535,000 in 2014-15 (Department for Transport, VCA 2015). A recent attempt to completely privatise its operation failed due in part to questions over its independence (Leftly, 2014).

This semi-commercial aspect compromises the agency's independence and attempts at data collection to monitor both its own performance and that of the car industry. For example, when asked to confirm which vehicles it had tested, in particular Skoda models implicated in the VW Dieselgate affair, the Department for Transport refused to confirm which models had been tested "for commercial reasons" (House of Commons, 2016). Recent evidence characterises the relationship with car companies as that between a customer and shop, with the customer always right (House of Commons, 2016). Vehicle testing was characterised as "an arms-race" with the testing engineer reliant on the manufacturer to be honest, but lacking the up-to-date specialised training necessary to keep up. The need for specialist skills means that inevitably there is exchange of personnel with the car industry. In addition, a climate of "revenue and customer service" were the priority, with "the customer" defined not as the public/or the legislating authorities but the manufacturer. Similarly, in a complaint over inconsistent emissions from a Porsche, VCA advised "VCA is not empowered to be a regulator for vehicle type approval. VCA's role is to offer a type approval service to manufacturers" (House of Commons, 2016). The independence of the testing regime therefore appears to be significantly compromised.

UK industry sources however suggested that regulatory tests had never been designed to be "*a predictor of real world behaviour*" (Brace, 2015) but rather "*an incredibly useful tool for ranking*" of technologies (8). Improvements in software, monitoring and scientific evidence since the 1980s also meant that the initial tests were being unfairly judged. Non-industry impetus from European legislation or UK government support had not been the initiator, or force that produced improvement, *"theres been no Damascus turning point"* (3) but gradual technological improvements produced by the car industry itself. This comment suggests that some car makers justify their actions in terms of their own technology and dismiss the role of legislation in forcing innovation.

The UK government has proffered a number of initiatives to encourage car industry innovation. The Automotive Council was set up in 2009 to promote a "better dialogue" (11) between industry and the various branches of government, with a UK BIS civil servant explaining that it was important for government to understand the UK-based car industry's needs. Focus on low-carbon technology would bolster the UK-based supply chain and enhancement of labour skills to support industry would ensure future employment opportunities (Davies *et al.,* 2015; Automotive Council, 2013). The focus on established firms however reinforces existing regime knowledge and networks, rather than smaller-scale, potentially more innovative technologies and firms, maintaining power with incumbent actors. A similar pattern can be seen in the UK government's approach to the energy sector in comparison to Germany, the UK favouring large incumbent energy firms, Germany favouring small-scale local actors (Geels *et al.,* (2016).

The Office for Low Emission Vehicles (OLEV), (part of the Department of Transport and Department for Business, Energy and Industrial Strategy) aims to provide early market support for ultra-low emission vehicles by providing infrastructure support, normalising technology and fiscal measures to encourage uptake (OLEV, 2013). The Advanced Propulsion Centre (APC) at the University of Warwick was also specifically set up for UK industry automotive research, in particular to move research out of universities into car production (APC, 2013). Many of these organisations were industry-led and motivated in part by the wish to "embed" automotive jobs in the UK (11, 15). For example, a particular concern was the perception that much car production in the UK was dominated by "*IKEA assembley type activities*" (11) and to keep skilled jobs and production in the UK required the development of labour skills and support for innovative small and medium enterprises (SMEs) to supply to larger car firms (Automotive Council, 2013). A comprehensive 10-year £1billion package also includes fiscal measures to encourage adoption of low emission vehicles such as discounts on vehicle excise duty, capital allowances and company car tax.

The extent to which this activity is "sustainable" however in the sense of emissions reduction is problematic. "Sustainability" is often defined in terms of what "sustains" the industry and ensures its long-term prosperity, but more particularly in terms of retaining car manufacturing within the UK (1,2,3,4,12,22). Given the lack of UK-owned mass car manufacturing firms this was seen as a particular challenge, compared to other European states such as Germany. Interviewees suggested that the increasing contribution of UK car manufacturing both to employment, the balance of payments and the declining manufacturing sector as a whole meant criticism was taboo (9,10,11,13). This may mean that challenging the industry to innovate beyond purely short-term technology, i.e. to consider alternative materials such as bio-based ones is difficult. Spending cut-backs to government departments such as Business, Innovation and Skills (BIS) (staff estimated cut by 40%) and amalgamation with Department of Energy and Climate Change (DECC) to form the Department of Business, Energy and Industrial Skills (BEIS) may mean that the initiative and expertise to engage with industry is also lacking (11,18).

Increasingly the UK government appears to favour the electric car sector. One interviewee (12) suggested that other European states such as Germany considered electric cars less environmentally favourable using a complete life cycle analysis (LCA) because of German reliance on coal-fired power stations and their retreat from nuclear power (Doucette and McCulloch, 2011). The UK in comparison was able to make its CO_2 targets relatively easily, but this reduced the impetus for CO_2 emission reductions from cars:

> *I think the UK government is in a very fortunate position at the moment because of the closure of coal. (13).*

Bio-based materials were able to make a contribution here, with the conversion of existing coal-fired power stations such as Drax to bio-based materials (DECC, 2012). Increased use of electric cars because of their ultra-low emissions also addresses increasing concerns over air quality in cities particularly London. New UK electric vehicle (EV) car registrations grew from 3586 in 2013 to 14,498 in 2014 encouraged by the car plug in grant for £5000, effectively subsidising the manufacturer together with company tax exemptions. Policy initiatives have been particularly criticised for failing to stimulate consumer demand (Begley and Berkeley, 2012). The heavy weight of the electric car battery is considered a particular incentive to lightweight the rest of the vehicle and to reduce the range anxiety, which is thought to limit the electric car's appeal (2,11, Dijk *et al.*, 2013, Mazur *et al*. 2015). Electric cars, which emit no exhaust emissions, also offer an ideal opportunity for bio-based materials because of their lack of moving parts and less demanding engine environments.

This proactive UK government activity contrasts with an earlier stance which was reluctant to pick winners in the car industry (House of Commons, 2006). However, it would be more accurate to characterise UK government action as support for market winners. Whilst considered non-political, this support for profitable firms is not a politically neutral stance, but one shaped by the narrow technological regime. An alternative action to counter traffic emissions for instance by action to combat stationary traffic was not taken.(10). The short-term political term of five years, and shorter political cycle were seen as inimical to long-term transport planning. By allowing the market to decide, UK government is not favouring the growth of more environmentally-based technologies or materials actions which require long-term financial support.

Despite its centralised nature however, in particular the power of the Treasury and Cabinet Office, UK government rarely operates in a concerted direction. Ministers enjoy "autonomy subject to collective responsibility" (Marrs, 2014); one department such as Transport may favour a particular policy, but another department may favour another. The cross-cutting agenda and complexity of the car, industrial policy, transport and the environment complicates this further. Thus the Committee on Climate Change suggested that it is realistic to assume that by 2030 electric cars, will constitute 60% of new car sales. However without support from other departments and an integrated approach across government to include resources and materials, this may be problematic. The push produced by a particular Minister was seen as key to encouraging the promotion of industry, e.g. Vince Cable at the Department for Business, Innovation and Skills 2010-2015, emphasising the importance of political leadership (11,15).

The derogation within the original emissions legislation (EC, 2009) to small-scale manufacturers who produce less than 1000 vehicles, and to those who produce between 10,000 - 300,000, means that those smaller, more luxury manufacturers (such as JLR) who might be most expected to innovate, because of their higher profitability and niche appeal, are not encouraged to lightweight by the legislation.

However despite the economic crisis, the UK car industry has enjoyed increased sales and contributes significantly to the UK balance of payments through exports *(SMMT, 2016).* The car industry makes up 11 % of UK exports and these increased sales at a time of austerity are seen as evidence of the car industry's success (SMMT, 2014). Interviewees suggested that the increasing contribution of UK car manufacturing both to employment, the balance of payments and the declining UK manufacturing sector as a whole meant any criticism of the industry was taboo (9,10,11,13). Challenging the industry to innovate therefore beyond purely short-term incremental technology improvements, i.e. to consider alternative materials such as bio-based ones is therefore difficult.

4.6 Data on Emission and Weight Changes.

First, it is important to note that the regulation does appear to have significantly reduced CO_2 exhaust emissions compared to the earlier voluntary agreement (Gibson *et al*., 2015). Figure 4.2 below shows how, under the voluntary agreement, reductions in CO_2 averaged 1.2% per annum compared to the average 3.7% achieved since 2009 (Gibson *et al*., 2015).

In addition, all car manufacturers met 2015 targets (EEA, 2015) with average emissions of 123.3g/km in 2014, significantly in advance of the target of 130g/km for 2015 set in the legislation. The protracted discussion before the directive was agreed may have permitted manufactures to modify their production methods over a longer timescale. However, due to concerns over the stringency of the testing regime as discussed in sections 4.5 and at the UK level in 4.7, the reduced CO_2 emission figures are problematic (Bandivadekar *et al*., 2015; Gibson *et al*., 2015).

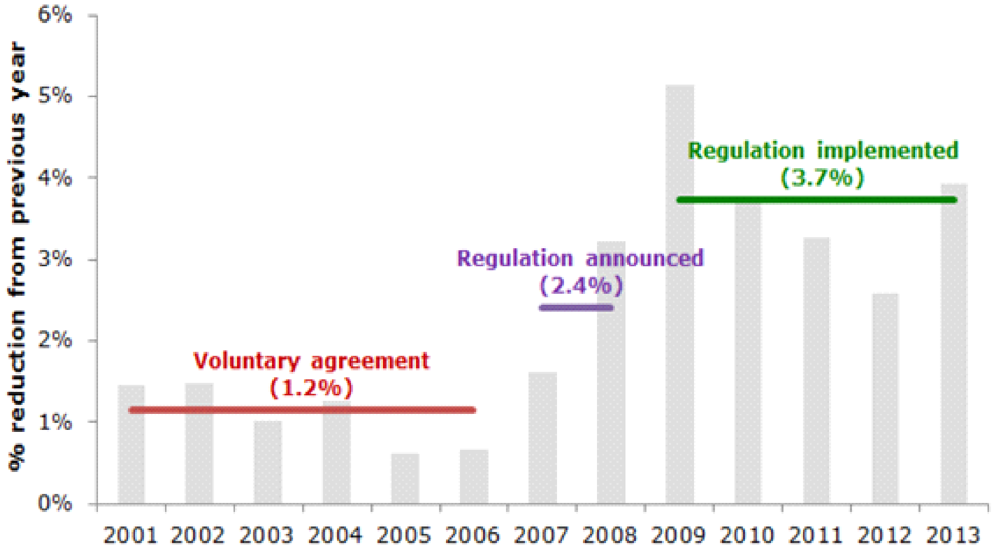

Figure 4.2. Effectiveness of regulation EC443/2009 on car CO_2 emissions reduction vs voluntary agreement. (Gibson et al., 2015).

However significant discrepancies between the type approval figures produced by the car industry on vehicle registration and real-world fuel consumption and CO_2 values have been identified with emission values not reduced as much as claimed (EEA,2015; Mock *et al*., 2012). These discrepancies mean that CO_2 levels have only decreased by approximately 7% against 2001 levels rather than the claimed 21% reduction (Gibson *et al*., 2015). Moreover the variance between real world and the type approval emissions figures is also thought to be increasing, with the divergence of 10% on average in 2001 increasing to 23% in 2011 and over 30% in 2013 (ICCT, 2014). A modeling-exercise based on submitted type approval information, including engine size and mass (Bandivadekar *et al*., 2015) found an average discrepancy between 2010 and 2013 of 19%, with the excess fuel consumption particularly marked for larger cars (i.e. those cars > 2 litre engine size). The smallest discrepancies at the member state level were found for UK and Denmark at 19g, the largest for Bulgaria at 54g. These discrepancies and variations matter because they blunt the impetus of the legislation and in consequence the incentive for manufacturers to innovate, sapping the case for investment in innovative material technologies.

UK figures to the EEA for new cars registered in the UK were declared at an average of 124.6g/km in 2014, well below the EU target for 2015 of 130g/km suggesting significant compliance by UK car manufacturers with the regulation (EEA, 2015). These figures represent a 24% fall on average UK new car emission levels in 2007 (SMMT, 2016) and compare favourably with other European member states. The fall suggests that UK car manufacturers have adopted innovations to achieve these targets in line with other European countries (EEA, 2015). However to reach the goal of 95g/km by 2020, average reductions in CO_2 emissions need to increase to 4.2% per annum. Given the discrepancies in the official data, much greater efforts to innovate are required if compliance with the Directive is to be maintained.

Over the last decade since the introduction of the legislation, there has simultaneously been significant increases in the weight of cars (Bandivadekar *et al*., 2015; Cuenot, 2009). Average mass has increased by approximately 10 % as shown in Figure 4.3.

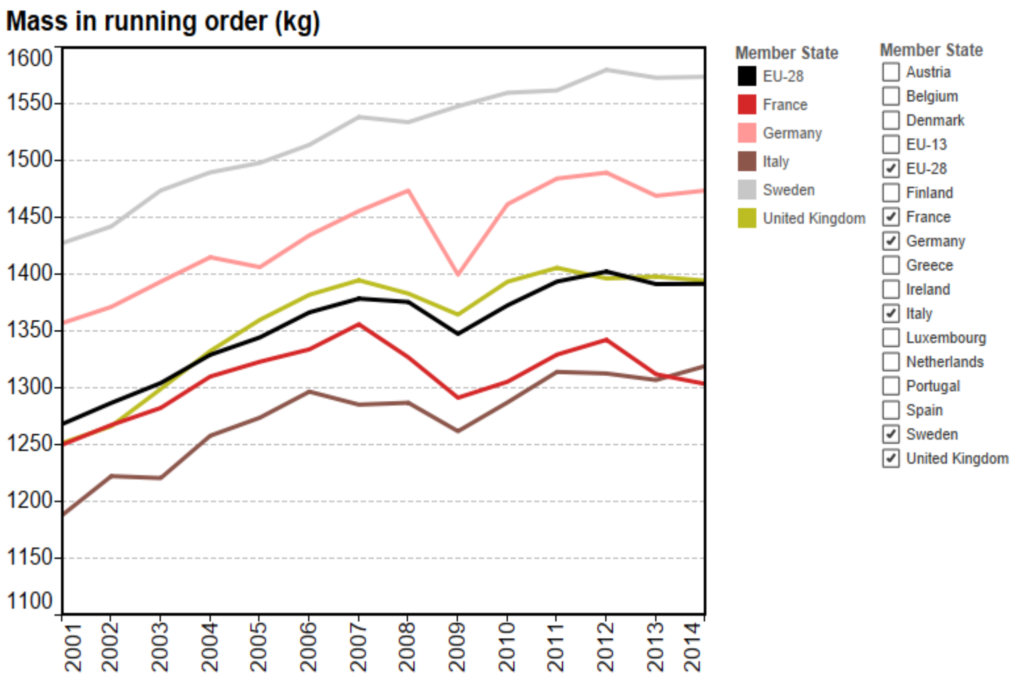

Figure 4.3. Car mass weight (kg) by EU member state (Bandivadekar et al., 2015).

European car efficiency improvements have been used to improve acceleration, comfort and increase the size of many European cars rather than to reduce emissions alone (Cuenot, 2009). US commentators have also noted how tighter emissions rules from CAFÉ will need to restrict average US car weight.

This affect might be regarded as an example of Jevon's paradox (Alcott, 2005) where an improvement in economy actually produces more consumption rather than saving energy. The "rebound" effect where improved efficiency is used for increased speed, size and power was also previously noted in the US car market and the development of the VW Golf (Throne-Holst, 2003). Whilst Sprei and Karlsson (2013) argue that since 2007 some 77% of technological improvements in Swedish cars have gone into actual reductions in fuel use, their argument is blunted since they ascribe this efficiency improvement in large part to a shift to diesel, rather than petrol, car sales.

Therefore whilst legislation at the regime level was incentivising fuel efficiency, a landscape effect of economic imperative meant that car makers were increasingly focused on the luxury sector of the car market due to the significantly higher operating profit per car (as shown below in figures 4.4). Porsche, for example, makes 17.6% operating profit per car and BMW 9.5% whereas Volkswagens profit is 4.5% (Edelstein, 2014). This increasing bifurcation of the passenger car market between luxury and base models has intensified since the economic crisis of 2008, squeezing the traditional mass car market (Wells and Xenias, 2015). The effect has permitted JLR, formerly considered a niche luxury car market to increase production significantly.

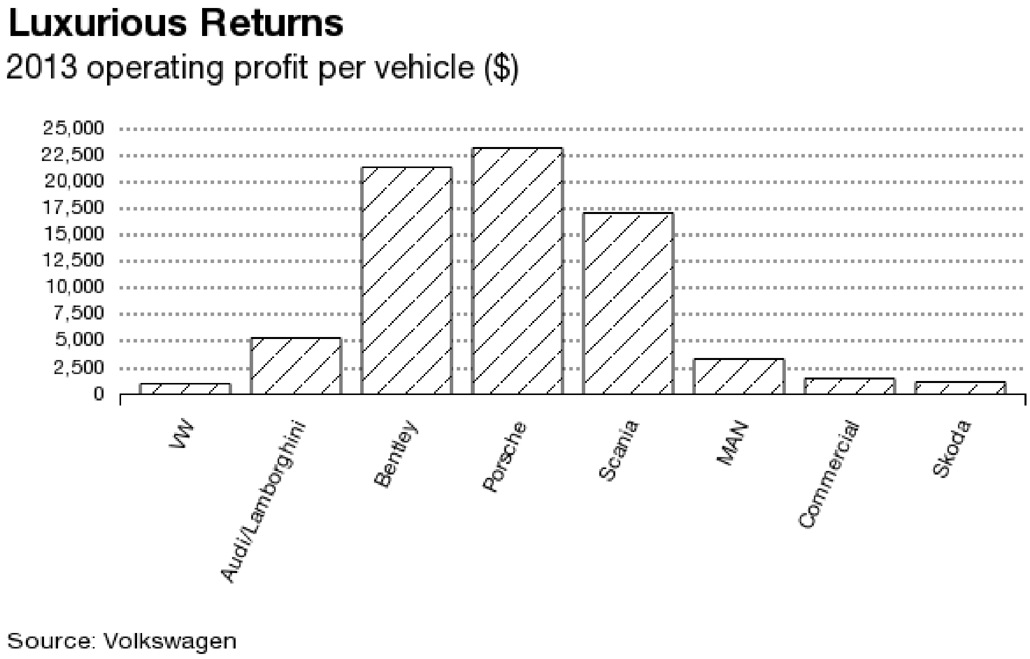

Figure 4.4. Operating profit per car $ per vehicle (Edelstein, 2014).

As the more expensive, luxury cars which make the most profit tend to be the heaviest, car makers are thus minded to add more luxury items to cars rather than focus on emission reductions. Forecast developments such as autonomous and connected vehicles and increased electrification (e.g. electric motors and power-assisted devices to move windows or steering) will also add weight. Innovation therefore was tending to increased luxury features producing "ridiculously over-engineered" cars (13) rather than more sustainable ones. Rather than pursuing technological improvements, a "sustainable vehicle" production requires "a different mix of performance parameters, built around safety, convenience, efficiency and emissions" (Ceunot, 2009, p. 642).

But greater mass also increases the generation of non-exhaust emissions, especially particulate matter such as those from tyres, brakes and road surfaces (Amato, *et al.,* 2014). These particulates are particularly harmful to human health because of their size, restricting the development of lung function in children over their lifetime. As the generation of these particles appears to be directly correlated to the car weight however, rather than exhaust emissions alone, electric vehicles will also contribute to the generation of these emissions (Timmers and Achten, 2016). The increased weight of cars also represents an increase in the use of material stocks without a corresponding increase in mobility (Cabrera Serrenho and Allwood, 2016). The importance of mass therefore is re-emphasised (Cheah and Heywood, 2011). Therefore whilst legislation (the regime) seeks to change the rules to promote sustainable innovation, wider "landscape" effects of market factors and customer demand are affecting how the automotive regime addresses this problem. The next section addresses the effects of the legislation on the automotive sector in the UK.

4.6.1 Effects on the automotive sector

As discussed in chapter 2, evaluation of automotive CO_2 emissions at the level of the sector is important because of the international nature of the industry and to address the gap in analysis in the transitions literature at this level (Markard et al., 2012). The EU also recognised that legislation to affect car CO_2 emissions was required at a European, rather than national level, to avoid a distorted market within the EU (EC 443/2009; EEA, 2014), emphasising again the importance of the sector. The single market, which creates an "even playing field" (2) for competition, is a significant trading advantage for European car manufacturers and highly prized, since it means that non-EU car manufacturers must meet European standards in order to sell into Europe. Creating a large protected market also offers economies of scale and effectively makes the European standard, the international one. This international aspect also means that it is reasonable to draw some universal conclusions about the effects of the legislation on the car sector from a UK interviewees' perspective alone. This was reinforced since car makers themselves (1, 2, 3, 7, 12) often emphasised the international nature of car design and production, with technical knowledge shared worldwide: as one major manufacturer put it:

> *There is a lot of interaction that goes on on a global basis. Similarly for the Americas market, there is a North American technical Centre, and we speak with them on a more or less daily basis (2).*

The international aspect of this sector, particularly at the earliest design stages of the car, indicates a specialist niche knowledge which is shared in many nation states, helping to create a shared international culture of a car regime.

First, interviewees were generally positive about the emissions legislation and believed that it had influenced their behavior:

> *"Legislation is key" (8)*

> *"The legislation changes the argument in the boardroom" (13)*

> *"It establishes liability and ensures standards" (18)*

Legislation also had the effect of spreading awareness through all levels of the firm, but particularly at board level, which was seen as crucial in effecting change in a large organization. This data suggests that legislation has a crucial role in shaping industry expectations, but particularly if the head of the organisation endorses it. An interviewee at a major OEM advised:

> *Who's the boss can have a big influence. We've been very lucky in having the one CEO over both organisations which has accelerated a lot of things, I suppose you could say, basically banged their heads together, just do it, please deliver! It's been a very big advantage. (2)*

Another suggested:

> *I think until quite recently, until environmental innovation as a corporate goal has came into place, we met with quite a lot of resistance from the engineers, they had a lot of difficult targets to meet already on their components and with nothing coming* ***from the top*** *[interviewees' emphasis] to say we needed to do it, they just kind of went [interviewee shrugs, pulls*

face] it was a closed door, 'we've got too much to do, don't darken my door'….(3)

Another noted the key role of leadership in counter-acting cost pressures*:*

The legislation changes the argument in the board room. The finance directors say 'we do not want to put an extra cent on the price of a new car'. So whatever the engineers say is possible, the finance directors say 'but we don't actually need it at the moment, it won't improve our sales, so let's just leave it in the laboratory'. And so the legislation encourages products to come out of the laboratory. (4)

Interestingly, interviewees from UK Civil Service roles suggested that the role of legislation had been overstated. Fuel economy improvements were industry responses to market demand for more fuel-efficient vehicles, produced by higher oil prices and further intensified by the economic crisis in 2008. Lower oil prices recently (2015) were thus weakening the case for light-weighting and fuel economy. Prior to the emissions legislation, fuel consumption improvement and CO_2 emission reductions were already occurring. A UK Civil Servant advised:

Even before the legislation was on the statute books in 2009 the car industry had started to adjust to the fact that this legislation was coming, they had two or three years' notice. (24)

And from another:

Market forces and legislation both have a role to play (11)

Returning to car manufacturers' perception of innovation, a number noted that introducing any kind of innovation into the complex automotive supply chain is challenging (Wells *et al*., 2012) but a new material even more so for a variety of reasons. Firms differed in their approaches to innovation however, with some firms more open to radical change than others, depending in part on their commitment to the all-metal body (Nieuwenhuis and Wells, 2007) and ability to reorganise themselves. In a light-weighting car project in Sweden, Kastensson (2014) highlights how the differing management styles of Volvo and Saab effected their approaches to innovation, contrasting the open collaboration in multi-disciplinary teams in Saab with the inhibiting effect of Volvo's commitment to steel, concluding that " we should be careful in expecting too much from established actors in the automotive industry." (Kastensson, 2014, p345).

Interviewees were very reluctant to discuss specific new material initiatives citing confidentiality and market sensitivity requirements, but advised that with a longer supply chain, involving more stakeholders, sharing information and materials requirements was more difficult.

> *It's basically as you get further and further down the supply chain, the information flow, and the availability and the understanding of that information, does get less as you get further down (2)*

> *Particularly with raw materials suppliers, we are very focused, because we are aware they are so far down in the supply chain that maybe a distorted message or an incomplete message gets through to them (5)*

A particular barrier could be material processors who were reluctant to damage capital equipment by introducing a new material due to contamination concerns and doubts over processing capability.

New materials were important however because:

> *We've pushed the power-train technologies (engine) as far as we can in terms of efficiency, so now the easiest way to reduce emissions and enhance fuel economy to reduce CO_2 emissions is to reduce the weight of the vehicle (2)*

This statement suggests that incremental improvements have been largely exhausted, and to now meet the standards, more radical innovation is required. Other car industry interviewees agreed on the importance of weight:

> *"Weight reduction is the number one topic at the moment." (2)*

> *"The only thing the company will pay for is lightness… it's a primary goal (4)*

Weight reductions can be achieved by a number of methods including reductions in engine capacity, improved design, parts consolidation and material choices. The evidence on vehicle weights above however suggests that this method is largely dismissed.

Car manufacturers use a system called IMDS (International Material Data System) (IMDS, 2016) for material suppliers to input detailed specifications of materials; but for confidentiality reasons only OEMs at the end of the supply chain can see the specification. As an international market, universal standards apply to all car materials, with OEM interviewees advising:

> *In the materials I can tell you that we have one standard that fits all markets, everywhere (3)*

> *We have very rigorous requirements on the materials and we don't deviate from them. (2)*

The requirement for universal standards on materials however means that those suppliers attempting to introduce new materials are disadvantaged, as they are unable to supply at scale to a variety of international manufacturing sites. This suggests that the earlier in the same supply chain, the greater the difficulty of introducing innovation in terms of processing or new materials. OEMs also advised that these firms also often lacked the technical expertise to supply detailed specifications including LCA assessments, emphasising the importance of established knowledge. Information was therefore sometimes questionable in IMDS having been introduced either by "jokers and wildcards", (2) those suppliers who either did not have the skills to enter such information correctly or were deliberately supplying incorrect information.

In the UK, such firms were just too small*:*

> *They are quite small companies and small organisations so they haven't specialists in materials or material application (3)*

> *Because they're tiny. They're too small. If you're talking the likes of xxx or xxx, who are massive, global companies who have billions of £s coming out, massive research centres, that can support the technical development customers need – they (small UK firms) just can't compete (2).*

> *Yes, larger players who have the technical capability to deliver a full solution. The smaller garage inventor has gone and the small supplier companies who have may be 4/5/6 employees, they've gone, and haven't the capability to furnish all the information we require. It's very, very difficult for them to break through now, they need a sponsor now, somewhere midway in the supply chain to drag them along and to open the invitation to the OEM. (7).*

UK OEMS also noted the lack of UK-based tier 1 firms, who might have the local and technical knowledge to sponsor such firms. However an NGO interviewee commented on UK car firms:

> *There aren't many British manufacturers around, so you have to understand that the UK arm is [often] purely about marketing and retail, all the design decisions and all the decisions around what material is used and how is decided in the headquarters of the parent company. " Actually we need to talk to Paris about that" or "We haven't got the expertise to actually fill you in on that". (19).*

This suggests the need for technical skills and knowledge, particularly materials, within the regime, and pushes the market to work at ever-increasing international scales, confounding the potential for innovation at the niche, small-scale or local level. The problem of scale was also recognized by the UK Automotive Council as they sought to shape innovation (Automotive Council, 2013). An interviewee from a bio-composite firm drew inspiration from the US military model of innovation from the defence sector but was critical of UK funding efforts:

> *The solution to one volume sector isn't the solution to another. This whole idea of by trying to address the big numbers the answers to the small numbers will fall out along the way, it just doesn't work at all. So long as the funding is geared around that level, they' re missing a large part of the market (22)*

However whilst most UK OEMs said they were keen to work with innovative smaller firms (2,3,12), they also advised that smaller firms often lacked the technical skills, time and expertise to devote to developing new solutions, in particular, in conducting LCA and in satisfying testing requirements.

Whatever we do, they need a technical rep in the UK or else it just doesn't work, we need somebody here on the ground who can interface with us. Language, everything (3).

UK-based firms supplying to OEMs had a different view. One SME interviewee with an innovative lighting solution with the potential to save approximately 10kg in weight per car suggested that:

> *The car industry has a particular knack of using you as a free research tool (14)*

which meant that smaller firms "get bled dry for your R & D and you don't see anything back for it" (14). A Tier 1 supplier advised that the increasingly shorter model life cycle exacerbated OEM requirements, meaning that speedier adaptations were required, with shorter production commitments (6). Some car OEMs often specified exactly in what way a material could be used and who could source it, limiting innovation possibilities, but preserving the supply chain:

> *If you've handcuffed me [the Tier 1 firm] to say, "I want you to make this part but you cannot, you cannot use anything but supplier b", then how can you affect change? You can't affect change. And 2, the onus is on the supplier, and he's got the upper hand, he says, sorry, you've got to come to us, because the customer said that you have (7).*

For example:

> *I've got a true example at the moment, where they've given us a drawing, where I can take 60% of the material out of that and in this instance, I've simulated the loading conditions and it's going to be no worse than your current product but I've taken 60% of the material out, and the actual feedback has been, supply it as its drawn at the moment and we'll think about it…(7)*

Removing weight however meant the need for revalidation and sometimes testing with significant cost implications:

> *And that's where the struggle is. Because they [OEMS] still want their cost out but it comes with so many caveats, and who's going to pay for it? And in an instance like that, we can only do so much, there's a cost for us to do the work to a certain point anyway but at what point does it change over to the customer?(5)*

A new material also faced the challenge of establishing a guaranteed long-term supply. Interwoven with this requirement was price. All industry sources (1, 2, 3, 4 ,5, 6, 7, 14, 20, 22), both large and small firms, OEMs or suppliers, noted the importance of cost in any innovation. As one Tier 1 supplier put it:

> *Its cost, cost - cost is down, its the main pressure, it's the only pressure we see really - its continually taking cost out of the product (7).*

The emphasis on cost, together with the preference for those suppliers already in the established supply chain is a particular regime influence, which hampers significant material innovation. Together with the car industry's preference for larger firms, due to their knowledge and ability to supply on a world-wide basis, UK government initiatives to encourage smaller firms to engage with the car industry appear inappropriate.

Despite these difficulties of introducing new innovation, the UK car market has seen significant growth in new car sales since 2009 (SMMT, 2016). Much of this growth, counter-intuitively given the economic crisis since 2008, is predominantly in high-end luxury, heavier cars such as those from JLR, and is credited to the introduction of innovative finance, PCP (Personal Contract Purchase) credit agreements (Barkham, 2013). These finance arrangements require a small deposit and a regular monthly payment for a low interest rate, generating a steady cash flow for the manufacturer.

Incidentally however, the contract terms, typically 2 year and 3 year, accelerate car turnover rates. Since the introduction of a new model is one of the key "windows of opportunity" (Geels *et al.,* 2016) when a new innovation or material may be introduced, this speeding up of the product cycle is a complementary incentive for innovation, and bolsters the internal company case for innovation. Such contract types could also be used to finance more radical innovation through different car material choices.

In summary therefore, the UK car industry has met the car emission targets and increased car sales at home and abroad, despite the economic recession. However, by making and selling more profitable, heavier cars, the incentive to reduce emissions rapidly by introducing more innovative light-weight materials has been blunted. Moreover, the emphasis on market solutions in the UK means that incentives are focused on those cars already selling well, and in selling low emission cars in addition to ICE cars, rather than transitioning to a different transport outlook. Focus on established market leaders however limits the range and types of innovation possible.

4.7 Bio-based materials

4.7.1 Effects of the Legislation on Bio-based Materials in Cars.

Overall then it appears that emissions legislation is framed within the narrow terms of technologies, particularly engine efficiency, rather than more radical changes in material choices or other concerns. There is no explicit discussion of materials in the legislative document (EC, 2009) but the emphasis on long-term targets (article 4) and new technologies (article 12) might potentially encourage the development of light-weight materials. As discussed, the emphasis on mass could also encourage the use of new materials; but the calculation method, being applied to the vehicle fleet as a whole, means that incentives to light-weight are blunted. The watering down of fines and gradual phase-in of targets (article 4) also weakens the effectiveness of the legislation. Given the cost of developing new technologies and the difficulties of integrating these into the existing production facilities, it is perhaps more cost-effective to “cheat” the legislation since the risk to reputation seems to be limited. Therefore the regulation appears to offer limited incentives to develop new lightweight materials and several disincentives.

4.7.2 Changes in Material Composition, including bio-based, used in cars.

This section considers how manufacturers have increasingly used a variety of materials in cars. Establishing a car’s material composition is challenging as this is often shrouded in commercial confidentiality. Over the last 20 years, the material composition of the car has changed to include a more heterogeneous mix of materials and in particular a declining percentage of metal (Kanari *et al.*, 2003; (2) (figure 4.5 below). . Plastics in particular make up an increasing proportion of the car (Ryntz, 2006) with the proportion of non-metallic and rubber materials expected to increase to approximately 40% by 2020 (Automotive World, 2016; Rouilloux, 2012).

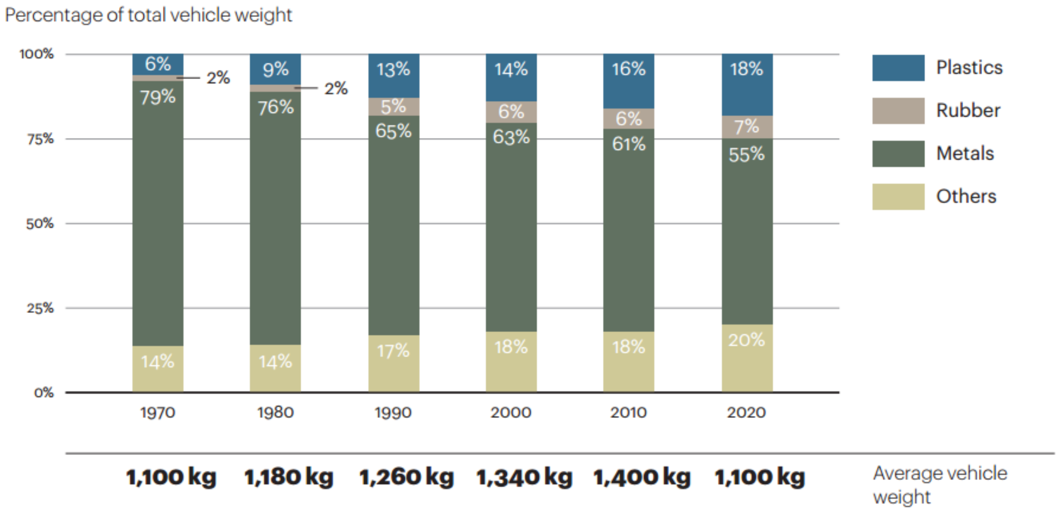

Figure 4.5. Changes in car material composition 2000 – 2020 (Rouilloux, 2012)

There are limited documented examples of applications of lightweight bio-based materials in cars (Table 4.1) although all interviewees claimed that they were aware of and used them, but were unable to discuss further. Those examples identified tended to be in company websites and company reports (Table 4.1) but were found by key-word searches for "green" and "sustainability", rather than "bio-based". Evidence was rarely found on UK car websites, although a notable exception was Ford, based in the US. Presentation in car firm advertising tended to emphasise bio-based materials "renewable" aspects rather than their "recyclable" supply. For example, on the new Peugot 308 model, 22% of the cars' plastics are bio-based, amounting to 45kg of material (Latieule, 2014).

Car industry interviewees suggested that reluctance to advertise this use was because:

It's seen perhaps as a detraction from the "premium-ness". (3)

and "fears over safety and reliability of the car" (2)

Table 4-1. Examples of bio-based materials currently used in car production.

Material	Source	Which car firms	Which car part	Which firm supplying	Volume	Information Source	Date of Production
Soya	Soya Bean	Ford Toyota GM, Lexus	Headrest, Seat Cushions	Ford Toyota GM	75% of US vehicles	Ford European Bioplastics (2016); CARS(2016)	2010 - present
Soya	Soya Bean	Ford	Tyre gasket	Ford	25% of US vehicles	Ford European Bioplastics (2016); CARS(2016)	2010 - present
Straw	Wheat	Ford	Reinforcements in plastics	Ford	NA	Ford European Bioplastics (2016); CARS(2016)	NA
Bio-based Resins	Corn, Sweet potatoes, sugarcane	Ford	Thermoplastic resins	Ford	NA	Ford European Bioplastics (2016); CARS(2016)	NA
Bio-based Nylon 11	Castor bean oil	Ford, Fiat Chrysler, Alfa Romeo	Fuel Tubes	Ford, DuPont	95% of US vehicles	Ford European Bioplastics (2016); CARS(2016)	2010-present
Bio-based plastic	Hemp	Mitsubishi, GM, Honda	Plastic fittings	Faurecia Interior Systems Findlay Industries	NA	European Bioplastics (2016)	2016-present
Bio-based polyamide (EcopaXX)	Flax, banana fibre	Mercedes Benz VW	Engine,Crankshaft Covers,Underbody panels	Royal DSM	NA	European Bioplastics (2016); CARS(2016)	2016-present
Sisal, kenaf, Jute,	Jute, Wood chips, flax	BMW, Mercedes Benz	Interior Door Panel	BMW, Mercedes Benz	NA	CARS(2016)	NA
Coconut fibre	Coconut	Ford	Loadfloor	Ford	NA	CARS(2016)	NA
Bamboo	Bamboo	Toyota	Interior Trim	Toyota	NA	CARS(2016)	NA
Corn	Corn	Nissan	Floor Mats	Nissan	NA	CARS(2016)	NA
Sugar Cane	Sugar Cane	Mitsubishi	Floor Mats	Mitsubishi	NA	CARS(2016)	NA
Cashew Nut	Cashew Nut	Mitsubishi	Oil Filler Cap	Mitsubishi	NA	CARS(2016)	NA
Flax, linseed	Flax, linseed	Ford	Body	Ford	NA	CARS(2016)	NA

Manufacturers were also sensitive to negative media coverage presenting bio-based materials in their cars as unreliable and technologically backward, for example, as in the Daily Mail "Tufty ate my Toyota! Driver claims squirrels feasted on "green" plastic car parts after firm switched to eco-friendly materials" (Massey, 2015).

One OEM interviewee advised:

> *I think we wouldn't tell the customer avidly about it. We'd be more likely to have it in our sustainability-type statement but we wouldn't market it to the*

customer, but we probably would market a bio-sourced material, a banana fibre or something, we probably would make a deal out of that (3).

Bio-based materials suffered from the difficulties of introducing any new material but particularly cost and supply:

The bio-stuff is not only more expensive, but there's less of it, therefore that also increases the price, therefore we haven't really been able to utilise that (2).

Material usage however depended on where the part was destined for: interior parts generally had lower strength requirements but higher standards in terms of appearance and finish meaning that it was easier to introduce bio-based material to the interior of the car (Toyota, 2010). Introduction of some bio-based plastics at another firm for the interior however had encountered issues with smell at warmer temperatures which were considered unacceptable by customers in early marketing tests (2). A Tier 1 supplier also mentioned that odour problems had led to resistance from employees who found the odours from bio-based plastics unpleasant and unfamiliar (7). A more typical usage for bio-based materials currently was for example in door liners, where bio-based material had the added advantage of dampening noise.

These UK attitudes contrasted with the US, where as discussed earlier, higher emission standards have been introduced. Here significant investment has already been made in US bio-based materials, given geo-political concerns over foreign oil (Energy Independence and Security Act, 2007), allied to significant political will to develop alternative markets for US agricultural products following the economic crisis. The importance of developing new materials, including home-grown bio-based ones, to address this challenge has been recognised at a federal level with significant investment for composites in the automotive sector (White House, 2015). US support has been forthcoming despite continuing lower commodity and oil prices, which UK-based experts advised had weakened the case for investing in bio-based materials in Europe (16,17).

Bio-based materials experts also pointed out that the US military had acted as a trail-blazer for bio-based materials in the US car sector (16, 22). Light-weight bio-composites and carbon fibre had the additional advantage of reducing blast casualities on the underside of military vehicles through their fibrous light-weight structure, "maximum survivability" as well as weight and fuel savings, which were particularly important in a hostile environment (Plasan, 2016). The UK however lacked the military budget of the US, or the appetite for investment, particularly at a time of economic austerity. The US example might be considered an example of a niche application gaining access to the regime in the way anticipated by both SNM and transitions theory through a stretch and transform process, (Geels *et al.,* 2016) in contrast to the UK, where bio-based materials were having to adapt to the regime values.

Therefore a wider issue of landscape perception of bio-based materials by customers (and sometimes employees) exercised an inhibiting effect on innovative change, particularly in the UK. Interviewees pointed out that some other EU states such as Italy and France, because of their commitment to national farming and a desire to generate another income stream for farmers, was much more politically supportive of a bio-based industry (Staffas *et al.,* 2013; Vandermeulen *et al.,* 2012). Because of the emphasis on cost however, materials producers often introduce bio-based materials for cars as hybrid ligno- and bio-blends to enjoy the benefits of these materials but minimise new capital plant investment, thus retaining both fibre-strength and licencing standards (Monteiro *et al.,* 2009). The lack of standardisation to these mixes however means that there is an increasing array of materials, in varying material mixes, in the car and consequently at end of life.

A number of organisations representing bio-based materials and their use were formed over the course of the research such as the EU Bio-based Industries Consortium (2014); the European Bio-economy Alliance (2015) and the UK Bio-based and Bio-degradeable Industries Association (2015). The formation of these trade, industry and research bodies suggests that bio-based materials have reached a certain scale at which the industry requires formal networking abilities and possibly the ability to represent themselves politically.

In summary therefore, the connection or alignment between bio-based materials and the automotive sectors has not explicitly been made, meaning that there is limited demand pull-through. The lack of synergy between the sectors has been recognised at the EU level and partially addressed by the Horizon 2020 calls for Bio-based industries development to refocus research on integrating biomass development through partnerships with end markets, including specifically the automotive sector, in order to create “market pull” (Bio-based Industries Consortium, 2016).

4.8 Summary and conclusion

This chapter has analysed the formation and implementation at the EU and UK level of the primary EU legislative instrument EC443/2009 to understand its development and effects.

Analysis showed that the legislation took considerable time to emerge and was initially strongly resisted by the automotive sector. The design of the legislation, particularly the use of the value limit curve, reinforced technological solutions particularly in the engine and added weight. As the design of the legislation implicitly rewarded heavier, more expensive and profitable luxury cars the car industry’s preference for incremental technological solutions, rather than more radical material ones, has been reinforced. Automotive sector lobbying for delays to the imposition of fines for failure to meet the targets also blunted the urgency of action. Ineffective type approval testing at the national level, including the UK means that exaggeration of CO_2 savings is common-place. Therefore whilst CO_2 emissions are declared lower by car manufacturers, the increasing weight of cars and their greater number, means that CO_2 emission levels from the car sector continue to rise.

Introducing any innovation, but particularly a material one such as a bio-based composite or plastic faces barriers from the existing automotive regime because of its lack of guaranteed supply and higher cost but also because the nature of the supply chain, which minimises cost through competition, and tends to favour larger, specialist suppliers, particularly in the UK. UK government actions to promote the car industry have tended to focus on existing incumbents rather than smaller scale new players.

The review suggests certain implications for transitions theory. Whilst at an EU level, the legislation sought to drive innovation and reduce emissions, national states actions e.g through lower tax rates for diesel and other market-base incentives, together with lax vehicle approval testing, have frustrated this goal. The legislation therefore fails to act as a block to existing practices, moving manufacturers away from a particular technology, in a “creative destruction” way, (Kivimaa and Kern, 2016, p205), an underappreciated part of the transitions process. The analysis suggests that the emphasis on market solutions, particularly in the UK, appears to clash with sustainable innovation because there is no cost advantage.

5 The End of Life Vehicles Directive (ELV) EC2000/53/EC

This chapter considers the second case study, the End of Life Vehicles Directive, (2000/53/EC) or ELV. The chapter also explicitly addresses the first and third questions:

RQ1: How has European automotive legislation affected the development of more sustainable innovation in the automotive sector?

and

RQ3: Are there legislative barriers to the use of bio-based materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

It therefore considers European waste legislation, but specifically the End of Life Vehicles Directive, (2000/53/EC) or ELV, which set targets for disposal and recycling of materials from cars. As discussed in chapter two, a key advantage of bio-based materials is their potentially unlimited supply, but this chapter considers their disposal. Analysing this legislation therefore allows us to see the ways in which a key piece of legislation that seeks to facilitate sustainable use of materials can help (or not) to foster the increased uptake of innovative, potentially more sustainable, biomaterials.

In terms of the MLP analysis, as the oldest of the three case studies, the directive is now well-established, fitting the definition of the regime as "the locus of established practices and associated rules that enable and constrain incumbent actors in relation to existing systems" (Geels, 2014 p 23). The directive's focus upon the end of life of cars means it addresses sustainability in the sense of the environmental impact of car waste.

The structure of the chapter mirrors that of the emissions' chapter. After an outline of the problem and development of the legislation, a summary explains how the legislation is designed to work.

It examines European then UK implementation of the directive and its effect on the automotive sector as a whole. The analysis highlights the car industry's material preference for metals, rather than other lighter materials, and suggests that the emphasis on recycling in the ELV legislation is a significant barrier to the use of bio-based materials because of their lack of recycling routes.

5.1 The Problem – Then and now.

When a car reaches the end of its useful driving life, there is a significant problem of safe disposal (SMMT, 2011; Smink, 2002). Cars may contain many materials, such as oil, lead batteries, or air bags that can contaminate land and water if not safely removed and disposed of carefully. The car also possesses significant material resources, such as metal and rubber, which might be usefully recycled or re-used (Cooper and Allwood, 2012).

The process of dismantling generally follows the same procedure and is illustrated in Figure 5.1 below (SMMT, 2011*)*. First any useful parts that might be resold are removed for re-use, then the car is shredded into chunks and sorted, primarily to remove the metals (approximately 75% of the weight of the car in the 1990s) (Kanari *et al.*, 2003), but also to reduce the volume. Metal can be relatively easily separated from other waste using a variety of techniques such as screens and magnetic sorting technology (Ferrão, 2006). The air cyclone will then separate out lighter (aluminium) and heavier (primarily steel) metals, with magnets attracting ferrous, (iron-containing), metals such as steel. The final remaining portion, known as automotive shredder residue (ASR) contains the waste that might be regarded as hazardous, such as plastics, electronics, textiles and glass (SMMT, 2011). Analysis also suggests that a significant portion of this ASR is polymer mixes (Morselli *et al.*, 2010). Prior to adoption of the ELV Directive, in EU countries this unwanted portion was usually shredded and disposed to either landfill or incinerated with limited regard to its environmental impact (Cossu and Lai, 2015; Smink, 2002).

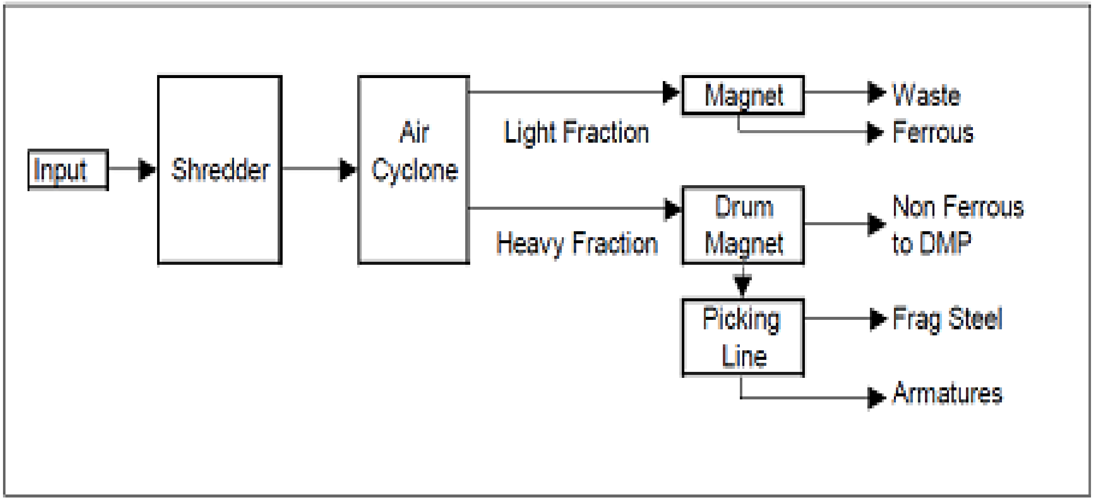

Figure 5.1. Automotive recycling process (SMMT, 2011).

However, the nature and scale of the problem of safe disposal of cars is changing, particularly given the international market for waste and the variety of national ELV approaches which can subvert environmental disposal of ELVs (Sakai *et al.*, 2014). There are a growing number of cars on the road in the UK, rising from 21 million in 1995 to 26 million in 2015 (SMMT, 2016). A number of reasons have been put forward for this increase in the UK including a growing population, number of households, economic prosperity, and a lack of alternative public transport options (BBC, 2016). As car ownership increases, particularly in China, the problem of environmentally safe disposal of cars also increases, meaning that the design of effective legislation is important (Sakai *et al.*, 2014). The chapter also highlights the increasingly varied mix of materials used in car production, as discussed in chapter 4, which complicates their safe disposal.

5.2 Development of the legislation.

Before the ELV (2000) legislation, a significant recycling industry had grown up, particularly in the UK and Germany, to dismantle and recycle cars (Lucas, 2001). Largely unregulated and unconnected to car makers, a variety of voluntary agreements had developed involving a variety of stakeholders, of various sizes, but connected to a global waste market, primarily driven by the value of the metal recyclate (Smink, 2002). These voluntary agreements were not present in all member states however and lacked regulatory force.

Car recycling first attracted legislative attention in Germany in 1990, with the German Federal Ministry suggesting manufacturers should take responsibility for their product (Orsato, *et al.,* 2002). By 2001 Germany had approximately 1400 authorised recycling plants under a voluntary agreement with car manufacturers (Lucas, 2001). Smink (2007) traces Danish concern to the late 1970s with the development of a voluntary agreement with the car recycling business association concluded by 1999 and encouraged by environmental concerns. In the Netherlands, a system of voluntary agreements between government and economic operators had met waste handling targets set by government (Smink, 2007).

In the UK, a voluntary agreement, the Automotive Consortium on Recycling and Disposal (ACORD) was implemented after some negotiation in 1995, and included government, car manufacturers represented by the SMMT and dismantlers (Zoboli and Leone, 1998). The UK's differing geology and legacy of quarrying had meant that landfill was a cheaper disposal option than in many European states, thus ASR residue was frequently landfilled rather than incinerated (Edwards *et al.,* 2006). Recycling activities were largely driven by the value of the metal recyclate, but a fall in the metal recyclate price, and the lack of any legal requirement to deal with the waste at this time led to increasing numbers of abandoned cars. The visibility of this problem was intensified by the scale of car theft and abandoned/burnt out vehicles, causing an eyesore, hazard to children, and cost to local authorities, police and fire services (House of Commons, 2001). These issues meant that there was increasing dissatisfaction with the voluntary agreement and a new Labour government in 1997 was keen to promote a more environmental, pro-European approach.

Before compulsory European legislation, some car makers had already become involved in recycling through the voluntary agreements. Orsato *et al.,* (2002) suggests that this engagement taught car makers the "real costs" of recycling so that they learned that the recycling process offered them little economic advantage and that car purchasers lacked sensitivity to the issue. In this process, they also focused on those parts that were easiest to dismantle and were most cost-effective, i.e. the metal content, thus largely ignoring the plastics. This learning process also provided car makers with information to frame the debate with European legislators around the range of practicable recycling options available, both in terms of cost and technology (Orsato *et al.*, 2002). Developing this knowledge using an existing network might be regarded as a key way in which the car-manufacturing regime has been able to utilise those key processes for regime stabilisation.

At a European level, the "Priority Waste Streams Programme " (1991) had outlined six priority waste streams including car waste, signalling a wish to address this problem. End of life legislative development was also "inspired by the Dutch experience" (EC, 1996, p. 13) which since 1995 had focused on dismantling (higher cost, due to the use of labour) rather than the use of the shredder residue. Articulated underlying principles here were the prevention of the generation of waste and reductions in the use of hazardous materials (EC, 1996), with the EU clearly making its expectations known. Broad agreement on the need for ELV legislation was largely agreed under the EU Austrian Presidency 1998. The differing national voluntary agreements may have acted as an additional stimulant to action, as they highlighted the need for a European-wide solution so as to avoid distortions to the internal market (Smink, 2002). In MLP terms, this might be termed an additional regime pressure.

Car companies were concerned with the cost implications of the directive, particularly the emphasis on design for disassembly, which would be necessary if cars were to be thoroughly dismantled. They were also reluctant to accept complete "producer responsibility" for disposal by 2003, whilst the Commission was seeking to move away from "end of pipe" solutions towards more preventative measures. The European Automobile Manufacturers Association, (ACEA), therefore favoured voluntary agreement rather than compulsory legislation (Smink, 2002). When Germany took over the EU Presidency in 1999, the chairman of ACEA (and Volkswagen (VW) Ferdinand Piech, lobbied the German Chancellor and EU president, Chancellor Schroder (who had also previously been a VW board member), to delay and amend the ELV text (Wurzel, 2000).

As a directive, allowing member states to choose their own arrangements effectively weakened the impact of the legislation on the car industry as a whole. Final amendments also left “an unusually high degree of discretion to member states” (House of Commons, 2001) over how the scheme should be implemented and who exactly should bear its costs, meaning that a “patchwork” of systems were developed (Garcia-Quesada, 2014).

5.3 The End of Life Vehicle Directive.

The directive is part of a suite of legislation focused on waste including the Landfill Directive (1999/31/EC), the Packaging Waste regulations (EU 94/62/EC) and the Waste from Electric and Electronic Equipment (WEEE) Directive (2002/95/EC and 2012/19/EU) initially adopted in the late 1990s. These shared a common goal to divert waste from landfill, primarily for environmental purposes (Burnley, 2001). More fundamentally however they sought to ensure that the costs of environmental standards were evenly spread to avoid market distortions through Europe (Smink, 2002), a regime imperative.

The principle of the waste hierarchy, as shown below in figure 5.1, underlies this legislation, proposing general principles for the preferred handling of waste on environmental grounds, and prioritising recycling over disposal.

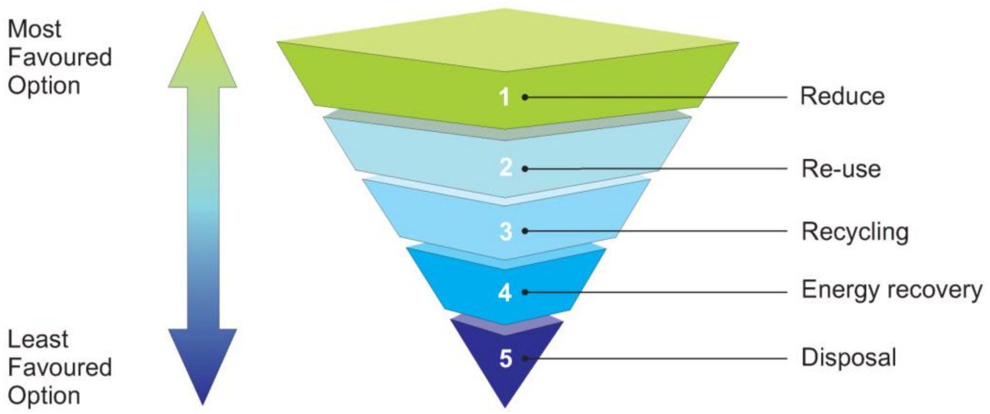

Figure 5.2. The waste hierarchy. (EC, 2014b).

The hierarchical structure of the waste hierarchy suggests a transition process in which progress proceeds by moving from one stage to another; for example, from disposal/landfill to energy recovery to recycling. However, this transition route is not necessarily either the optimum sustainable path or particularly practicable. Each stage involves differing infrastructure requirements, cost and stakeholder involvement. For example, in an automotive context, moving towards “reduction” implies manufacturers redesign parts and/or changes in materials, or processing improvements which might be deemed a regime issue. Alternatively such a change might require purchasers to adjust their expectations, towards smaller cars, considered a landscape change. Energy recovery requires infrastructure investment to safely incinerate car waste and removes materials from the cycle. Each stage also involves differing stakeholders, possibly disadvantaged by a move to a more environmentally favoured option. Therefore planning for reduction rather than recycling, or recovery rather than re-use implies differing institutional arrangements and incentives (Wolsink, and de Jong, 2001).

The directive had three primary aims**:**

To reduce the use of hazardous materials in cars, in order to reduce the amount of hazardous waste in the environment

To organise the collection and treatment of cars at end of life.

To encourage recycling and other forms of recovery to avoid landfilling of car waste (EP, 2000).

The Directive is aimed primarily at two different stakeholders, manufacturers and member states. Manufacturers were supposed to take “producer responsibility” and internalise the costs of disposal at the earliest stage (Sachs, 2006). This is a logical extension of the “polluter pays” principle, (Organisation for Economic Co-Operation and Development, (O.E.C.D), 1972), which implies that car manufacturers should consider, at the earliest stage in product development, the end of life of their product. Therefore material choices and manufacturing methods that might facilitate recycling and utlilise recycled materials, should be prioritised whilst simultaneously minimising the use of hazardous substances such as lead, mercury and cadmium. Lead in particular was extensively used in alloys to strengthen steel but with known toxic effects particularly to children from environmental exposure its removal was considered a priority (Goyer, 1993). This would be aided by manufacturers clearly marking car parts and the setting up of an IDIS (International Dismantling Information Service, 2016) for dismantlers to aid recognition of those parts that might be recycled/recovered.

Member states were charged with three key tasks: the setting up of collection systems, to ensure that manufacturers used coding standards for dismantling of cars and to provide information on implementation. The key targets were for 85% of all materials by weight to be reused and recovered by 2006 and 95% by 2016. The re-use and recycling target was 80% by 2006 and 85% by 2015 (article 7, EC, 2000). In practice, the 10% difference between the recovery and recycling targets is interpreted as the percentage of car waste that can be incinerated. The target dates of 2006 and 2015 addressed the ACEA's opposition to the retrospective nature of the originally proposed legislation, recognising the expected life-span of cars and the lead times required to implement new design features, but meant that a lengthy time-lag was built into the system, blunting assessment and effectiveness.

5.4 European Implementation

The success of Member States in achieving the ELV targets between 2006 and 2012 are shown below in table 5.1 (Eurostat, 2014). The table shows that almost all EU states, apart from Italy met the recovery target, although the lower recycling target remains unmet, reflecting the relative ease of incineration over recycling processes. Significant improvements have also been made in the dismantling of cars and the removal and disposal of hazardous materials, especially mercury, cadmium and hexavalent chromium, used in metal processing (EC, 2014). As such, the ELV is widely considered to be a very successful piece of legislation, given the significant improvements in disposal of cars, particularly by the car industry itself (SMMT, 2016).

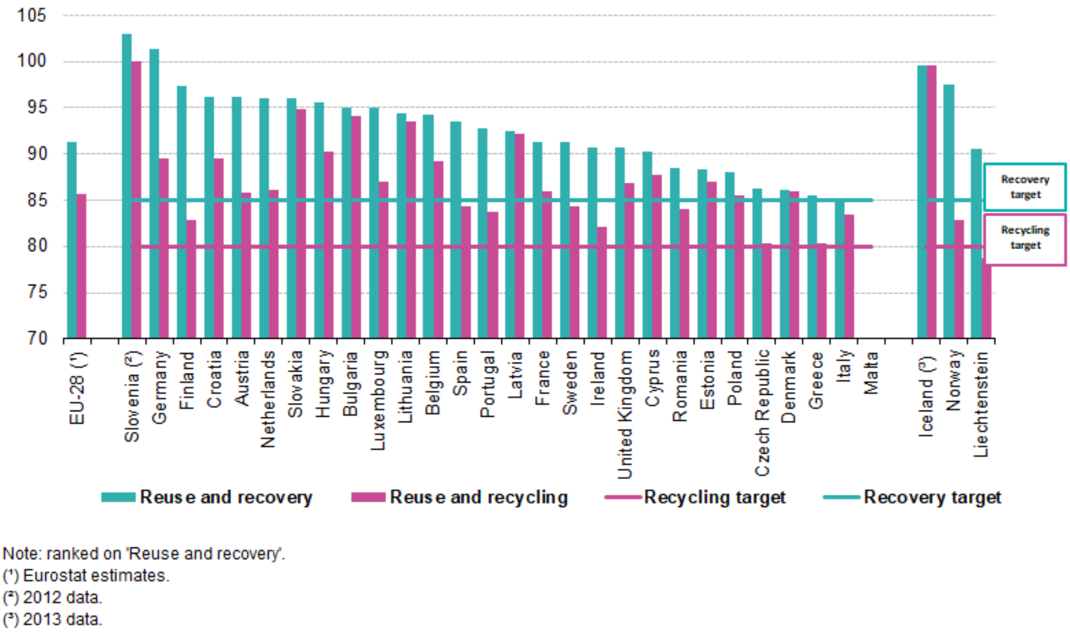

Figure 5.3. Recovery, reuse and recycling targets met in EU states 2012/2013 (Eurostat, 2014).

However there are a number of factors affecting these figures which means they must be treated with some caution. First, even Eurostat figures suggest that at least 30% of ELV are either illegally disposed of or exported (EC, 2014). The extent of the gap is difficult to quantify but whilst total European ELVs were estimated at 14 million in 2010, they were actually only 7.2 million (EC, 2014). In addition from 2009-2012 the number of ELVs reported fell by 30% (Eurostat, 2014). Thus whilst many of the authorised facilities may be achieving the targeted recycling rates, they are only dealing with a fraction of the total quantity of ELVs. One senior UK civil servant suggested that this might be considered "a statistical gap", (24) trivialising the extent of the missing ELVS and implying that no substantive action would be required or taken to address it.

Second, as a directive, all EU member states were required to achieve the ELV goals but were left free to choose the best methods on how to do so (Article 288 Treaty on European Union (TEU)). Therefore implementation was uneven across Europe as member states transposed the directive into their own jurisdiction. The established voluntary schemes, which reflected member states' disparate capacity, infrastructure and attitudes to waste, also shaped implementation. Even those states that appeared similar, such as Denmark and the Netherlands, (neither of which possess car manufacturing facilities, but both enjoyed an established environmental legislative framework) went for very different schemes (Smink, 2007).

Diverse legal definitions of recycling were adopted, for example, “backfilling” (i.e. filling an empty quarry/hole with waste) is counted in some states as landfill, but in others as recovery, because the waste is fulfilling another function. A lack of administrative information technology (I.T) systems to tie registration and roadworthiness certification into the required Certificates of Destruction (CoDs) adds another layer of complexity to timely comparisons of recycling rates. The Commission was therefore obliged to issue detailed rules on monitoring of the targets with further updates in 2008 and 2013 *(EC, 2014).*

Schaper (2002) in a prescient article suggested that the way that ELV legislation was transposed nationally would be important to prevent the legislation acting as an inhibitor of innovation. Being fixed to rigid recycling quotas, which lacked markets, would act to unintentionally hamper the development of new lightweight materials (Schaper, 2002).

Third, different methodologies were adopted to report results. Several states, but particularly the UK, were reluctant to burden either car manufacturers or small dismantling businesses with this obligation for cost reasons. The Commission therefore issued more detailed rules for reporting, which permitted states to use a Metal Content Assumption (MCA) based on trials, which is used by Germany, UK and Portugal (EC, 2014). Use of this system works on the assumption that all metals from ELVs are recovered, but means that some recovery figures are only theoretical, rather than actual, complicating comparisons with other member states using other systems.

Fourth, different levels of technology affect recycling and particularly recovery rates, “recovery” usually being interpreted as “incineration for energy” recovery. Whilst post-shredder technology is required to meet the 2015 target, often the richer major car-producing states, such as Germany are not the ones where the cars are eventually dismantled (EC, 2014). Poorer states, such as Poland, which are often the site of dismantling may also lack the necessary infrastructure to handle dismantling efficiently, particularly of any non-metal components (EC, 2012). But to dismantle cars effectively, requires information to be shared along the recycling chain, including manufacturers and recylers (IDIS, 2016).

Fifth, a number of supplementary amendments have been implemented since 2000, as shown in Figure 5.3. These amendments highlight the increased number of exemptions for the particular additives such as lead, which is often difficult to remove from recycled aluminium or steel.

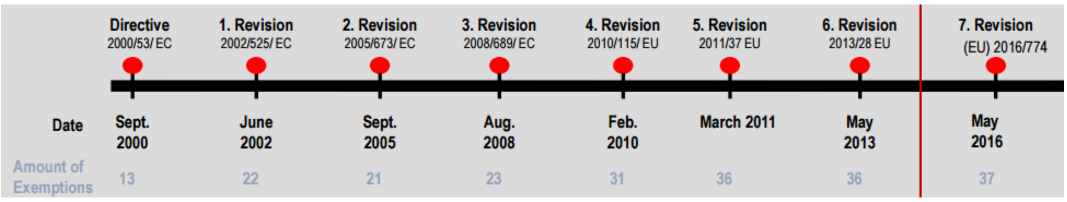

Figure 5.4. Revision to ELV legislation since 2000 (Hoock, 2017).

Thus whilst heavy metals such as mercury, cadmium and hexavalent chromium have almost been phased out completely through incremental processing improvements, aluminium use due to its near 100% recyclability and lightweight properties has increased (Gerrard and Kandilkar, 2007; EC, 2014). There has thus been significant technical attention to incremental processing improvements of metal rather than materials used to make plastics or polymers, although these processes are well-established.

Sixth, although the car manufacturing industry was targeted in the preamble to ELV (EC, 2000 section 22) Orsato *et al.*, (2002) notes how the use of the phrase “that member states assign responsibility to “economic operators” i.e. not specifically car manufacturers, essentially distanced car manufacturers from producer responsibility. The EU therefore sought to tie the car sector more directly to ELV through the type approval process with EC 2005/64/EC, by making it a legal requirement that cars could only be approved for sale in the EU if they were reusable/recyclable to the ELV standards of 85%/95%. This was in accordance with the industry standard ISO 22628 (ISO, 2002), which specifies a method for calculating recyclability or recoverability of a new vehicle and produces a mass fraction of recyclability**.** Smith (2010) argues that EU institutions have permitted a compliance deficit on ELV to allow European firms to remain competitive relative to global firms not obliged to comply with ELV.

To permit a more detailed analysis, the next section considers implementation of the ELV at the UK level.

5.5 UK implementation

As discussed in section 5.2, prior to adoption of the ELV, the UK's absence of regulation, reliance on landfill (Gille, 2010) and the comparative lack of incineration facilities meant that car waste disposal in the UK was primarily market-driven and particularly sensitive to the metal recyclate value (Smith and Crotty, 2006; Gerrard and Kandlikar, 2007). A Landfill tax introduced in 1996 at the rate of £7 per tonne was widely perceived as a government revenue-raising exercise rather than an environmental one but was initially perceived as too low to effect significant change and infrastructure investment (Morris *et al*., 1998).

Another contemporaneous piece of legislation however, the EU Landfill Directive 1999/31/EC (EC 1999) increased legislative pressure on the recycling sector (Burnley, 2001) introducing stricter standards for landfill sites, including company registration requirements and compulsory landfill lining, making landfill disposal more expensive and therefore increasingly problematic as a disposal option. Gradual rises in the rate of landfill tax followed, but until the introduction 2007 of annual increases of £8 per tonne, were arguably too low (Seeley, 2009). Interviewees, particularly those from UK Civil Service, suggested that this pressure of cost of disposal, produced by the regime, rather than the legislation itself, had been a significant driver in diverting car waste from landfill and delivering the investment in infrastructure required to implement the ELV Directive.

However the UK government generally took a positive approach to implementation of the ELV. The number of abandoned vehicles in the UK meant that there was local authority pressure to address the issue and the metal recyclate price at the time was relatively high meaning that there were clear market drivers to collect metal. A senior UK Civil servant at Defra suggested:

> *The ELV wasn't seen as something to avoid, it was seen as a bit of European legislation that would be useful to the UK and addressing real economic and environmental issues.*

Consultations with relevant stakeholders in the automotive, dismantling and recycling sectors however hit a number of issues:

> *That's not to say that it was all plain sailing, there were certainly prolonged discussions with the car manufacturers on the model that should be adopted by the UK.*

The UK was therefore keen to deliver the requirements*," but at the same time in a way that the businesses that were affected were (he does hand gesture of quotes) "most content" and caused the least impact.*

UK government sought to:

> *maintain the variety and breadth of facility that had historically developed across the UK and simply tying a facility to a network that a manufacturer would have needed wouldn't have worked." … and of course the government would argue the more choice, the more flexibility; the more competition the better*.

UK implementation therefore lived up to the impression of a "muddle through" on environmental legislation (Wurzel *et al.*, 2013, p148) with an aim to preserve the existing recycling network although this network, predominantly made up of SMEs, lacked the infrastructure, either in recycling or incineration facilities, to effectively meet the ELV targets.

The results of consultation on the transposition of the directive therefore resulted in manufacturers taking on little of the costs of legislation directly; instead this was pushed down the supply chain onto recyclers (Smith and Crotty, 2006). The UK therefore adopted a “zero-cost” system, which meant that rather than manufacturers being directly responsible for takeback, they would set up their own recovery yards. Recyclers resisted this innovation, despite British Metals lobbying the EU for a collection contract given the high value of metal recylate at the time (Coates and Rahimifard, 2007) meaning that UK car companies avoided the charge. Whilst this outcome might reflect the complexity of the value chain, by disconnecting manufacturers from the costs of the legislation, material innovation effects were minimised (Mazzanti and Zoboli, 2006).

The UK administrative framework for complying with the directive is spread over several departments with differing commitments to implementation: “Appetite in the UK government is different in different department ” (13) and

> *…the UK government is torn three ways, between the Department of Transport, DECC and BIS, and sometimes the Treasury of course too, split four ways. (13).*

which complicates compliance, as information and knowledge are compartmentalised within single departments, rather than “government” as a whole. The lack of connectivity between the different domains of expertise and lack of timely, joined-up information blurs clear lines of responsibility for implementation.

Treatment of ELVs is undertaken by authorised treatment facilities (ATF) which are inspected and regulated by the Environment Agency (EA). There are 1782 ATFs in the UK (Environment Agency, (EA) 2016). The ATFs are supposed to issue a Certificate of Destruction (COD) for each car using an online DVLA system. Cars at an ATF are recycled free of charge therefore avoiding the problem of abandonment. However, out of the 1700 authorised facilities, barely some 400 were reporting figures into BIS despite the fact that all were required to do so. Prosecutions for “failure to report” only took place for the first time in 2011, and totalled eleven firms by 2012, suggesting that enforcement in the waste market is not prioritised (Date, 2012). A review of government waste legislation (HM Government, 2016) noted concerns from ELV operatives that inspection and enforcement by the Environment Agency was lacking but failed to address this. This lack of enforcement at a national level may be a significant reason why many pieces of European legislation are only implemented in a “patchwork” fashion (García Quesada, 2014), but also means that incentives to change behaviour are ineffective.

The UK reports the highest number of vehicles scrapped but this may in part reflect efficient registration systems via road tax collection and the importance of a road-worthiness MOT certificate. UK reliance on car taxation and compulsory insurance, together with improved IT systems means that registration and destruction are considered comparatively accurate. The extent of the problem of missing vehicles still remains however. Even in the UK, out of an estimated 1.7 million cars scrapped a year, some 500,000 are not officially recycled, approx. 30% of the total. Recent bans on cash sales for metal in England and Wales in 2012 and Scotland in 2013 are thought to have reduced illegal treatment of cars. However the lack of a section on the V5 UK car registration document obliging the last recorded keeper to record that the vehicle has been recycled or exported may be regarded as a continuing administrative gap. However a senior UK civil advised that*:*

> *against the background of maintaining an approach that is proportionate and cost-effective, it is quite tricky”*

which suggests that the administrative costs were not considered a priority.

The UK is one of three states that utilises the Metal Content Analysis (A) to calculate its targets (EC, 2014). A senior UK Civil servant explained that there were three main reasons for using MCA, which primarily relied on the market value of the metal recyclate*:*

> *The MCA was pushed by us at the time when the Directive was being agreed as a means of first lessening the burden on facilities to account for what*

they're dealing with, we know that metal is a relatively high value material, and come hell or high water it will be recycled, and that got support from the Commission, hence the agreement to use a MCA.

MCA was also adopted because of the difficulty of gaining accurate information*:*

Absolute nightmare. If anyone contends that the figures are absolutely accurate is kidding themselves, not just in the UK, across the piece, which is why we take a model approach to some of the numbers.

Moreover, the UK lacked the infrastructure to handle recyclate, particularly due to the lack of investment in incinerators noted in the UK:

Simply in terms of the infrastructure in place, many of them (small recycling yards) don't even have the ability to weigh the vehicles that are coming in, they're arriving in all sorts of conditions.

These interview data suggest that using the MCA allowed the UK to comply with ELV without burdening businesses, including manufacturers with limited facilities with administration; and was comparatively cheap and robust in its methodology.

Trials undertaken by the DTI on 400 cars in 2005 established a recovered metal content of 75% from the average ELV (Weatherhead and Hulse, 2005). An average car age of 15 years was used for the sample, with models drawn from the 400 most popular cars of 1990. In the trial, the average weight of the UK ELV, excluding fuel, was 971kg. The authors noted how this compared to similar work in the Netherlands (855kg) and France (900kg), (Weatherhead and Hulse, 2005). UK civil servants suggested that the EU *" very much like the UK model unlike the other approaches in other EU states*" but this could not be confirmed with EU personnel.

Interestingly, this figure of 971kg has remained identical in UK reported figures to Eurostat since 2005, despite all other countries showing variations and generally an increase in average weight of approximately 10% as shown below in table 5.2. (Eurostat, 2014).

Table 5-1. Reported average weight of recovered metal from cars 2007-2014 (Eurostat, 2014)

	2007	2008	2009	2010	2011	2012	2013	2014	Mean 2007–14
EU-28 (1)	:	:	:	:	:	992	1 035	1 033	1 020
EU-27 (1)	928	947	930	980	993	992	1 035	1 033	1 120
Belgium	1 005	1 018	1 026	1 034	1 041	1 068	1 083	1 094	1 046
Bulgaria	1 000	1 000	1 139	1 074	1 040	1 029	1 017	1 017	1 039
Czech Republic	850	900	947	931	892	914	943	928	913
Denmark	989	1 001	1 028	1 044	1 078	1 074	1 026	1 136	1 047
Germany	921	929	898	1 032	1 005	998	981	981	968
Estonia	974	991	1 024	1 057	1 062	1 095	1 114	1 129	1 056
Ireland	971	1 071	1 070	1 069	1 032	1 032	1 060	1 060	1 195
Greece	880	939	1 002	968	930	929	947	961	1 079
Spain	952	952	959	959	959	959	1 051	1 051	981
France	925	943	933	978	991	1 016	1 085	1 028	987
Croatia	:	:	:	:	:	943	903	1 165	1 004
Italy	870	920	856	995	1 036	969	1 095	1 117	982
Cyprus	890	890	890	890	890	890	890	938	896
Latvia	924	964	845	907	1 078	1 020	1 004	969	964
Lithuania	1 082	994	967	980	1 045	1 144	1 172	1 109	1 062
Luxembourg	855	886	943	970	920	970	1 092	1 015	957
Hungary	695	760	1 054	980	1 147	937	998	909	935
Malta	:	:	:	873	881	860	876	1 071	912
Netherlands	944	961	976	999	1 016	1 022	1 031	1 041	999
Austria	819	816	849	828	842	867	885	890	849
Poland	876	896	915	838	963	987	998	1 016	936
Portugal	871	888	887	896	920	946	933	936	910
Romania	880	854	867	851	854	875	910	905	874
Slovenia	718	706	771	779	864	831	:	:	778
Slovakia	822	751	797	779	764	788	805	847	794
Finland	933	933	933	1 000	1 000	1 000	1 000	1 077	984
Sweden	1 164	1 189	1 216	1 216	1 230	1 246	1 268	1 271	1 225
United Kingdom	971	971	971	971	971	971	971	971	971
Iceland	:	978	893	1 044	1 032	993	1 295	:	1 039
Liechtenstein	1 110	1 110	1 111	1 131	1 117	1 079	1 086	1 074	1 102
Norway	1 005	1 032	1 032	1 032	1 044	1 177	1 156	1 132	1 076

(1) Eurostat estimates for 2007–09 and 2013–14. For reasons of comparison, EU-27 data are also shown for 2012–14, although EU-28 data are available.

For example, Italy's average ELV weight is 870kg in 2007, but 1117k in 2014, whilst France's increases from 925kg in 2007 to 1028kg in 2014 (Eurostat, 2014). Since average vehicle weight is used to calculate achievement of the targets, this introduces a significant error in the UK results. The assumption that both metal content and vehicle weight has remained constant since 2005 also seems implausible. Recently another trial was conducted to reassess these numbers, with costs shared between the industry and the government, which arrived at a new UK ELV base weight of 1130kg, an increase of 16% from the previous figure (SMMT, 2016). The metal content however was assumed to have remained at 75%. A senior Defra civil servant interviewee (24) recognised and expected that the changing ELV weight and material content would mean an on-going need to re-evaluate and adjust the model, suggesting that to understand, monitor and attain sustainability goals, will require continued, rather than discrete engagement.

The UK did not meet the 2006 ELV target of recovery and recycling of 85% until 2011 (Eurostat, 2014) and achieving the 95% target required in 2015 is considered particularly challenging (Gerrard and Kandlikar, 2007; SMMT, 2016). *A former UK MEP (13) advised that:*

> *That legislation has been around now for the best part of 15 years and the UK is still far off accounting for every car that reaches the end of its life.*

In summary therefore, the UK implemented the directive in such a way as to minimise the regulatory burden on manufacturers in particular but also on recyclers. The diffused administrative structure and lack of enforcement and clear government advice over definitions however inhibits innovation in treating secondary products from recyclates, particularly on the part of car companies (MVDA, 2014).

5.6 ELV and the Automotive Value Chain

This section discusses the effects of ELV on car manufacturers, particularly in terms of their material choices and recyclability. Issues around car manufacturers reusing and integrating recycled material back into the car are addressed in the CE case study, but recyclability effecting material choices is covered here. The analysis suggests that UK car manufacturers now regard the ELV as a part of the regime, but the emphasis on recycling and the structure of the supply chain has reinforced firms' differing capabilities and material choices. Firms that have thus tended to predominantly use metal have retained this as a material choice.

As discussed in the emissions case study chapter 4, there is limited evidence of manufacturers reducing the amount of material they use in car production. Cars have generally increased weight since 2000 with the average mass of UK cars around 1400kg since 2010 (ICCT, 2014). There are no incentives in the ELV to reduce the use of materials, such as for example by making the car smaller, or to consider new materials.

Simultaneously however, the material composition of the car has changed to include a more heterogeneous mix of materials and in particular a declining percentage of metal (2, 3, 6; Rouilloux, 2012; Kanari *et al*, 2003), making the recycling of a car more challenging.. Definitively establishing a car's material composition is difficult however as this is often shrouded in commercial confidentiality.

Evidence in peer-reviewed journals of manufacturers incorporating recycled materials into new production cars is scant. This lack does not mean that this activity does not take place, but it is challenging to confirm due to the difficulties of tracing material and car firms' commercial confidentiality. The type approval process does not require manufacturers to show how much of a new car is from recycled products. In any event since recycled steel can be incorporated with no loss of strength back into the metal-casting operation, metals would fulfill this obligation. There are some well-publicised examples of incorporation of recycled materials into production such as the Nissan Leaf which claims to be made from 25% recycled materials but Nissan admits that most of this figure is from the steel (Nissan, 2015). These figures are difficult to independently quantify however.

There is also little evidence of automotive firms using recovered material in a "closed loop" production cycle in part due to problems of quality; difficulties of dismantling; and concerns over safety. Seitz (2007) offers a rare example of an automotive firm taking back engines for re-working, but points out this is done for reasons of brand respectability rather than resource/cost purposes. Supply side uncertainty is a key constraint here. Mass manufacturers require a guaranteed supply of tested reliability. Knight *et al.*, (2015) also argue that supply side factors have critically affected the market development of Bioenergy from Organic Waste (BfOW), another potentially more sustainable innovation, because a core requirement for the financial investment required is confirmation of guaranteed supply. The next section considers how recyclability has affected manufacturers choice of materials.

5.7 Recylability influencing material selection

Interviewed UK car manufacturers suggested that the ELV (2000) was a very successful piece of legislation which had led to the safe disposal of ELVs and the redesign of cars to increase the amount of recycling. Interviewees agreed that cars were "one of the most recycled products on the market" (SMMT, 2016, p20) with a much higher recycling rate for cars than e.g. planes. All new UK cars were being designed with a 95% recovery rate in mind in co-operation with ATFs and car waste to landfill had been reduced by 94% compared to 2000 (SMMT, 2016). Interviewed car manufacturers and UK civil servants agreed that this was in large part due to the landfill tax rate in the UK, currently £84.40 per tonne (HMRC, 2016) which had added "chunky amounts of money" (24) onto the costs of disposal. Increased demand from European incineration waste firms for automotive waste and differential landfill tax rates across Europe had also bolstered this effect (Scharff, 2014).

Car industry interviewees, both from OEMs and SMEs, agreed that ELV was now accepted, suggesting that ELV is now regarded as part of the regime. As a major car manufacturer put it:

> *End of life vehicle legislation now seems like a very old subject, its accepted now. It was at the time, 15 years ago, a very big challenge and it changed a lot of the thinking, here in Europe, as to how we engineer and develop vehicles. (2).*

ELV for European car manufacturers had emphasised the importance of materials i.e that they must be recyclable and how they were put together.

> *End of life of vehicles made us focus on how we use the materials and how we connected them together. Things like screwing things together, self tap screws. But now we try and weld them together or join them together by some compatible means, so that they're easy to separate at the end of life. And we're using less materials along the way too. Its also, if you design and develop a*

vehicle that is quick and easy to put together, it's quick and easy to take it apart (3).

Manufacturers had therefore found additional reason to build ELV into their thinking, i.e the requirement to reduce lead in ELV, which is particularly used as a solder, had pushed innovation in joining methods, which had the added advantage of reducing both manufacturing production time and the side benefit of easier dismantling. This is an example of an incremental process improvement which characterises the regime. Several interviewees noted that the emphasis on recyclability had meant that unrecyclable materials were avoided altogether in production:

If it falls foul of all the recycling stuff, its not going to make it into a car. (20) and

- *[We can't use it] because of the difficulty of recovering that material at the end of the vehicles life. (2)*

These interviewees therefore articulated an expectation that because of the requirement in ELV for recyclability, certain materials, including bio-based composites, were not expected to form part of the future of the car. For one major manufacturer ELV had meant a reduction in the number of types of materials used:

(We are) very focused on reducing the number of types of material that we work with and using materials that are easy to recover. So like our plastics material applications, 75 to 80% of all the plastics on a xxx vehicle are polypropylene derived or TPO material, which makes it much easier to recover or to recycle. Basically you just rip the parts off the vehicle and throw it in one skip and it's all polypropylene in origin so it's much easier, though not all the same grade. A lot of our competitors have huge mixtures of materials which makes it much harder [to recycle]. (2)

Ease of recycling therefore also depended on recyclers making the effort to disassemble the car, driven by value, using information freely supplied by the manufacturer (IDIS, 2016). If the recylers don't disassemble then once the metal has been removed and any other useful parts of the car, the remainder is shredded, (ASR) to reduce volume, making the extraction of re-usable materials more difficult. The heterogeneous nature of this material however means that pre-treatment of material is often required (Cossu and Lai, 2015).

In contrast, for car industry interviewees at other firms, (3, 6 and 7) ELV had emphasised a historic reliance on metal, both because of the established market for recycling metal and their own supply chains with established networks for delivery and their knowledge of metal processes. JLR for example had moved increasingly to aluminium, rather than high-strength steel, and developed a new metal alloy that tolerates recycled scrap, with the goal of using 75% recycled aluminium in body structures by 2020 (Ludwig, 2016). Being owned by Tata Steel, JLR thus drew on an established supply chain route which also recognised metal processing knowledge strengths. Sticking with established suppliers was interpreted as a reduction of supply-chain risk and construed as an additional motivation for complying with ELV. A materials buyer at a major Tier 1 firm for example advised that the tight auditing processes required by automotive firms relating to due diligence, inhibited the cultivation of new suppliers.

All interviewees however from the car manufacturing sector agreed that a material must be "at least as good as" the existing material standard, (1 – 7) even if they agreed that that standard might not always be appropriate. By insisting that any new material must match or exceed current standards however prohibits the introduction of many new materials, contributing to a regime bias in terms of knowledge.

Turning from metal, to plastics, established recycling routes are less clear with historically most UK recovered plastics sent to China (WRAP, 2016). Plastics can theoretically be recovered through melting but this leaves a fraction, which cannot be landfilled, but possesses a high calorific value, which can be incinerated for energy recovery. This usage was explicitly addressed in the ELV 2008 amendment when "recovery" was re-defined so that incineration could be "waste serving a useful purpose by replacing other materials which would otherwise have been used" (Article 2 – ELV, 2000). There is some evidence this material is being exported to Europe for incineration as there is limited UK infrastructure to handle this waste.

There are three sources of plastic waste: the first from off-cuts used in the production process, the second from dismantling (for example, bumpers) and the third from (ASR). The first source is the preferred choice of recyclers as it is often clean, sorted and type-identifiable; moreover, since safe disposal of these off-cuts is a liability for manufacturers, there is a happy co-incidence of interests between manufacturers and recyclers on these parts. Dismantling of larger plastic parts is minimal. Only France (3974 tonnes) and Germany (1242 tonnes) provide any significant figures here, there are none given by the UK (Eurostat, 2014). Plastics recycling from ASR is also uncommon with only one facility in France and one each planned in UK and Germany, (EP, 2010). This means that whilst theoretically 85% of plastics might be recycled, the actual amount is much less.

The amount of ASR is difficult to quantify but estimated at approximately 2.5 million tonnes per annum (Zorpas and Inglezakis, 2012; Morselli *et al.*, 2010). Morselli *et al.*, (2010) further estimates that 70% of the ASR is polymers but cautions that much of the material is too fine to analyse and that car model variations means there are wide variability in percentages. As the efficient incineration or pyrolysis of materials depends on the material mix, this complicates the disposal of the shredder residue, since many poorer states, where older cars may end up, may lack the infrastructure to effectively handle them.

Since the ELV focus is on eradicating harmful materials used in processing metals, not on those used to develop composites or plastics, various compounds found in composites such as fire-retardants and stabilisers are not addressed. These materials are retained in the ASR, in varying concentrations and constitute hazardous waste (Morselli *et al.*, 2010). Moreover, the increasing amount of electrical items in cars means that this portion of ASR is set to increase. There is potential legislative conflict here also with the Waste Electrical and Electronic Equipment

Directive (EP, 2012) and Batteries Directive since recycling of these heavy articles would mean that recycling targets could be achieved easily, but were counted twice.

Incineration is further complicated by variations in recycling regulations and infrastructure worldwide (Sakai *et al.,* 2014). The US for example lacks federal legislation to cover ELV (Paul, 2009), and ASR is usually disposed to landfill. Japan in contrast has a 70% compulsory recycling rate on ASR, rather than the complete ELV, with recycling and recovery funded by an intiial buyers fee (Sakai *et al.*, 2014). These legislative differences in standards complicate the cost of disposal, intensifying the market pressure for waste disposal in those states outside the legislative envelope, but also means that the environmental costs of disposal are borne by others (Scharff, 2014). The lack of connection between car manufacturers and the international waste market means that car manufacturers who seek to standardise production are therefore further dissuaded from effective ELV design. As one car maker (USA) put it: *ELV is fifteen years away, probably in another country and definitely not my problem.* (1). Further treatment of ASR by recyclers can only be justified in terms of further recovery of metals (Ruffino *et al.,* 2014), reinforcing a material preference.

Given the international nature of the car market, and the differing legislative and infrastructure requirements, even within the EU, it seems likely that a market solution to ELV will predominate rather than environmental legislation. Focus on recyclability to comply with ELV has therefore meant an additional barrier to the introduction of any new material, not just bio-based materials, as discussed in the next section.

5.8 Bio-based Materials and their end of life

As outlined in Chapter 4 which focused on emissions reductions, bio-based materials are increasingly utilised for a variety of uses, including cars, due to their light-weight nature (Akampumuzu *et al*., 2016; Alves *et al.*, 2010) but are particularly visible in US, rather than EU, car manufacturing (Hill *et al*., 2012), (15). Of particular attraction is the materials' potentially unlimited supply, in comparison to petroleum-based plastics, meaning that increasingly bio-based practitioners emphasise ‘renewability of supply’ (British Plastics Federation (BPF), 2012) rather than bio-degradeability (Mohanty *et al.*, 2000). Whilst oil prices are often volatile, bio-based materials, often produced as a by-product of biofuel processing, are considered more stable.

The focus on “renewability of supply’ however means that there has been comparatively little attention paid to the disposal of bio-based materials at their end of life (Glew et al., 2013). Analysis suggests that this was in part because bio-based materials were not tied to one particular materials market, but were multi-sectoral, meaning the industry itself lacked consensus on one ideal solution (Glew *et al.*, 2013). Being utilised for varying materials, including as plastics, as cloth material door cladding, or in fibre-reinforced composites meant that no dominant consensus existed on the material disposal or recycling route. As discussed in chapter 4, many bio-based materials are also blended with other materials for processing into plastics or as composites as in fibre-enforced plastic.

There was no degree of consensus around disposal of bio-based materials between interviewees. This lack of agreed expectations around the future direction of the industry suggests that a transition pathway is not yet clear (Vandermeulen *et al.*, 2012). One interviewee suggested that in the UK, the bio-based market was focused on energy rather than materials (25), meaning that incineration was the default disposal method. Given the lack of UK incineration facilities, this often meant that bio-based and other ASR materials were exported to other EU member states such as the Netherlands, who had invested in this infrastructure (Scharff, 2014). Another suggested that the UK waste industry lacked the flexibility to adapt to changing materials “ we’ve got an entrenched, conservative waste industry” (17) and was focused on the separation of compostable materials from food waste (Carus *et al.*, 2014). A senior representative of the UK bio-based sector suggested that recycling for bio-based materials should not be an option, due to the difficulties and costs of collection:

> *Or you stop fussing around with this damn stupid recycling, which costs a fortune and doesn’t work. Its like flogging a dead horse. But if you say that, its politically incorrect. What about the resources they say? (25).*

This quote suggests that recycling is not considered a high priority by the industry.

5.9 Effects of the ELV Legislation on Bio-based Materials in Cars

As discussed earlier, the ELV Directive and subsequent amendments are focused on removal of hazardous substances such as lead, mercury and cadmium, which are used in metal processing (EC, 2014a). There is very limited discussion on the treatment of plastics or other materials meaning that there is a lack of incremental incentive to encourage the regime to undertake this activity. Given the increased amount of plastics and polymers as well as bio-based material utilised in cars, as discussed in the emissions chapter, this will become a more urgent issue in the future (EC, 2014b).

The rigid emphasis on recycling in ELV (2000) appears to act as a disincentive to adopting bio-based materials in the car industry. Car manufacturers appeared to agree that if the product could not be made recyclable, it would be difficult to integrate into the car (20, 2) but bio-based materials producers were not even agreed that recycling was a priority for them. This suggests that given the higher standards of 85% recyclability on ELV car materials, that bio-based materials would have a very limited contribution to make to future cars. Car manufacturers suggested that the current volume of bio-based product in the car meant that this was not yet an issue. Moreover whilst producer responsibility is the clearly the intention of the legislation, car manufacturing interviewees often justified their lack of comment on this area as lack of expertise (1,2,4), although as materials experts, end of life of all materials might be expected to figure in their remit.

Since the ELV legislation is focused so much on the need for recyclability, the lack of clear secondary markets for bio-based materials is a major barrier to their adoption by the car industry. As discussed in chapter 4, material processors try to mix materials using the same plant to do so. Doing so reduces the need for capital investment whilst obtaining the benefit of these materials, retaining fibre-strength and licencing standards (Monteiro *et al.*, 2009). These hybrid mixtures however may further complicate the waste value or disposal chain because of their lack of standardisation and the lack of consideration of their fate at end of life. The wide variety of materials means they can be difficult to classify and sort. There is also no market for reuse, or recyclability. Whilst the most obvious disposal solution is incineration, this depends upon the ability to isolate and collect them together with infrastructure to do this.

The lack of clear recycling routes for non-metallic material means that the higher target of 95% material recovery required by the ELV could not be easily met if significant portions of the car were made from non-metallic materials. Interviewees from the car manufacturing sector felt that some incineration and energy from waste would be always be necessary for ELV, and that energy from waste in particular should be classified under ELV as “re-use”. Since many bio-based composite materials are not recyclable, it is assumed that they will be incinerated.

5.10 Conclusion.

This chapter has reviewed the End of Life Vehicle legislation 2000 (53C) initially tracing its history and development at the European level then examining implementation of the Directive in the UK, and its effects on the automotive sector in order to answer the research questions:

RQ1: How has European automotive legislation affected the development of more sustainable innovation in the automotive sector?

and

RQ3: Are there legislative barriers to the use of bio-based materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

The analysis showed that the ELV legislation has been key to increasing the safe disposal of cars at their end of life, both in the UK and other EU states, and that the work to eliminate substances of high concern such as mercury has stimulated innovation particularly in metal processing. Protecting this recent investment however reinforces the primacy of metal as a car material, particularly at the luxury end of the market, where most innovation is thought to occur. The established recycling route for metals and recyclate value means that this material choice remains the norm *within the regime.* Other new materials such as bio-based plastics or composites, with limited routes for disposal at end of life, or lack of secondary markets are thus disadvantaged since they cannot meet the ELV legislative requirement to be recyclable. The established and valued knowledge within the regime also blocks their integration.

The analysis suggests that the legislation developed gradually, in part due to increased public awareness of environmental issues, but also gained political regime relevance, as the failure of voluntary schemes to address the problem began to distort the European market, conflicting with a key EU goal. However the variability in implementation across Europe and the "missing" ELVs in many states, including the UK, suggests that efficient recovery of all material resources in cars is not being addressed.

The analysis suggests that the established regime of the car and the developing bio-based materials one are not well-matched, for example in terms of valued knowledge. From a legislative viewpoint however there is a specific barrier in that the EU ELV legislation prioritises recycling, but most bio-based materials in cars are currently not recyclable but instead incinerated. Whilst bio-based materials can be freely integrated into cars, particularly in the US, which lacks ELV legislation, in the EU there appears to be a legislative block to their use.

This legislation sets much of the background and context towards development of the Circular Economy package, which is addressed in the next case study. The Circular Economy package includes amendments to a variety of waste legislation, including ELV but also the disposal of household waste, which could potentially serve as a feedstock for bio-based materials.

6 The Circular Economy Package

6.1 Introduction

This chapter examines the adopted Circular Economy (CE) plan (EC, 2015a) to examine the implications of its adoption for the increased uptake of biomaterials in the automotive sector. The chapter therefore particularly addresses the third and fourth research questions:

RQ3: Are there legislative barriers to the use of bio-based materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

RQ4. How could EU legislation be modified to support sustainable technologies in this sector?

As discussed in chapter two, a possible key advantage of bio-based materials is that they are renewable, with a theoretically unlimited supply, as compared to more traditional, recyclable automotive materials such as steel (Cooper and Allwood, 2012). The CE plan (EC, 2015a) includes the proposed amendment of existing directives and could provide a direction of travel that offers the potential to act as a stimulant for innovation if it provides incentives for manufacturers to use renewable materials. Hence the plan is examined here to determine whether it has the mechanisms to provide incentives or obstacles for the increased use of biomaterials, particularly in the automotive sector.

Study of the CE plan is pertinent as it addresses both the production of materials and their disposal (EC, 2015a). The car industry is a major consumer of raw materials (Cabrera Serrenho and Allwood, 2016) and car waste is a significant waste stream (EC, 2014b). Moreover, since many European member states, such as the UK may lack many raw materials, increased material efficiency, including use of recycled and bio-based materials, offers an innovative opportunity to root production in Europe, creating “smart, sustainable and inclusive growth” (EC, 2010). In terms of bio-based materials this chapter addresses their supply.

Study of the CE plan (EC 2015a) is also relevant as it amends a suite of waste legislation, most specifically, the End of Life Vehicle Directive (ELV 2000/53/EC) discussed in the last chapter. Analysis of the package therefore permits intra-case comparison against previous legislation together with examination of how existing European legislation is amended and may be developed. Research into a currently developing package also provides access to a contemporaneous range of data sources, adding methodological depth and validity since contemporary interviews/reports may illuminate current perceptions and interests more acutely than *post-hoc* reports. In comparison to previously discussed legislation, interviewees gained the opportunity to articulate their expectations, which SNM theorists regard as a significant aspect of transitions management (Markard *et al.*, 2012; Weber *et al.*, 1999).

However as a package, rather than a specific piece of legislation, the focus and structure of analysis in this chapter is slightly different. Following definition and discussion of the academic roots of the concept as discussed in the literature review, the chapter uses the landscape, regime and niche as an analytical tool to structure the analysis (*inter alia* Geels, 2014; Kern, 2012; Markard *et al*., 2012). The history of the development of the package is described with analysis of its impact on bio-based materials development. The chapter then considers the national level and the approach of the UK, then the sector level of the automotive and bio-based materials sector.

6.2 Circular Economy: background and definitions.

The Circular Economy (CE) concept proposes that when resources or products reach the end of their useful life, rather than becoming waste and thus disposed of, these resources might then act as the raw materials for new production (Ellen McArthur Foundation 2013a; EC 2014a; Velis 2015). The term was first used in the work of industrial ecologists (Pearce and Kerry-Turner, 1990; Ehrenfeld, 1997) who aimed to account for the external costs of development and address the use of the environment as “a sink” for waste.

As such, they reflected an approach that was dissatisfied with traditional economics and sought to include environmental costs within market prices so that resources might be preserved for future generations. Industrial ecologists drew on earlier work (Boulding, 1966) that saw the earth as a closed system with limited resources, and sought to move away from a “cowboy” economy towards a more sustainable society which preserved resources through extended product life, reuse and recycling activities (Stahel, 1982).

Industrial ecologists (Pearce and Turner, 1990; Ehrenfeld, 1997), therefore challenged the way in which traditional economics adopted a linear model in which waste was generated at each stage of the production process: as raw materials were extracted, used and disposed as shown below in Figure 6.1.

Figure 6.1. Linear economy model. (ISWA, 2015).

This linear pattern can be clearly seen in the automotive sector where for example, waste is generated at each stage of the production process: as raw materials for metal are extracted, manufactured and used together with the final disposal of cars. The accumulation of these wasted resources is a significant economic and environmental cost.

In contrast, as shown in Figure 6.2, the CE approach prioritises the preservation of material resources and energy, suggesting that it is desirable to maximise recycling efforts in order to reduce waste and environmental impacts (Anderson, 2007). Material stocks are reused and reintroduced within the cycle extending material life and increasing material efficiency. Designing products to minimise their impact from the earliest life-cycle stages (Braungart and

McDonough, 2002), also reduces environmental and human health impacts. In addition to recycling activities, products should be designed so they can be upcycled, used for other purposes, or returned to the soil rather than just reducing, reusing and recovering resources. CE approaches also suggest minimising resource use and using cleaner technologies. By minimising the amount of waste generated and reducing the need for virgin raw materials, a CE approach can therefore produce both environmental and economic benefits (Anderson, 2007).

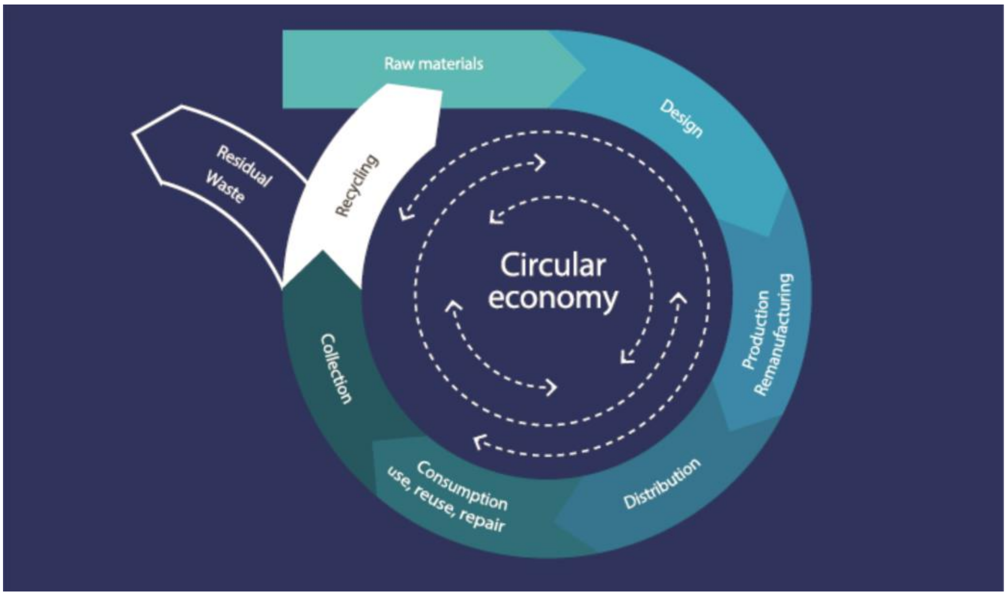

Figure 6.2. Circular Economy model (Ellen MacArthur Foundation, 2013a).

But if the environmental rationale and benefit are clear, the economic case is less well developed. The linear economy is driven by the market value of the sold product, with the wasted resource having little cost or value attached, and the sold product prioritised. Resource savings could potentially reduce costs for businesses but virgin materials will always seem more attractive if environmental impacts are not included. In this sense, the market fails to take account of all costs. If the full costs, including the environmental impact, of disposal or waste cannot be internalised into the market price, policy initiatives can provide an important driver for behaviour change. Moreover, since each part of the economy, not just the sold product, is important a wider range of stakeholders should be involved in policy-making. A variety of stakeholders will therefore require policy initiatives at multiple points along the value chain to sustain impetus and replace the market driver (Ghisellini, *et al*., 2016).

However, there are limited examples of successful implementation of a CE approach. These examples may be split between China and Europe; those systems imposed from above by legislation (China) and those which have developed gradually (see Lieder and Rashid, 2016 for a review) with the literature dominated by case studies examining Chinese industries and eco-industrial park development (*inter alia*, Li and Ma, 2015; Geng *et al.*, 2009; Yong, 2007). Many of the Chinese examples adopt an industrial symbiosis approach in which firms and industries, often in close proximity, collaborate in a systemic, planned approach through a "closed loop" to use each other's waste resources (Chertow, 2000).

China's reliance on commodity imports and the environmental impacts of rapid industrial development meant that the CE ideal was particularly attractive, offering a way to 'leap-frog' past the environmental costs of development (Gong and Doberstein, 2008). A head-lined Circular Economy law (People's Republic of China (P.R.C), 2008) actually focuses more on the reduction, reuse and recycling of resoures rather than on more CE activities such as eco-design and might be considered a waste law. Significant results have been achieved but from an admittedly low base and suggest that implementation of the CE in China relies heavily on the legislative driver (Mathews and Tan, 2011) together with the structure of a centralised, command and control, planned economy. The success of claimed for results must also be treated with some caution since the accuracy and reliability of statistics produced by the Chinese state are open to some question (Koch-Weser, 2013).

Successful non-Chinese examples of CE have tended to be limited to small-scale, local products, for example within the automotive sector, the production of plastic bumpers from scrap production (Nissan, 2015). Inspiration for "closed loop" production has been drawn from the example of Kalundborg in Denmark (Ehrenfeld and Gertler, 1997) where several partners including a power station, oil company, local council and pharmaceutical plant gradually developed mutually beneficial agreements to use each others' waste energy, heat and products. A circular economy therefore gradually evolved through close proximity and social links and was "discovered" by academics. Initially the importance of their geographical proximity and local, social links was emphasised, (Chertow, 2000) but more recently, greater attention has been paid to their commercial viability (Branson, 2016). Nevertheless, there is a sense that "we should keep that loop as closed and small as possible" to avoid transaction costs such as transportation and data collection. Similarly, in the absence of profit or legislative drivers, CE models only work when "led by the boss." (Williams and Schaefer, 2012). The lack of data on successful CE implementation is also a barrier to increased involvement by private industry (Ellen MacArthur Foundation, 2013a).

The limited scale and paucity of examples of successful CE implementation suggests that there may actually be limited economic drivers to a CE. This lack of cases also means that there are particular challenges in designing legislation or policy to shape a whole economy to operate on a more CE basis. The small-scale nature of many cases also implies that the EU, or any supranational body, is not the best venue for fostering CE activities. Moreover the international scale of waste management and material resource consumption, particularly for energy, may mean that creating a closed policy and resource loop is simply impractical (Haas *et al.*, 2015).

Not all materials are equal however. In the CE approach, materials are divided into two categories, technical and biological (EC, 2014b). "Technical" materials such as metals, alloys or hydrocarbon-derived such as plastics are not biodegradable, they are based on limited resources, remain within the system and can be recycled (ibid.). "Biological" materials such as wood, crops, and algae are potentially renewable and unlimited resources (ibid). But as not all bio-based products are bio-degradeable, this division may be too simplistic. Material recovery may also involve significant energy inputs and environmental impacts which might be greater than those in non-circular designs.

In summary therefore, the CE concept has relevance to the automotive and bio-based materials sector in a number of ways. First since it suggests that products should be made with an awareness of their material inputs and highlights the importance of eco-design to consider the complete lifecycle of a product. Second, since it promotes the use of recycled materials and addresses how waste from existing products can be utilised as feedstocks, CE promotes design for disassembly. Several important implications for the car industry follow. First, car manufacturers have to take responsibility for thinking through the entire life cycle of their product. Relatedly, the dismantling of cars must be considered by producers at the earliest stage of the car's lifecycle. Since several metals currently used in cars are in short supply, and must be recycled, their efficient usage to maintain affordability at a time of rising demand is important. Bio-based materials are increasingly used in cars and are a renewable, available European feedstock, guaranteeing domestic security of supply. Third, the CE approach suggests a radical re-evaluation of the importance of a variety of stakeholders throughout the value chain.

Having established the academic background, the next section considers development of the CE package at the European Union level.

6.3 Development of the EU CE Package

This section traces the development of the EU CE package. Initially discussed in 2012, (EC, 2012), the first package was presented in 2014 (EC 2014a), withdrawn in December 2014, and a revised package presented in 2015 (EC 2015a). The package includes a range of measures to improve waste handling, including a financial investment, legislative proposals, and data collection improvements to improve implementation. However the package amendments demonstrate that the legislative regime is contested.

The first CE package (EC, 2014a), proposed by Environment Commissioner Janez Potocnik in July 2014, focussed on improving and unifying a number of existing waste directives, such as the ELV. An ambitious timetable was set out to 2030 and included banning recyclable waste being sent to landfill by 2025 and increasing municipal waste recycling to 70%. The 2014 memo explicitly recognised the wide disparity in sustainable waste management between EU member states, with landfill rates approaching 0% (in the Netherlands, Denmark or Belgium) implying significant recycling activities, but more than 70% of waste still going to landfill in states such as Greece, Slovakia or Cyprus.

The package came in for considerable opposition however. For example, BusinessEurope, the national business organisations representative, called for withdrawal of the July 2014 package, particularly opposing the target of 30% resource efficiency on materials (Business Europe, 2014). The Commission withdrew the package in February 2015 despite opposition to such a move from the European Parliament. Commission Vice President, Frans Timmermans, promised a “more ambitious” programme, justifying withdrawal on the grounds that the package needed a wider scope to encompass not just waste, but also end users, for example from manufacturing and retail (Velis 2015). Timmermans later justified the revision because (2 Dec 2015) “I prefer realistic ambitious steps forward to just pie in the sky.” (Crisp, 2015).

The second package (EC, 2015a) included generally less ambitious targets with the deadlines extended. Key legislative amendments on waste included: a reduced target for recycling 65% of municipal waste by 2030; a binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2030; a simplified and improved definitions and harmonised calculation methods for recycling rates throughout the EU; and Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g. for packaging, batteries, electric and electronic equipment, vehicles).

The content of the CE package appears to have been influenced more by the business discourse surrounding circular economy approaches, rather than the academic ones. More specifically, the CE proposal appears to have been shaped by the influential Ellen Macarthur foundation report (Ellen McArthur Foundation 2013a), which identified a range of CE advantages including reduced volatility in material prices, and reduced political risks generated by resource scarcity and price rises. The 2014 proposal echoes these claims and also highlights savings for businesses, explicitly referring to the CE’s multiple benefits in terms of employment, economic growth, reductions in greenhouse gases and reduced dependency on imported raw materials (EC 2014a).

6.4 Changes between the 2014 and 2015 packages

To illustrate the scale and nature of the changes between the 2014 and 2015 EU CE packages, a comparison of the two packages and their likely effects on bio-based materials for industry, particularly the automotive sector, is shown in Table 6.1.

Table 6-1. Comparison of EC2014 and 2015 CE packages with respect to bio-based materials. Typology refers to relative importance of this activity on the adoption of bio-based materials, especially supply, with ***** most impact * least impact

Typology	**Waste source**	**2014**	**2015**	**Comments**
*****	Household waste recycling target	70%	65% with exemptions for many E. European states for 5 years	Fallen by 5%. Not "closing the loop" so poor for high value biomaterials The exemptions mean the delay is exacerbated. Aimed at household not industrial (or car) waste
**	Packaging waste	80% to be recycled	75% to be recycled by 2030	Weaker- suggests more incineration as disposal route – poor incentive
***	Food waste	Reduce by 30% 2017-2025	No target given. Replaced with non-binding aspirational UN target	Weaker – but difficult to measure this potential reduction as small scale, no clear data methodology
*****	Separate collection of bio-waste	Ensure separate collection by 2025	Ensure separate by 2025 " if technically, economically and environmentally feasible" "Member states shall, as appropriate".	Positive for bio to have separate collection. But weaker than original and leaves to member states producing potential distortions. If waste stream is contaminated then products can't be used, meaning no "free" (from waste) supply of bio
*****	Resource efficiency	30% target	No target	No data methodology.
**	Landfill of municipal waste	Limited to 25% of total by 2025	Limited to 10% of total by 2030	Higher target on municipal and household waste – less pressure on industry to adopt bio-materials
**	Landfill	2030 - Total ban on recyclable & compostable HH waste to landfill	Maximum limit of 10% of all waste to be landfilled in 2030 (binding restriction) but that can include recyclable and compostable waste.	Move to target of 10% on **all** landfill waste i.e not material specific. This is a more ambitious target but again aimed at local authorities rather than business. Limits potential supply of bio-based material

A policy that discourages the use of other materials such as metals or those that are easily recyclable or closes recycling routes is seen as an incentive for bio-based materials and is given 5 stars; a policy that fails to incentivise adoption of biobased materials, particularly their supply is given less stars. The analysis shows that there is little incentive in the CE package for adoption of bio-based materials. Moreover, depending upon the mechanism used for implementation there may even be some perverse incentives that will hamper the adoption of bio-based materials. Primarily bio-based material is addressed in terms of its disposal, or use as a fuel, not as a material. Bio-based materials are also addressed in terms of research but not their application. Whilst bio-based materials lack recognisable recycling routes, it is easier to incinerate them. Currently the CE package does not provide any economic incentive to move away from the cheapest form of disposal, which is usually incineration. This oversight is counterproductive on a number of grounds.

First, since bio-based materials often include a high water content their incineration is relatively inefficient and yields little energy compared to other materials. Second since manufacturers have not been extensively involved in development of the package there is little demand-pull through of new materials. Third since food waste is not collected separately, a potentially cheap, sustained supply of "free" bio-based waste is unavailable. The contamination of other recyclates increases the cost of any recyclate processing. As food waste is not collected separately, virgin development of non-food crops for industry is cheaper and easier than recycling, undermining a core sustainability advantage of bio-based materials, their non-competition with food crops which undermines the "waste" side of the CE and means that virgin materials are easier to use. Fifth, if bio-based material is incinerated there is no reliable supply of material.

6.5 The European level: landscape and regime pressures.

This section interprets the development of the CE package in terms of the Multi-level Perspective (MLP) (Kern, 2012; Geels, 2014). As discussed in the literature review, if we use the MLP's theoretical framework and define (i) the landscape as being the "exogenous socio-technical landscape" (Geels, 2014 p23) i.e. factors beyond the control of actors and (ii) the regime as "the locus of established practices and associated rules that enable and constrain incumbent actors in relation to existing systems", (*ibid*, p 23) and if we assume that a regime includes existing legislation and institutions, we might conceptualise the EU policy context as the regime and the wider international background as the Landscape. Figure 6.4 is designed to facilitate understanding and presents events in terms of the landscape, regime and niche concepts (Geels, 2002; Geels, 2014).

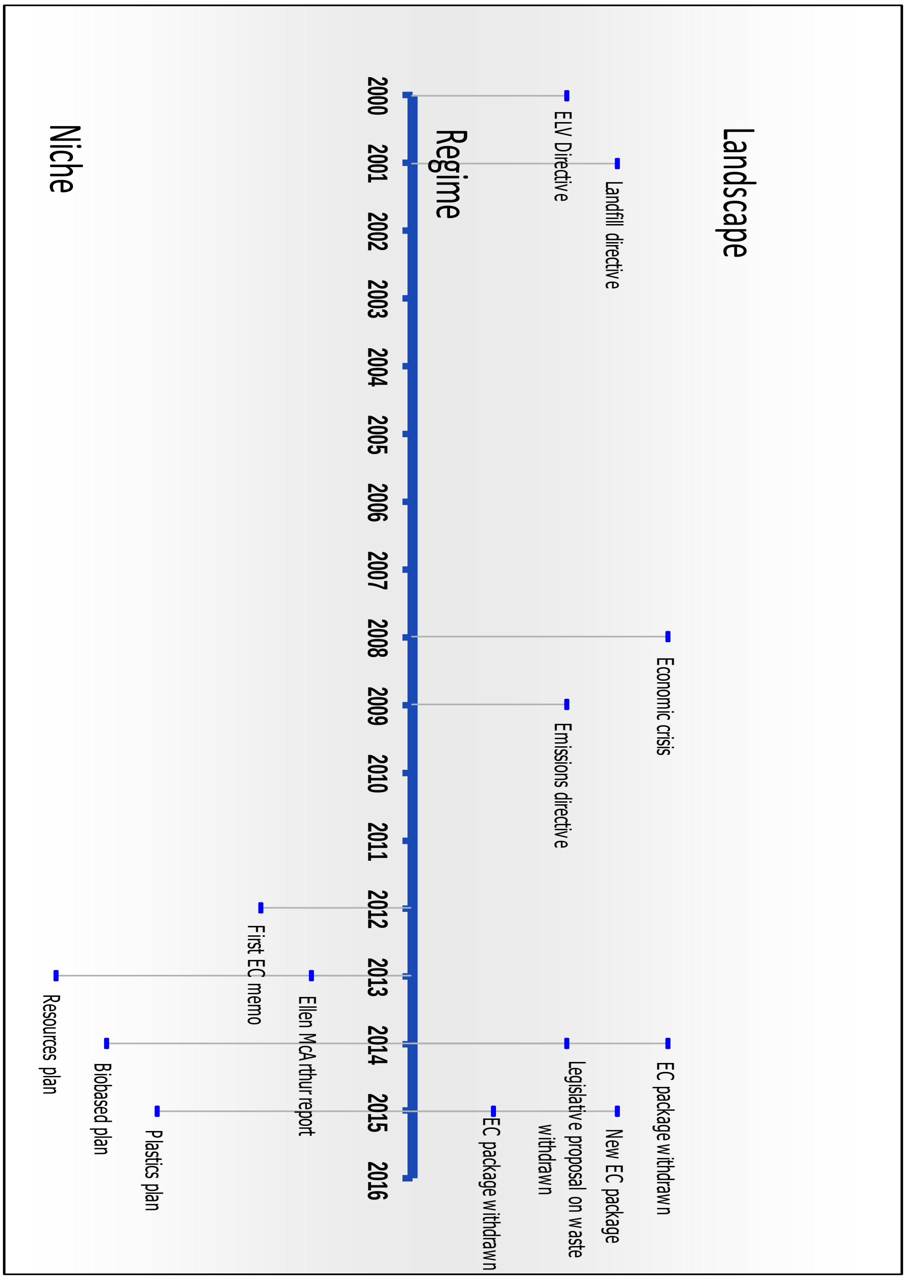

Figure 6.3. CE development in terms of landscape, regime and niche. Authors own. .

Landscape factors therefore included the 2008/9 economic crisis, which produced rising unemployment and declining GDP figures. There was a discourse at the international level, which added to the growing sense that the time was ripe for the development and implementation of CE (UNFCC, 2010). The UN Rio Earth summit might be considered to have added additional international pressure.

At this time there were also growing fears over a shortage of critical resources, volatility in material prices and the threat these posed to economic development (EC, 2008; Defra 2012). The lack of many raw materials in Europe lead to the development of a critical list of materials, the EU14, (EC, 2011; EC, 2014d), that are commonly sourced from states such as China, Russia and Africa, which are considered either politically unstable or potentially serious economic rivals (EC, 2014d). Table 6.2 below shows the EU14 list together with their usual source and use in cars.

Table 6-2 EU Critical materials list and use in cars (Zheng et al., 2014; Cullbrand and Magnusson, 2011; UNEP, 2009).

	Material	**2010**	**2013**	**Source**	**Sub**	**EofL**	**Use in car sector**	**Imp**
1	Antimony			China	0.62	0.11	Limited-lead alloy, flame retardants, brakes, PET	*
2	Beryllium			USA	0.85	0.19	Extensive in alloys with copper and in alloys with aluminium	*
	Borates		Y	Turkey	0.88	0	Mineral - used in furnaces, incinerators, mouldings, batteries	
	Chromium		Y	South Africa	0.96	13	Metal - anti-corrosion use, used in paints, catalysts, brake liners	***
3	Cobalt			Russia	0.71	16	Metal - used in lithium ion batteries	***
	Coking coal		Y	USA	0.68	0	Fuel for ore smelting	***
4	Fluorspar			Mexico	0.8	0	Mineral (Flux) used in metal smelting , ceramics and glass	
5	Gallium			USA/China	0.6	0	Metal for alloys/electronics/semi-conductors	*
6	Germanium			China	0.86	0	Metal - semi-conductors/ glass / batteries	*
7	Indium			China	0.82	0	semi-conductors//solders//catalytic converters	***
	Magnesite		Y	China/Turkey	0.72	0	Mineral - used in furnaces, incinerators / alloys	**
8	Magnesium			China	0.64	14	Aluminium alloys, lightweight - trad aerospace, increasing auto	****
9	Natural Graphite			China	0.72	0	Electronics, metal processing, brakes / composites	**
10	Niobium			Brazil	0.69	11	For high strength low alloy steel in cars	**
11	Phospate rock			US/China	0.98	0	Fertiliser production / paints / batteries	
12	PGMs			South Africa	0.83	35	Precious metals - high value - used in catalytic converters	***
13	REEs heavy			China/Russia	0.77	0	Rare earth elements - alloys, batteries e.g. catalytic converters	***
14	REES light			China/Russia	0.67	0	Rare earth elements - alloys, batteries	**
	Silicon metal		Y	China	0.81	0	Steel/aluminium and semiconductors	***
	Tantalum		N		0.81	0	Minor component in alloys, corrosion-resistant, capacitors	*
	Tungsten			China/Russia	0.7	0.37	Alloys/strength/turbo chargers	***

Several nations, including the USA (US Department of Energy, 2010) and Germany, (B.M.U.B, 2012) developed resource plans that seek to address the geopolitical risks of critical shortages of raw materials such as metals and rare earth materials. The emphasis on recycling/waste handling vs resource strategies hazards depends upon a state's capabilities and outlook (US, 2010). Thus EU documents tend to focus on recycling, resource efficiency and trade agreements whilst China for example, as a producer of many materials, emphasises protecting resources through production quotas and reductions in illegal trade (US, 2010). To date, the UK has not developed a resources strategy, but instead focused more on recycling (Defra, 2012).

Variability in commodity prices has been an important underlying influence to the circular economy debate (Haas *et al*., 2015*).* Production of many plastics and polymers from virgin oil are largely determined by oil prices, which can vary widely, e.g the average annual oil price for Opec crude stood at $94.1 in 2008; averaged $60 in 2009; peaked at $109.45 in 2012 but dropped again to $40.68 in 2016 (Statista, 2016). Defining whether this is a landscape or regime factor is challenging however as its longevity is questionable. Prices for plastics recyclates reflect some of this variability and were rising steadily until 2008 and the economic crisis, since when they have fallen sharply (Velis and Vrancken, 2015). An EC MEP noted that the price falls had also effected expectations at the European Parliament and Commission level and weakened the case for involvement: as it produces uncertainty with regard to long-term investment strategies:

> *There was a strong argument in favour of supporting the circular economy and investment in it. And some of those arguments are [now] much weaker, albeit perhaps only on a temporary basis, but some of the rug has been taken out from under that business argument.*

Yet the price differences also emphasise that waste is truly a global trade, with China the leading importer of plastics world-wide, accounting for 87% of EU27 plastic weight exports by weight in 2012 (Velis, 2014). The large-scale export of EU waste means that the infrastructure and incentives to deal with this waste or alternatively process this material resource in the EU are dependent on a market which seeks the cheapest processing point world-wide. Improvements in inspections of plastic waste by the Chinese to reject poor quality or contaminated product further demonstrated the fragility of a global recycling system. (2016).

The EU policy context in 2014/15 was also different from that which surrounded the formation of the ELV in 2000 and the Emissions directive in 2009 (Ekins *et al.,* 2014). First, the effects of the Lisbon Treaty 2009, which came into effect for the first time following the European Parliament elections in May 2014 held that a European Commission President should be selected on the basis of the elections. Jean-Claude Juncker, the European People's Party candidate, which had taken the largest share of the vote was elected, succeeding Jose Manuel Barroso. Juncker took office in late 2014, emphasising the better regulation agenda, particularly the REFIT programme (EC, 2015b) which sought to re-evaluate legislation in order to reduce costs, cut "red tape" and make the EU more effective (Radaelli, 2007). This on-going programme of re-evaluation found strong national support from states such as the UK (Gravey, 2016).

The package presented certain administrative issues for the EC. An EC Civil servant (DG Climate) suggested that the cross-cutting nature of the CE involves many more stakeholders (including other EC departments) than usual:

> *This is a difficulty but its also a strength.(21*)

meaning that wider political consultation and negotiation was required for the package to pass. He noted that

> *Now in the Commission, there is a repeated working assumption that we "need to break the silos" ... ensuring that these departments can talk to each other… the effect will be more tangible. (21)*

Smith (2010) suggests that the focus on growth after Lisbon 2009 and the onset of the economic crisis meant a greater drive for jobs and thus more regulatory accommodation with businesses.

Some interviewees suggested that because of the lack of new policy initiatives in Europe, there is a tendency for more interest groups to attach themselves to any new package to shift the narrative towards their interests and develop new alliances. (9, 13) The lack of new regulation might in part be due to economic austerity but might also be the natural product of retrenchment following the initiation of many new pieces of legislation earlier, meaning that most of the Commission work was now centred around amendments, improvements and consolidation (Lodge and Wegrich, 2012).

Critics of the revised proposal, saw the revision as "a wasted year" (Friends of the Earth, 2015) since the withdrawal of the package left those states that wished to move forward without direction, and provided justification for delay to those who disapproved. They also noted the lower ambition of the second package, most notably the reduction of the municipal waste target from 70% to 65%. One interviewee (13) suggested that the Commission had "*talked a good talk*".

An EC Civil servant however suggested that initial expectations had been raised so highly by the first package that subsequently Parliament and environmental NGOs were

> *quite sceptical before… I think they were quite hesitant to say the least!" (21).*

However as the proposal developed it began to be viewed more positively:

> *so its gaining in momentum and understanding as well. (June 2016) (21).*

The CE therefore was presented as one of a range of options for helping Europe to pursue resource efficiency and sustainable economic growth, perhaps presenting traditional environmental concerns in a more business friendly way. In many respects it was a potential panacea that addressed both economic and environmental issues, offering "a path out of the current crisis towards a reindustrialisation of the European economy*"* (EC, 2012).

Several interviewees suggested that the UK's voice was somewhat weakened at the European level by the Conservative party decision to break away from other centre right parties (9,13,21).

Under European parliamentary rules to form a grouping there must be an alliance with MEPs from seven EU member states. Parting company in 2009 from the European Peoples Party (EPP), who take a federalist view of Europe, meant that the UK often lacked the 'heads-up" (13) on issues, or the ability to develop effective coalitions to secure beneficial negotiations. Moreover, the withdrawal had

> *a knock-on effect outside Parliament because Cameron doesn't go to EPP summits.. so he misses out on the opportunity to network and lobby ahead of the European Council summit meeting (13)*

By losing these informal knowledge and networking possibilities, two key processes in the MLP framework, the UK had lost influence and strategic input into developing packages, including the ability to represent their own national interests. An interviewee also suggested that some UK Conservative MEPS were somewhat sceptical of the EU and took a limited role in committee work or representation (9, 10).

The car sector appeared to take comparatively little interest in the CE package. An EC Civil servant noted that whilst the package was deliberately not sectoral:

> *"We have lots of active stakeholders from other sectors… in fact everyone BUT car manufacturers" (21).*

it was noticeable that the automotive sector had not actively lobbied their department but suggested:

> *The automotive sector has not been active in this respect, I don't know, probably they have different problems these days, maybe more existential, more short term related problems (June 2016). (21)*

which was a reference to the VW scandal dominating automotive lobbying activity. ACEA publicly argued that any increase in recycling targets would have “no environmental benefit” and took the view that enforcement of existing legislation, such as ELV 2000, “already had the potential to improve circularity” (ACEA, 2015b), thus shifting the burden away from the automotive industry towards governance.

6.6 Criticisms of the CE package

The CE packages have drawn criticism on a number of grounds, particularly issues around data integrity, comparison and collection

First, data to understand the processes and effect the development of the EU CE package are limited and often lack comparability. Data information on a shared basis for effective planning is particularly important for the CE, due to the lack of market pricing signals and was recognised as a particular barrier to implementation in China (Geng and Doberstein, 2008). At the national level for example Municipal Solid waste (MSW) is defined in different ways, with some states including Automotive Shredder Residue (ASR). Data comparability between MS was recognised as a key issue. Without comparability it is difficult to assess the compliance of member states or determine the effectiveness of policy measures. An EC interviewee also pointed out that data was also important to develop the business case for investment in infrastructure. Moreover if this data was not collected on an EU wide basis, national variations in waste handling would be exacerbated.

But collecting data is difficult, time-consuming and expensive. Most waste data reported into the EU concern local authority municipal waste, predominantly that collected from households which represents only approx. 7% by weight of all waste collected. A modelling exercise using selected different national waste definitions applied to waste streams illustrated variations of up to 15% on declared national recycling rates (Greenfield and Woodard, 2016). Business waste in comparison is much more homogenous, but there are very limited data on the amount and structure of this part of the waste sector (Ekins, 2015), particularly in the UK (Greenfield and

Woodard, 2016). It may be necessary to gather this data however to establish a market across the EU, a key goal, particularly since many industrial sectors, such as cars, may move materials frequently over national barriers as part of their extended supply chain. Lack of data also inhibits goals; for example, one of the reasons offered for not setting a target for food waste prevention was the difficulty of measurement. The legislative burden also falls on states rather than industrial actors, which illustrates the difficulty of taking a sectoral/industrial approach (Greenfield and Woodard, 2016).

Collecting data from firms is particularly difficult due to the commercial sensitivity of this data. For example, knowledge of waste amounts and flows may provide commercial advantages to competitors which is difficult to overcome unless there are established bonds of trust as at Kalundborg (Ehrenfeld and Gertler,1997). Moreover, the lack of data explaining the benefits to existing businesses and economic advantage means that the language of the CE may not be resonating with the business audience. Unless meaningful data on business waste are captured and presented in monetary terms, it is difficult to make the case to business for change. Business behaviour however may be much easier to change rather than that of private households. First, because there are fewer businesses than households, so it is more efficient to target the limited number, second because businesses are more rapidly attuned to market signals. Changing individual consumer behaviour may be much more challenging (Walker and Shove, 2007).

Second, the focus of the package is upon MSW and packaging, rather than industrial waste, which puts the focus on post-consumer waste and collection, predominantly the responsibility of local authorities and governments rather than the industrial generation of waste: a true CE approach needs to emphasise both. Some interviewees commented that post-consumer waste collection was both inefficient and challenging. Moreover, by focussing on MSW and the end of the production process, rather than on eco-design and the early product development, producer responsibility for the end environmental impact of their products was not encouraged.

Third, the 2015 CE package provides limited economic or legislative incentives to move away from the cheapest form of disposal, which is usually incineration. The proposal does suggest that energy recovery should be limited to non-recyclable materials. Environmentally effective incineration is technologically dependent however and thus undermines the development of alternate uses for recyclates, including bio-based materials, as there is no security of supply. A recent EC memo on incineration warned of the danger of "stranded assets", i.e. capital investment in incineration facilities, and sought to deter investment in these activities (EC, 2017). This could be interpreted as a disincentive to further investment in these facilities, hinting at a recognition of the danger of commitment to this disposal route and technological "lock-in" (Unruh, 2000).

Fourth, the package suggests that materials can be broken into just two groups – technical and biological (EC, 2014b) but there are numerous mixtures of the two groups, which do not readily fit into either, such as composites. In addition not all bio-based materials are bio-degradable. A more material- specific target for recycling, rather than an overall rate, such as in Japan with a specific recycling rate of 70% for ASR (Sakai *et al.*, 2014) might drive the separation of waste and more realistic recycling activities.

Given the wide variability in waste handling between different European member states, targeting recycling efforts and restructuring to the poorest performing states might have been considered the quickest, most efficient way of improving European waste handling in general (Bartl, 2015). But the proposals contain no discussion of how to enforce existing targets or improve the patchwork of implementation (García Quesada, 2014) apart from guidance on better reporting.

The CE challenges conventional governance because it advocates a cross-cutting economic approach. Using a package permits the EU to develop a range of proposals rather than concentrating on legislation alone. The criticism received and adjustments required may reflect the challenges faced by trying to use a top down bureaucratic supranational body to deliver policy rather than allowing things to develop from grass roots (Lieder and Rashid, 2016). They also reflect the need however to include as wide a range of stakeholders as possible. As noted above many of the successful developments of CE in Europe have emanated from small-scale bottom up projects. However to retain a common market across Europe, whose size is particularly attractive to larger firms seeking to exploit economies of scale, there is a need for coherence across departments within the Commission and at the national level to ensure consistency of goals.

Summary

This section has traced the development of the CE at the European level, noting differences between the 2014 and 2015 packages. It has also identified some the problems with CE and presented the development of the CE in terms of the MLP.

6.7 The national level – The UK's approach to a Circular Economy.

This section considers the UK's approach to the CE to understand how national historical background and implementation might affect the adoption of bio-based materials in industry. The UK waste management and resources regime are analysed because of their relevance to bio-based materials in the car industry at both the beginning and end of the life-cycle of the car. As the UK lacks a national resources strategy, the focus is the UK waste and recycling infrastructure.

Since the 1980s the UK has lacked an industrial or manufacturing strategy, instead pursuing a market-based economy specialising in high-value manufacturing and finance. The waste management regime therefore primarily relies on market-mechanisms, with significant change only produced due to European legislation (EP, 1999). The resulting UK Landfill Act (2001) and Landfill Tax are regarded as the major reason for the UK's move away from dependency on landfill disposal to more environmentally aware disposal methods such as recycling and incineration (Seely, 2009; Morris *et al.*, 1998). Investment in UK recycling and incineration facilities has lagged behind other European states but more recently the opportunities presented by energy from waste mean that this waste option is increasingly realised either in the UK or overseas. From a low recycling base therefore, the UK has improved waste handling significantly to now sit almost exactly at the average of European states in terms of landfill disposal, incineration and recycling (Cossu and Lai, 2015; Cossu, 2009).

The UK waste management regime/policy is based on local authorities being responsible for municipal solid waste (MSW) generated by households. A significant portion of MSW is food waste, which generates GHG if landfilled. To develop this waste as a resource and mitigate the GHG generated by landfill however requires separate collection from households. However waste collection in the UK is organised at a local authority level with no consistency of recycling procedures, complicating collection and increasing costs (Gille, 2010). A nationally based system would mean that a consistent universal waste policy could be adopted. Each local authority organises collection and disposal in a waste market dominated by five large non-UK multinational firms, including Sita, Veolia and Suez (Wilson and Pearce, 2015). These international firms appear to be re-positioning themselves as suppliers of raw materials, rather than waste disposal firms only and as such as advocates of the EC CE (Suez, 2014; Hislop and Hill, 2011). Their approach therefore appears more inclined to a European perspective than many UK-based, but much smaller, firms take on recycling and reuse, seeing waste as a resource with value (Suez, 2014).

Whilst the EU is encouraging member states to develop more ambitious recycling targets, the UK government appeared "*sceptical on targets*" and "*lacks the appetite*" for legislation (23). Some disquiet was expressed by the waste and recycling industry on the UK CE stance, including representatives of the large waste firms, as without government targets and long-term forward planning, there was no business case for investment in facilities to utilise waste as a resource and feedstock.

As discussed earlier, the UK lacks a strategy on critical materials, its absence drawing particular criticism over its approach to rare earth metals (Science and Technology Committee, House of Commons 2011). Moreover, a range of departments are involved in resource programming including Defra and the now defunct DECC amongst others (EEA, 2016a). However, it is not clear which Westminster department is ultimately responsible for security of supply of raw materials, Defra or BEIS, which hampers recycling industry attempts to effectively lobby for change (MVDA, 2014). Recent civil service cutbacks exacerbated the situation, with a view that

that UK government lacks personnel with a deep understanding of manufacturing and product development (19, 23). The Green Alliance has suggested that failing to address resource security in comparison to other regions or economies, such as the USA, the UK is failing to support its own manufacturing industry (Green Alliance, 2015).

The Scottish and Welsh devolved administrations have specific resource policies which are currently lacking in England and Northern Ireland, although both have a Waste Prevention Programme (HM Government 2013b, 2016). The Scottish Resource Plan is designed in part to address the decline of the oil industry, but suggests a degree of proactive initiative lacking currently in Westminster (Scottish Government 2016). Scotland and Wales recycling rate has increased significantly since 2010, (Scotland 32.5% to 42% and Wales 44% to 56%) whilst Englands (41.2% to 43.9%) has barely changed (Date, 2016) due in part to changes in food waste collection.

The UK waste and resource regime has shaped the UK bio-based sector in a number of ways. In the absence of legislation, and the primacy of market-development, the UK bio-based sector is focussed on developing the potentially large market for energy from waste and the mass chemicals market. This focus prioritised a robust and cheap supply of material, maximising volume and ensuring security of supply and quality in order to reduce costs. The manufacturing sector in comparison was perceived as smaller and more challenging, requiring greater technical skills. New markets, such as for food packaging and personal products, value bio-degradability given growing concerns over the long-term environmental impact of a wide range of petroleum-based plastic at End-of-Life e.g. impact on the marine environment through ingestion and transfer of toxic chemicals up the food chain (Cole *et al*., 2011). But since, as discussed above, UK household food waste is not collected separately, a potentially large, cheap, sustained supply of “free” bio-based and biodegradeable waste is not available. Virgin development of non-food crops for industry is therefore easier and cheaper, undermining a core sustainability advantage of bio-based materials- their non-competition with food crops. Lack of volume increases costs and introduces uncertainty, making the business case for capital investment in processing facilities more difficult.

Separate household food waste collection would also remove the contamination of other recyclates, again reducing processing costs and improving quality.

Currently this biological waste contaminates other collected recyclates and adds water to waste. The UK Bio-based industry therefore favours separate household food waste collection on a national not local basis, an objective aligning with the 5 big waste firms, and the Chemical and Energy markets who also benefit from the separation of biodegradable and other recyclable materials. The removal of large amounts of biological waste would improve the quality of other recyclates, increasing prices and reducing costs. A secure supply of bio-based material from waste would create a market that was untainted by food for crops issues. Removing water would mean other waste burned more efficiently in energy for waste incinerators. The UK bio-based industry association therefore emphasises the interdependency of bio-based and biodegradability (BBIA, 2016). Emphasis on household food waste collection meant that the waste sector in particular was perceived as a natural ally for the bio-based industries and meant both sectors shared a proactive view towards legislation.

UK Bio-based industry sources expressed frustration at the lack of UK government interest in their sector’s potential. To attract the Treasury, attempts were made to tie into the Northern Powerhouse dialogue by presenting the industry as a potential employer. The Treasury, (16, 17) was perceived as pro-active at a time of austerity in comparison to other departments. Interviewees also suggested that industrial actors felt that they had been tainted by association with the previous Labour government (16, 17) and were perceived unfavourably as “environmentalists”. Bio-based industry sources also shared disquiet with the waste sector that the UK position in European negotiations on CE did not reflect that of all stakeholders (Resource Association, 2016).

Forming a trade industry association is a recognised route to access EU research funding and influence policy at the European level (Anastasidas, 2014; Grossman and Woll, 2007). Several UK–based organisations have formed, such as the Resource Association and the Bio-based Industries Consortium to unite and promote the industry at a European level. The formation of a trade organisation was important in order to represent the industry at the European level, access funds and to tie into other countries' networks and skills. This may also reflect the fact that many recycling firms are smaller in size and may be more influenced, particularly on environmental issues, by regulators than large firms (Hillary, 2004). Given the perceived lack of UK government representation of their interests, including a reluctance to legislate, both the UK waste and bio-based industries looked to Europe for policy signals through the CE initiative. Bio-based industry interviewees felt that legislation was:

> *totally fundamental. We're at a competitive disadvantage firstly because of scale and then because of introducing something new. If you haven't got the scale it becomes a niche market and niche markets are too expensive and you need the scale to get the price down. (22).*

The UK government was considered inactive in representing bio-based industries at the EU level (16, 19, 25) but representatives suggested that as other EU states such as Italy, Germany and Sweden were strongly in favour of the agenda, *"it really doesn't matter if the UK government is there or not"(25).* In transition terms this might be expressed as the niche looking directly to the supranational regime for guidance, rather than the national.

Several interviewees suggested that the UK government attitude to the car industry was somewhat different, with one interviewee explaining:

> *Theres a very strong focus on those traditional industries that have done very well in the UK, such as aerospace and cars, that have stayed strong and successful so there is a whole focus on making sure that they stay strong and that takes up most of the bandwidth (10).*

There was a general view that the UK government values car makers for their significant contribution to manufacturing and the balance of payments, and is therefore "in thrall" to them (10). This means that there is limited appetite to "interfere" with the industry or encourage it to behave in a more sustainable way, for example by utilising home-grown bio-based waste. On ELV and disposal of cars, as discussed in chapter 5, the UK allows the market value of the metal recyclate to drive the market. The metal content assumption used in calculating ELV recycling requirements reduces the administrative burden on car firms meaning that an increasing proportion of non-metallic waste in ASR can be ignored. This light-touch approach means that the UK government is not encouraging the UK car industry to adopt a CE approach including developing more effective recycling of their own products.

Summary

The UK appears to lack a coherent joined-up strategy to transform from a waste-disposal focused approach to a more CE resources based approach including bio-based materials. This gap is evident geographically with differences between England and the devolved administrations in Scotland and Wales, with no clear ownership or responsibility for the issue at the administrative level in Westminster. Rather it appears to be private actors such as the Ellen Macarthur foundation and the waste industry, which is largely European based, that are shaping the agenda. This disjointed approach has two implications. First that UK bio-based actors are focused on maximising supply to satisfy other markets apart from high value manufacturing. Second because of the lack of UK government strategy these actors have developed strategies for representation at the European level, particularly through a trade association and by aligning with the European waste and chemical industries rather than manufacturing or farming sectors. Since there are no market drivers or state-sponsored initiatives to either foster a guaranteed supply of “clean” bio-based materials or to sponsor resource-aware strategies for handling bio-based materials at End-of-Life, there appear to be limited incentives for development of environmentally sensitive bio-based manufacturing in the UK.

6.8 The sector level – Applicability to the automotive industry.

This section considers how the automotive industry has previously addressed concepts within the CE package to determine the likelihood of a CE approach being adopted voluntarily, at a bottom up level, along the automotive value chain. The crucial role of this sector in materials demand was specifically acknowledged by the Ellen Macarthur foundation (Ellen MacArthur 2013b). A distinction is drawn in each section between activities undertaken by the Original Equipment Manufacturers (OEMs) and other stakeholders in the automotive value chain.

The European car industry currently operates in a very linear fashion as described in section 6.2. At each point of the international supply chain, suppliers compete to offer materials at the lowest possible price to the car industry. The international nature of this trade and the competitive economic environment means that the landscape pressures as discussed in section 6.5 exert long-standing and on-going pressures.

Fears over a critical shortage of resources and commodity price volatility are particularly relevant to the car industry. For example, cobalt, is used in the development of lithium-ion batteries for electric cars (Vayrynen and Salminen, 2012). Magnesium is necessary for casting steel alloys, niobium for the production of steel alloys and magnets and platinum group metals (PGMs) are used in catalytic converters (Tharumarajah, and Koltun, 2007). Rare earth materials are also increasingly used in automotive batteries and hybrid cars, but their extraction causes significant environmental damage (Koltun and Tharumarajah, 2014). Trends towards electrification, (using batteries to move the car rather than the traditional combustion engine and to move windows for example rather than motors or hydraulics) also increases demand for metals meaning that long-term prices are expected to rise, potentially threatening European prosperity. Material alternatives to metal are therefore increasingly important.

6.8.1 End of life of Vehicles

There are limited but significant amendments to the ELV legislation proposed by the CE package, primarily concerning reporting standards required of member states. This article proposes that data reported by member states on ELVs should include a quality check report and in addition be independently verified. Analysis suggests that there are wide variations between member states in their definition of ELVs and the veracity of their reporting procedures and reports. For example, the definition of reuse is believed to be used to cover the illegal export of ELVs to other member states. The illegal export of ELVs, which are claimed as exported for reuse is a loophole that has not been addressed (Bartl, 2015). By ensuring that member states use common definitions this part of the CE is an important step in improving data quality to ensure effective implementation.

The emphasis on reporting by member states however means that producer responsibility by car manufacturers for their products at end of life is limited and responsibility diffused through the value chain of recyclers and waste firms. This pattern of OEM non-responsibility is repeated at other potential material-loop points such as recycling. In a related point, when discussing landfill of certain materials, there is no proposal to ban Automotive Shredder Residue (ASR) from landfill. By failing to address this gap there is no legislative signalling of long-term expectations to encourage stakeholders throughout the automotive value chain to consider how non-metallic End-of-Life material in cars might be repurposed or to invest in processing facilities.

Addressing these data gaps is particularly significant for operation of a CE package. As discussed in section 6.1, a CE approach suggests that materials should move within loops in the economy, to preserve their value and minimise wastage. The problem of illegal export of ELVs as previously discussed means many cars and these resources end their lives overseas. This means a loop can’t exist but also means producers are not tied into the disposal issue. This emphasises how the European legislative system is only as strong as the weakest national link.

6.8.2 Reducing Material Resource Needs

Apart from the economic cost, there are currently very limited incentives to manufacturers to reduce the amount of material used within a car. Indeed, as discussed in chapter 4 on emissions, vehicle mass has increased on average 30% over the last thirty years, with specific models such as the VW Golf increasing mass by 67% (Danilecki *et al.* 2017). This increase demonstrates that technological improvements have been prioritised over material usage, causing vehicles to become heavier with a more varied material composition. This material heterogeneity is significant for the CE because the more compositionally complex the product, the more challenging it is to disassemble and then repurpose the materials (Crang *et al*., 2013).

Traditionally, car manufacturing has been located close to the largest markets to reduce transport costs and allow local market adaptations. By locating production within established markets, car firms have been able to draw upon the "power of economic nationalism" as discussed in Section 2.5.2 (Sturgeon and van Biesebroeck, 2009), accessing more favourable trading conditions for example, subsidies, tax advantages and training opportunities. But as the growing car markets are expected to be in Asia not Europe and as most of the raw materials come from the same geographical areas there will be increased pressure to locate factories in these locations. Should production move to these nations they may understand the need for resource-awareness much more (Fuchs *et al*., 2011).

6.8.3 Reuse and re-manufacturing

Re-use is defined as products "used again for the same purpose for which they were conceived." (EC, 1999) i.e. re-using a part again without need for any re-working. Remanufacturing in comparison is" a standardised industrial process by which cores are returned to same-as-new, or better, condition and performance. The process is in line with specific technical specifications, including engineering, quality and testing standards. The process yields fully warranted products*"* (CLEPA, 2016). Both activities are seen as key principles within a CE economy, potentially producing more employment, particularly within SMEs (Rizos *et al*., 2015), extending product life, reducing material usage and cost savings for consumers. However there is currently limited evidence for either activity in Europe. For instance, the UK does not collect or input any reuse figures to Eurostat. This does not mean that reuse activities do not take place but rather that the UK's mode of data reporting based on the metal content assumption, discussed in Chapter 5, does not require businesses to record these data. Other EU countries, such as France, report significant amounts of reuse. Therefore it is difficult to assess the potential extent and importance of these two activities.

Significant reuse of car parts is dependent on a number of factors, including the car manufacturers permitting parts to be clearly labelled, parts being easily dismantled from old vehicles, and replaceable without effecting either warranty or functionality on the new car and also partly on consumer willingness. Increasingly complex cars also make potential repairs utilising reused parts more challenging. Whilst in the US has introduced legislation (e.g. Massachusetts Right to Repair law) to oblige OEMs to provide appropriate technical information, such a development has yet to emerge in Europe. Moreover, whilst life-cycle analysis of reuse in the clothing and furniture reuse markets shows quantifiable environmental and costs savings (Castellani *et al.,* 2015) there is very limited research in the public domain on reuse in the automotive sector. The potential significant cost savings are thought to be outweighed by the unreliability of supply, product conformity and disassembly problems (Schraven *et al.,* 2012).

In contrast remanufacturing of engines, i.e. restoring them to their original condition is offered by several European car manufacturers. However the Choisy-le-Roi remanufacturing facility, part of Renault, was the only example of automotive re-manufacturing offered by the Ellen MacArthur Foundation in 2013 (Ellen MacArthur, 2013). Here, approximately 25,000 engines were remanufactured in 2013 (Renault, 2016). Car firm motivations for undertaking this activity however were not clear. ELV legislation does not appear to be a motivator for this behaviour, at least in German and UK-based factories (Seitz, 2007). Instead OEMs might choose to re-manufacture to maintain warranties, brand values and customer satisfaction, particularly where older parts might be in short supply, rather than being motivated by resource, sustainability reasons or profit (Seitz, 2007). Similarly re-manufacturing was used by Brazilian OEMs to protect their brand but interestingly some 30% of their profits also came from this activity (Saavedra, 2013). Brazil lacks any ELV legislation but re-manufacturing is encouraged through a trade organisation focussed on this activity. Customer loyalty and profitability were also cited as reasons for undertaking this activity at Renault (Renault, 2016). Diesel engine remanufacturing is explicitly encouraged in China, on the grounds of cost, energy and materials savings but remains an extremely small part of the total car market (Zhang and Chen, 2015).

These cases suggest that remanufacturing can be undertaken by OEMs voluntarily under the right market conditions without the requirement for legislation. However these activities appear to require a combination of economic drivers, data information and consumer demand. Offering credits to OEMs for re-manufacturing activity however might act as a potential incentive.

The sustainability of remanufacturing however may be problematic on two grounds. First, changes in emission standards may mean that the original condition is no longer sufficient and the remanufactured part may actually need to be upgraded. This means that there is an important inconsistency between emissions legislation (EP, 2009), and the CE (EC, 2015a). Second, an LCA comparison of a remanufactured engine and a new one shows that despite CO_2 savings in the material and manufacturing stages, the greater impact of the use phase (as discussed in chapter 2 – Figure 2.1) meant that overall emissions were much higher in the remanufactured part (Zhang and Chen, 2015). This contradiction means that extending product life through the CE may not always be the most desirable option on environmental grounds.

6.8.4 Recycling

As discussed in chapter *5*, the automotive sector is considered a front-runner at recycling since it successfully meets the 85% recycling target set by the ELV recycling target (SMMT, 2016). This compares favourably to other industrial sectors, for example, aerospace. However this is primarily achieved through the use of recycled metal, which due to its high density and magnetic property makes it easy to separate from other materials and doesn’t fully reflect the proportion (volume) of car material recycled. Moreover as discussed in Chapter 5 this activity is outsourced to a wide variety of secondary actors, such as breakers yards and scrap merchants, rather than the car manufacturers themselves. Once recovered and processed, recycled metal is then available to the OEMs through the open market, outsourcing producer responsibility but ensuring that the car industry is supplied at the lowest possible cost.

A key issue with non-metallic recycling is the dismantling and separation of materials. Since the car industry sources materials at one international standard regardless of production location due to economies of scale, acceptance of recyclates is compromised (2, 5). Despiesse *et al.,* (2015) compares UK and Japanese treatment of ELV and suggests that the UK might adopt a more CE approach by encouraging more dismantling rather than shredding since used car parts often have higher value. However whilst manual dismantling produces better quality recyclate, this activity has been estimated at a net cost per ELV of 12 Euros due to wage costs and recyclate values (Coates and Rahimifard (2007). As a result of this higher cost, the majority of the non-metallic material at End-of-Life is currently shredded into Automotive Shredder Residue (ASR) and incinerated or landfilled.

Manufacturers are reluctant to disclose exact material compounds due to commercial sensitivity. This lack of transparency limits the potential for recycling of materials for the CE and the economic incentive to develop innovative recycling technology (de Man and Friege, 2016). Further development of recycling technology is also hampered since much recyclate is currently incinerated for energy from waste. The CE package provides a limited legislative block to energy recovery, by proposing that incineration should be limited to non-recyclable materials, "whenever possible" (Article 12), making the commitment to recycling technologically dependent but also dependent on member states capabilities.

It might also be environmentally preferable to contain most waste within a European Circular Economy to reduce transportation costs and ensure treatment at the best environmental standards. Some UK waste for example is exported to energy-from-waste plants in Europe such as the Netherlands and Germany where there is spare capacity and air pollution control, rather than going to UK landfill (Velis (2015). Waste however is an international market with most waste exported outside the EU to exploit lower wages, poorer environmental standards and take advantage of "different regimes of value" (Crang *et al.,* 2013). There is nothing intrinsically superior however around European waste handling rather than its management outside the EU (Crang *et al.,* 2013). The reality of this international market fundamentally compromises the idea of a closed loop for materials within Europe as envisaged by the EU CE.

There is some limited evidence of car manufacturers reusing recycled product in a closed loop design i.e. where the OEMs directly source materials from recyclers at End-of-Life unless the material is particularly valuable or easy to dismantle. Nissan (2015) report the recycling and re-use of bumpers but were hampered by the difficulty of paint removal, since methods to remove paint, such as acid compromised the ability to respray the new bumper to an acceptable finish (2). Frosch and Gallopoulous (1989) working within General Motors USA advocated an industrial eco-system approach, or "closed-loop" recycling method for platinum in catalytic converters due to the metal's high value.

6.8.5 Introducing a new material

As discussed in Chapter 4, the car industry finds introducing new materials into a car challenging for many reasons, including (i) the complex supply chain which is focused on reducing cost, and (ii) the lack of UK-based Tier 1 firms and legislative standards. Industry sources advised that small firms lacked the technical knowledge to provide required detailed information (2, 3). Smaller firms however shared some consensus around the difficulties of working with car firms in particular the emphasis on cost and the problems of information sharing and scale.

Summary

There is limited evidence of the car industries' involvement in material reduction, reuse, remanufacturing or recycling, which suggests a lack of impetus to initiate CE activity voluntarily unless there is a clear economic, technological or regulatory reason.

6.9 Biomaterials in the automotive sector

6.9.1 Effects of the Legislation on Bio-based Materials

As discussed in section 6.4 many of the reduced targets and longer time scales in the CE package act as a disincentive to the establishment of a secure supply chain of biomaterials from household waste. Since the car industry prioritises a secure supply chain at the lowest possible cost, there therefore appears to be a fundamental mismatch at the landscape level, which the regime as represented by the EU CE package, is not yet addressing.

6.9.2 Bio-based materials and their supply

Given previous discussion on the use of bio-based materials in chapter 4 and their end of life in chapter 5, this section primarily addresses the sourcing of bio-based materials.

Bio-based materials may originate from a number of sources and include wood, sugar, the waste bagasse material produced as a by-product from biofuels, agricultural waste, virgin crop development and municipal household waste. Whilst the US has prioritised alternative crops for US famers and their use in US cars through the "Made in America" programme (Brugeman and Cregger, 2016), increased use of European virgin crops for bio-based materials is limited by the CAP. For example, the sugar production quota is not expected to be lifted until 2017. To avoid conflict between growing crops for food and non-food crops, the BiOC was focussed on bio-based waste, particularly from households.

Given the potentially much larger market for the chemicals and packaging industries, Bio-based industry sources were focussed on developing a large and cheap UK-based supply chain (16, 17, 25). Since the emphasis was on bio-degradeability, attention was focussed on developing "clean" collection of materials i.e without contamination from other recyclates. Car manufacturing was regarded as a smaller, more technically demanding, market requiring extensive value-chain development and skill investment beyond the scope of bio-based industries. However in the absence of legislation, either UK or European, or recognisable recycling routes, most bio-based waste is currently sent to landfill or incinerated. As the 2015 CE package fails to provide significant legislative or economic incentives to move away from the cheapest form of disposal, this seems likely to continue.

De Besi and McCormick (2015) analysed a number of bio-based strategies and noted a common theme for biomass optimisation is the cascade principle (Sirkin and Houten, 1994; Keegan *et al.*, 2013) i.e. using materials for the highest added value first before use as an energy source and using waste and agricultural residue as feedstocks. However there appear to be few European incentives for bio-based production in comparison to bio-based fuels or waste incineration (Carus *et al.*, 2014). The lack of pull-through of higher value products, such as from the automotive sector, thus constrained investment in all bio-based material processing.

Yet this view contrasts, for example, with the USA and its "Made in America" manufacturing campaign for bio-based materials and its explicit tying together of the two sectors (Brugeman and Cregger, 2016). In the absence of legislative, or government incentive, cost is the paramount factor for UK manufacturers meaning that bio-based materials are sourced from the cheapest available location, often the US (17, 22).

Although many bio-based products are not biodegradeable, as discussed in section 6.1, the perceived conflation between bio-based and bio-degradability in the public mind, a wider landscape effect, and emphasised by the bio-based industry association meant that negative consumer reaction was feared by car makers. However, the lack of industry advertising of this factor, as outlined in chapter 4, suggests that car makers are not exercising any role in shaping this.

However both car and bio-based industry sources suggested that increasing use of car leasing agreements might provide a greater incentive to car companies to undertake CE activities.

> *The new model of leasing cars… theres an element of selfishness from the car industry, because if they end up retaining the ownership of some elements of the cars, the electronics, the software, the more valuable parts of the car, and that could push the CE a bit more, you'll then have more car manufacturers involved (23).*

If customers return more often to have their car "upgraded" this offers more "windows of opportunity" for car companies to introduce more innovative materials. The increased value, but need for regular updating, of electronic components would oblige drivers to return regularly for upgrades but mean the car company essentially owned the car materials. This would create a "closed loop" of use that would ensure a clean supply of materials for reuse or recycling, demonstrating the cascade principle in action.

6.10 Conclusion

This chapter has analysed the EC Circular Economy package using a transitions perspective to gather data to answer Research questions 3 and 4

RQ3: Are there legislative barriers to the use of bio-based materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

RQ4. How could EU legislation be modified to support sustainable technologies in this sector?

The chapter first considered the academic roots of the concept, traced the development of the package at the EC level and how the package might impact the bio-based sector in particular. Consideration then turned to the UK approach and then how the automotive sector has voluntarily addressed CE issues.

The analysis suggests that the current CE package offers limited support to the development of bio-based materials, particularly in the car market. Of particular concern were the lack of provisions for producer responsibility, issues around enforcement of waste legislation, data collection problems and the reduced ambition of waste and landfill targets.

The UK bio-based sector saw legislation as key to market development, by increasing the value of "waste" materials that might act as feedstocks and to improve security of supply. Expectations in the UK bio-based sector were firmly centred on EC action for market development. Higher waste standards and enforcement action would increase the cost of waste disposal and make "waste" efficiency more important, making bio-based feedstocks more attractive. These expectations contrasted with UK government and automotive industry perceptions, which were focused on the continued prosperity of existing sectors, a general suspicion of regulation at either the UK or European level and a preference for market-based tools.

The CE challenges the structure of governance because of its cross-cutting economic nature. Rather than focussing on individual industrial sectors with specific targets, the CE attempts a re-evaluation of materials across sectors throughout Europe. This widening of focus means that identification of individual targets at the sector level is lacking. Moreover as individual sectors tend to be influenced by different European Commission DGs and often exercise particular influence in different DGs (e.g. the car industry is considered more influential inn DG Grow rather than DG Environment), there is a need for coherence across European Commission departments to ensure consistency and coherence.

The next chapter pulls together the findings from all three empirical chapters in order to address the research questions in detail.

7 Discussion

This chapter draws on the previous empirical chapters to summarise and provide a succinct, systematic cross-comparison of the empirical and theoretical findings. Following a recap of the thesis aims and research questions that emerged from the literature review, empirical insights and themes are presented. The discussion then considers theoretical insights from the research including a discussion of the main strengths and weaknesses of the theoretical concepts. The research questions are then addressed synthesising the findings from the empirical and theoretical cross-comparison. The chapter concludes with a summary of the thesis contribution, limitations of the research and future research avenues.

7.1 Recap of thesis aims and research questions

This thesis seeks to make an original theoretical and empirical contribution to the sustainability transitions literature. The literature review highlighted a number of broad knowledge gaps in the literature, in particular a lack of empirical data for theory-building and study at the sector level (Markard *et al*., 2012). A lack of consideration for political processes was also noted, in particular a failure to take account both of the formation and implementation of legislation and how this then shapes the innovation process (Lawhon and Murphy, 2012; Smith and Raven, 2012; Loorbach and Rotmans, 2010). Therefore a number of research questions were developed to explore this research gap, using concepts from transitions theory, particularly the "regime" (Geels, 2014; Kern, 2012) to examine how EU legislation has effected the introduction of a new material into the automotive sector.

Three environmental policy measures were chosen to reflect the life-cycle environmental impact of the car which have been recognised as significant by initial industry interviewees and the academic literature. Using documentary analysis, original interview data and industry literature to examine the formation, implementation and impact of these legislative directives and packages using bio-based materials in the UK as an exemplar, allowed fine-grained study of recent developments in sustainable innovation in the automotive sector.

7.2 Cross-comparison of main empirical findings.

A cross-comparison of the findings across the three case studies was implemented to identify similarities and differences in the form, implementation and impact of the policy measures. A particular advantage of this comparative case study approach was that it allowed for study of the impact of the policy measures throughout the life-cycle of the car. The next section summarises the key empirical findings seen in table 7.1 into themes.

Table 7-1. Comparison of case studies

	ELV	**Emissions**	**CE**
Date	2000	2009	2014
Instrument	Directive	Legislation	Package
LCA impact (2010)	5-10% end of life	70% -use	15-20% - sourcing
Problem perceived	Environmental/wast e	Environmental	Resources
Emerging issues	ASR waste More electronic waste	Heavier cars – rising CO_2;	Recylclate prices
Economic context	Rising GDP	Buoyant/crisis	Austerity
Pre-implementation	Long-run up. Voluntary schemes. Challenged EC market	Long run up. Voluntary scheme.	Long run up
Intended innovation focus	At design and recycling stages	Engine technology	Eco-design Material sourcing
European Implementation	On-going heavy metals removal	Delay of fines for non-meeting goals	n/a
UK Implementation	Diffused responsibility at govt level. Reliance on market tools. MCA calculations	Independence of testing and WVTA stations. Diesel tax.	n/a
Car industry expectations	Initially resisted – responsibility diffused to recyclers – now seek enforcement	Technology solutions focused on engine, increasing weight	Limited interest – seeking enforcement of ELV.
Material effect	Heavier, recyclable materials i.e metals	Metal and rare earth materials	Bio-based materials
Effect on bio-based materials	Negative – no clear recycling routes	Positive -as lighter	No cascade effect
Legislative inconsistencies	Total % recycled rather than material specific	Higher standards blocking reuse (CE)	Re-use definition (EM)

7.2.1. Changing nature of the problem

Unsurprisingly the differing time-frames in which the policies developed (2000, 2009 and 2014) presented contrasting political and economic contextual factors, enabling or hampering the choice of legislative instrument. In 2000, a time of comparative economic prosperity, the issue of car waste was considered an important environmental issue which required EU-wide action; in 2009, CO_2 emissions and global warming were important and policymakers drew impetus from this wider political concern.

Yet despite the declared intention of promoting sustainable innovation and curbing the environmental impacts of car use, sourcing and disposal, some two decades after these concerns were first addressed, CO_2 levels from cars are still rising and there has been comparatively little disruption of the automotive regime. Moreover sustainability is a diffuse imprecise goal, which is bound to keep changing with further knowledge, meaning that there is a continuing need to revisit and update the legislation, taking into account new knowledge, forms of evaluation and the effectiveness of previous measures.

Although not the original intention of the study, the cases consider contrasting EU policy instruments to address automotive sustainability. The cases reflect a broader movement away from government to governance instruments *(*Wurzel *et al.,* 2013) over this period with institutions drawing on a wider policy mix of instruments to affect change. During this time both the EU and UK have also attempted to reduce the number of policy instruments through the re-fit programme and "one-in, one-out" programme so that " regulation is now viewed as a last resort, rather than the default" (B.I.S, 2014, p4). The analysis suggests that UK legislators in particular think that they lack the mandate to use regulation as a policy tool. Yet from a transitions viewpoint, this means legislators are unable to act as a disruptor of the existing automotive regime.

The issues which the policies were designed to address have changed over the studied time period, reflecting wider changes in public concern, which is classified as a landscape effect. For ELV, initially there was a very specific issue to address, of unsightly and dangerous disposal of ELVs. The problem has changed however to include increasing amounts of electronic waste, including very small amounts of rare materials, and mixed materials including different blends and types of plastics. These materials are often more difficult to disassemble and lack established recylate routes. The development of these materials complicates the application of the legislation as it is unclear if they should come under the WEEE Directive or if their weight should be considered part of the ELV. The impact of poor ELV handling though has until recently been exported to China, and without this there is increased urgency to address this issue within the EU..

The CO_2 emissions problem has also changed. Whilst successful in reducing CO_2 per km, the rising number of cars on the road, distances travelled and increasing car weights mean that more CO_2 in total is being produced. However, increasing concern over air quality, partly from non-engine generated particulates, including from tyres and road surfaces, which are in part caused by heavier cars, are increasing in relevance.

7.2.3 Role of industry in policy development

Both the ELV and Emissions legislation had a relatively long developmental trajectory during which the Commission signposted to industry its intention to take action. Voluntary schemes in both cases were used by industry to address the problem, but were insufficient, in part because they did not produce sufficient change but also because their unevenness disrupted the common market, a key regime goal for the EU. Policymakers meanwhile noted the difficulties of getting policies agreed and particularly the role of information in shaping the policy, with the lobbying process whilst information in the media shaped the wider regulatory context.

Once implemented however, in both cases the car industry's view of the policies appeared very positive with the policies credited with driving significant change. There were also calls for tighter enforcement which may be because these higher standards raise costs and limit market entry by new players, such as Tesla or Google. It was noticeable however that UK legislators tended to ascribe change to market instruments such as higher fuel tax rates and the recession incentivising drivers to consider more efficient cars. Whilst both car makers and legislators mentioned the technology possibilities for market growth including autonomous cars and the growth of EVs, car makers appeared to look to legislation to provide certainty for the future and as a landscape factor, whilst legislators appeared more conscious of long-term trends, including climate change and increasing congestion. These differing kinds of expectations from regime actors echoes with analysis on the German car sector which saw car makers focused on laws, the regime, whilst the German government looked to the wider socio-technical landscape (Budde *et al*., 2012).

Meanwhile the newest policy measure, the Circular Economy package appeared to be receiving limited car industry attention. There may be a number of reasons for this such as that the car industry does not consider this so important, or that diesel-gate and the related recognition that CO_2 levels were also incorrect (Oroschakoff, 2015) was instead absorbing car industry lobbying efforts.

Yet this differing political context may offer a "window of opportunity" (Geels *et al.,* 2016; Geels and Schot, 2007) for bio-based materials since the long-standing but unofficial rules of how the industry works are challenged (Wells *et al.,* 2012) Practically, a more stringent testing regime might incentivise manufacturers to re-double their efforts to innovate to meet the testing standards, particularly if a more independent testing regime could be arranged. Moreover, the reputational damage that some firms may have suffered might incentivise innovation efforts to distract attention at the landscape level.

7.2.4. Issues around implementation and knowledge

A number of implementation issues were noted across the cases, at both the EU and national UK level, particularly the collection of accurate data.

Significant pressure could be applied to car manufacturers by the EU, particularly at the point of sale, because of the opportunity to sell into the internal single market which offers manufacturers considerable economies of scale and a degree of legislative certainty over a large geographical area. Yet member states differing interpretations, methods of data collection and differences in definitions, such as in the Metal Content Assumption by the UK for reporting on ELV means that implementation is uneven but also opaque. More EU-level effective co-ordination of implementation such as independent testing however conflicts with a key EU principle of subsidiarity. However if analysis is focused on the car sector, rather than individual car firms, it can be argued that individual member states are simply not effective against the sector as a whole. Since member states such as the UK often use market instruments to effect policy, this can create uneven incentives to car firms in different countries.

In the UK, for both the ELV and Emissions, the issue of deciding which department had responsibility for specific aspects of the policy, complicated and blunted policy effectiveness. For example, information for ELV was collected by Defra and the Office for Product Safety and Standards; the EA inspected landfill sites and DVLA considered the status of the car. Documents on car components are only required to kept for at least 4 years, which is shorter than the average car life, meaning that it is difficult to see how the proper disposal of cars could be tied back to the car manufacturer, who is supposed to be ultimately responsible. The variety of departments involved, to which responsibilities had been added in incremental steps, meant that it was difficult to gather data or to establish which department had responsibility for oversight. This diffusion of powers meant that government could not act in a co-ordinated manner, and only issues with individual car firms might be identified rather than problems with the car sector as a whole. For CO_2 emissions, despite the inaccuracies in declared CO_2 levels, and these form the basis of the UK car tax regime, there has been no action taken against any car manufacturer. This inaction suggests that national actors are limited in their ability to effectively control or nudge car industry behaviour.

Therefore whilst the EU aims to promote sustainable innovation on a European wide scale, this is sometimes distorted by individual member states use of price-based incentives. For example, in the UK, the use of reduced levels of tax for diesel cars encouraged diesel sales. Car manufacturers such as JLR thus were incentivised to keep producing diesel cars and invest in these technologies, so that diesel accounted for 70% of JLR car sales in 2016 (Rendell, 2016).

This incentive at a landscape level has therefore diverted research which might have been more effectively invested in sustainable material development.

At the supply chain level, the car manufacturers or OEMs occupy the apex of information in the supply chain, particularly in terms of materials information submitted to the IMDB, the materials database. Only the OEMs can see all the data, but this means that both dismantlers and other parties who might be interested in developing secondary markets for recyclate from cars cannot access accurate information. In IDIS, the car dismantling database, where manufacturers are supposed to submit information to aid potential dismantlers of cars, which might facilitate re-use or higher levels of recycling, information is not subject to any check.

7.2.4 Inconsistencies in the legislation and impacts on material choice and innovation

There are a number of inconsistencies between the policies, which although unintentional, may act as a barrier to the uptake of biomaterials in this sector and distort incentives to sustainable innovation. Table 7.2 summarises the effects of each policy on materials, together with the effect on bio-based materials in particular and possible policy options.

ELV with its total recycling target for car materials, measured in weight, has encouraged material-awareness in car makers, but the emphasis on a total recycling rate for the car has meant that it is easier to meet the recycling target by using metal. Yet as metal is more expensive than other materials, this has incentivised incremental process improvements in metal handling, such as the removal of lead. As metal tends to be used by the more profitable car companies, this means that innovation is encouraged on an existing pathway, rather than being pushed to consider alternative light-weight materials. A material specific recycling rate, for ASR, rather than the metal portion which can be relatively easily recycled might encourage more investment in recycling infrastructure and research. A possible recycling deposit paid on first purchase and then transferred with each sale might encourage wider public awareness of materials and by giving a value to the ELV, prompt higher recycling rates. Improvements to the V5 registration document or use of electronic databases might enable better tracking of the car at end of life.

Table 7-2. Policy instruments and their effects on bio-based materails in cars with potentially corrective policy measures

	ELV	Emissions	CE
Material effect	- Promoted heavier materials especially metal (measured on weight) - Use of recycled material limited (no consistency of supply or material quality)	- Promoted technological solutions focused on engine size to meet wider landscape appeal of larger more powerful cars	- No clear incentive for separate bio-based collection, limiting guaranteed supply - Total recycling rate rather than material specific one
Inconsistencies	_ Promotes recycling and some incineration to avoid landfill but incineration conflicts with CE	Non-recyclable light-weight materials deterred	- Re-use discouraged by improved emissions standards
Effect on bio-based materials	- High recycling target for cars means bio-based has limited capacity to be used	Neutral/positive= indirectly incentivises light-weighting	- Broadly positive – increasing resource awareness - Limited targets so limited incentive - Long time frames
Possible policy options	- Material specific recycling rate (rather than total weight) - Waste recycling deposit scheme for buyers – increasing consumer awareness - V5 document to specifically record end of life route (to avoid export/illegal reuse)	- Independent testing rather than paid for by car manufacturers. - Use of weight modelling tool to monitor - More focus on alternative modes of fuel-saving e.g enforcing reduced speed limits; more measures to address traffic congestion - Tying vehicle weight at point of sale to end of life to promote accuracy	- More recognition of mixed materials in use and recognition that no clear recycling route exists, - exemptions from recycling targets for new potentially more sustainable materials - Funding to address technological barriers to high value use, enabling “cascade” effect

For emissions, the car sector had tended to build on its strengths and develop ttechnological solutions to improve engine and power train efficiency. The legislations impact was dulled by widespread manipulation of emissions testing and the lack of enforcement of fines for non-compliance. The development of alternative light-weight materials was deterred however by ELV, which meant that recyclability was a prerequisite, blocking off some bio-based materials which are not recyclable.

The Circular Economy package seeks to encourage re-use but re-working an engine to the original standard to extend the product life, thus improving the life-cycle impact of the car, is thwarted by the emissions standards if the re-worked engine does not meet the improved emissions standards.

The analysis suggests that a more holistic integration of policies may be necessary, taking a complete LCA of the car into account so that a policy which is focused only on one point of the LCA, such as its ELV, does not inadvertently and detrimentally conflict with another.

7.3 Cross-comparison of main theoretical findings.

The different case studies permitted a number of theoretical findings to be drawn, meaning that these findings can be drawn with more confidence than from a single case study alone. A multi-case study approach provides the opportunity to carry out a cross-comparison of the utility of the MLP approach in evaluating policies designed to promote sustainability goals. A pair-wise comparison between the three case studies provides a mechanism to explore in detail the theoretical limitations of the MLP approach and evaluate the significance and role of policy measures.

The overall key finding of the thesis is the importance of the policies in shaping how the automotive sector has innovated and changed since their introduction. Their impact is not least since car firms seem to shape their expectations around the legislative regime, meaning that policymakers may be more influential than they realise. Some of the previous MLP literature has assessed policy changes on an individual case by case basis, but not appreciated the holistic, cumulative connectivity between the policies upon a sector over the longer-term (Stokes and

Steven, 2013). The thesis provides new insights into the temporal impact of polices over a variety of time-frames and how policies may evolve on a path-dependent trajectory.

The structure of the legislation suggests a narrowly technological view of innovation, reflecting the expert opinion on which the EC draws but re-confirming the dominance of the present car industry. Widening the knowledge and stakeholder base on which the Commission draws might also mean that alternative modes of achieving the same goal are considered, addressing stationary traffic generating fumes, encouraging lower speed limits or encouraging other forms of transport such as walking and cycling.

The cross-comparative case study approach to cover the whole life-cycle of the car was important because it illustrated that the discrete nature of policies as implemented on a sector in individual packages, fail to take account of the implications and impact over the whole life cycle of the car. For example, reducing the in use impact of the car i.e by promoting lower CO_2 emissions and greater fuel efficiency, which appears by some firms to have been achieved by increased dependence on light-weight metals such as aluminium, increases the life-cycle and environmental impact of the sourcing and materials extraction phase of the life-cycle, since metal production is an energy-intensive and unsustainable in the sense of there is a limited amount of it.

Sector study is challenging but important and timely as policies are designed to impact a whole sector, with very limited regard for small-scale exemptions (a notable exception being the emissions legislation). Yet the macro-influence of the car sector on manufacturing in general, especially in the UK as a significant and profitable part of the manufacturing sector is important. The CE in contrast to the other policies is not designed to be sector specific because it aims to cover all materials, meaning that it requires greater stakeholder involvement. But difficult to see how it can be effective unless it includes current industrial players.

Bio-based materials are not discussed in the policy measures at all, until the CE. However given the speed of technological innovation, governmental measures may always be in a situation of catch-up, as they attempt to adjust to technological improvements. Therefore there is a need for reflexive mechanisms to track technology developments. The EU however appears to find it difficult to broaden the range of technologies particularly if the new technology has not achieved a critical mass or organised itself to politically represent its point of view, as in trade associations. Yet this implies that established industries retain their powerful policy influence through lobbying activities at either the national or EU level.

However perhaps we need to accept that there should be gaps in policy measures and they are not all sweeping to allow innovative niches to develop. For example, the ELV legislation now aims for 95% recovery and recycling which industry finds difficult to meet as it imposes a prescribed route for end of life of materials : it may be that there will always be some waste.

CE is currently just an action plan so in setting the broad context rather than the detail of policy. Given the long-time frame in which transitions occur, the development of a wide-ranging consultation and the work of the Ellen Macarthur institute may be important in establishing the wider understanding of these concepts and their possibilities. This may be taken as a chance to shape the landscape effect of public opinion, which might in the future be brought to bear on the EU policy regime. It may also be necessary to accept that bio-based materials are not actually a sustainable material to introduce to the automotive chain, but rather to encourage other forms of transportation, that do not require so much energy use or materials.

As identified in the literature review, much of the MLP literature does not explicitly consider the role of legislation in sustainable innovation, nor the effect of a group of policy measures. Each of the case studies however demonstrated that legislation did have an impact on the automotive regime, although this affect in each case was blunted particularly by ineffective and uneven implementation at the national level.

Methodologically, the MLP literature emphasises three key processes in the development of sustainable innovation from the niche into the regime, knowledge, expectations and networks and the thesis extended these themes into analysis of the regime. Analysis of these themes is considered next.

7.3.1 Knowledge.

Although a diffuse term, the theme of knowledge permitted an appreciation of the power of expert knowledge in this sector. Car makers emphasised their expert knowledge eg in terms of LCA assessments, but these were often firm-specific and difficult to interrogate, meaning that comparison was difficult. These often acted as a barrier to new materials as the innovation had to be "at least as good" as the existing standard. However larger firms often have higher environmental standards than SME's and they should not be dismissed as potential sustainable innovators (Bergren et al., 2015).

7.3.2 Expectations.

Car makers expressed expectations primarily in terms of the legislative landscape and often referred to the importance of the legislation. Wider landscape factors such as consumer demand were sometimes mentioned together with high expectations of the technology. UK and EC interviewees however across the cases took a much wider landscape view of potentially important factors, frequently mentioning technological developments such as autonomous and EV cars, but also wider demographic changes such as an aging population outside cities. UK Civil Servants tended to downplay the role of legislation and instead explain change in terms of market-based instruments such as landfill tax, and car tax. Although the interviewee sample size is small, this finding echoes with Budde et al., in Germany.

7.3.4 Networks

The supply chain for car manufacturing is a key reason why the automotive sector regime finds it difficult to innovate, particularly sustainably on a large scale. The automotive supply chain is an extremely efficient way to reduce the unit price of car components but at each transactional stage, sustainability is not the key factor. The car maker enjoys a degree of power over the supply chain but is often unable to produce speedy innovations because of the difficulty of communicating with the earliest parts of the chain i.e the raw material suppliers.

It also became apparent over the course of the research, that a number of new trade organisations were forming to represent the bio-based economy, including the Bio-based industries Consortium (2014), the European bio-economy association (2015) and in the UK, the Bio-based and Biodegradeable industries Association (2015) and the British Composites Society (2014). The formation of these organisations at this time suggests that a number of industry players recognise a need to share knowledge and perhaps represent themselves politically, particularly at the EU level if at the national level, as in the UK, there appears to be very limited interest.

It might also suggest that bio-based materials had not previously been at such a point technologically or at scale as to warrant significant study. But given that these materials are currently being integrated into cars, it is interesting to see how much they are adapting to the regime, although because of the insistence that they must be " at least as good as" the existing material on all criteria, they are forced into patterns which only fit with the regime and may compromise their overall sustainability.

7.3.5 Landscape effect.

The thesis did not intend to examine landscape effects but comparison over the time frames indicated the importance of recent economic austerity which is regarded as a landscape impact beyond the control of regime actors (Geels, 2013). Yet whilst austerity has impacted government spending, particularly in the UK, the car industry, again particularly in the UK, has enjoyed higher car sales and profits, in part due to increasing finance options. This differential impact highlights how landscape factors do not necessarily impact all stakeholders in the same way.

Yet the effect of austerity is particularly noticeable in terms of expectations. As car makers sought to move the wider public to innovation that was focused on technology, their knowledge expertise – eg electric cars, autonomous and connected cars, there was less interest in developing those technologies that were perceived as green. By not advertising or highlighting this "greenness", it meant public pressure on policymakers was weakened. If as Geels hypothesises (2013) " a major investment surge requires substantial policy changes, which in turn requires public attention and support (for reasons of legitimacy)" then car makers are seeking to retain the landscape preference for metal because it suits their existing capabilities.

7.4 Strengths and weaknesses of the analytical framework.

The thesis used the MLP framework, particularly the concepts of the landscape, regime and niche to study the three EU policy measures. The framework is flexible permitting its use in a wide variety of sectors but lacks precision, with operationalisation of the concepts particularly fuzzy, complicating data analysis. Its application to different time frames meant that some data sources, such as interview data were more available for some cases than others, e.g there was more data to draw on in the contemporaneous CE chapter than ELV in 2000. Yet whilst it was easier to identify and interview CE experts, it was more difficult to assign weight to a particular expert view. Gaining an understanding of expectations and knowledge capabilities in the past was also difficult, with ex-post rationalisation evident. The older case studies however had the benefit of a wider secondary academic literature. The differing data sources and viewpoints mean that a degree of researcher bias is inevitable, but was mitigated whenever possible by triangulation of sources. Yet the study of sustainability transitions and an appreciation of their need may also be considered a normative viewpoint.

The framework's strengths include the encouragement of a variety of viewpoints and the consideration of wider factors than purely technological, economic or political ones. By integrating more study of the formation of policy at a variety of governance levels, there can be an enhanced appreciation of the importance of context. With greater understanding of the forces and conditions that encourage or may stymie innovation, there is the possibility of more conscious shaping of transition pathways.

Geels (2002) model of sustainability transitions processes was referred to in section 2.3 of the literature review, because of its influential role in developing the MLP and literature. The focus of the model is clearly on niche innovation, and how that breaks through to the regime, and the framework has been developed to consider a range of ways in which these transition processes might occur (*inter alia* Geels *et al.*, 2016; Geels, 2014; 2011; Geels and Kemp 2007). The emphasis on innovation in the niche has also influenced a range of governance processes that concentrate on how small-scale niche innovations might replicate, particularly through the processes of knowledge, expectations and networks. The regime in this model is presumed to be "dynamically stable". The model does not however represent the multiple ways in which the regime is maintained and resists innovation, particularly when this innovation might challenge long-standing features of the regime.

The model suggests that transitions occur almost inevitably, but accidentally through the " windows of opportunity" created by landscape pressures. It is a common criticism that the theory ignores the role of actors in shaping these processes however, and that it removes the normative pressure on incumbent regime players to actively shape and sponsor sustainable innovation. This thesis has sought to elucidate some of the workings of the "regime" in the automotive sector and found that the automotive sector often seems to resist or delay policy measures, through a variety of means such as intensive lobbying during the shaping of the policy, exploitation of privileged expert knowledge in the standards settings regime and through obfuscating information supplied to the public.

The next section synthesises the empirical and theoretical findings from the case studies to address the thesis research questions.

7.5 RQ1. How has European automotive legislation affected the development of more sustainable innovation in the automotive sector?

This question was explicitly addressed in chapters 4 and 5 on emissions legislation and end of life of vehicles. The analysis in chapter 4 of EC/443/2009 showed that legislation had had a significant impact in encouraging automotive firms to innovate and reduce tailpipe emissions in use. This has been achieved however at the cost of increased weight, increased material usage and non-exhaust emissions. The focus on the use phase of the vehicles life addresses the most significant CO_2 impact of the car during its use phase. ELV meanwhile has reinforced the predominant material of choice as metal, given its ease of recyclability, established secondary market, established processing techniques and constrained the development of new materials particularly from automotive shredder residue.

Ineffective enforcement is evident at the UK level in a number of legislative areas, particularly as discussed in chapter 5 and including the export of ELVs and the calculation of ELV recyclate figures. The probity of the carbon emissions figures produced at type approval stage and the testing regime for vehicle type approval are also problematic as discussed in chapter 4. Ineffective enforcement at the national level is combined with inconsistencies in data definition and data collection methodologies, hampering meaningful comparison with other European states.

The use of the fleet average tool in the emissions legislation is problematic. An increase in the weight of all cars produced by a manufacturer reduces the pressure to reduce emissions. Average car weights have therefore increased, with sales of heavier cars increasing. Whilst these individual cars may not produce as much CO_2 as an older vehicle of comparative weight, the amount of emissions produced by the fleet as a whole have increased. Berrgren and Magnusson (2012) agree that the EC legislation has stimulated innovation and that conventional technologies have still further potential. Wells *et al*., (2013) suggests that the definition of what is reasonable hinges on the availability or expectation of technological developments and also on the anticipated cost; *"If industry, ...makes claims for significantly increased costs then it is politically more difficult for regulatory agencies to impose apparently arbitrary standards"*. Price rises may be due to an ability to charge more for a particular feature, rather than the actual cost eg airbags/satnav (Wells *et al*., 2013). This means that legislation does not add significantly to cost and the automotive industry has more capacity to absorb costs than it frequently argues. Some incumbent actors may also be best placed, in comparison to SMEs, to innovate in the most environmentally aware ways (Bergren et al., 2015).

Successful regulation takes significant time to be negotiated but to push a sector, such as the automotive one, that has significant capital costs and a long product-cycle, legislative targets need to be long-term and challenging, but not require a whole new architecture (Bergren and

Magnusson, 2012). The analysis suggests that voluntary targets cannot counteract the intense market pressures in this industry, meaning they a inappropriate as a policy tool. The role of regulators however is key in this process with their independence, competence and credibility necessary to enforce standards (Tao et al., 2010).

7.5.2 RQ2. What are the barriers and drivers to the use of biobased materials in the UK automotive sector?

This thesis has not addressed the question of whether bio-based materials are sustainable *per se* but rather considered how existing policies effect their adoption in a particular sector. Given their increasing use in the car industry as demonstrated in chapter 4, there clearly are some incentives to use these materials.

Barriers.

The lack of an established guaranteed supply chain at low cost inhibited the UK auto sector from initiating the capital investment required to develop this supply chain. At a legislative regime level, the lack of established end of life or recycling facilities meant that bio-based material did not satisfy the ELV. There were suggestions that bio-based materials were being used but and effectively not worrying on compliance with ELV because of the poor implementation and checking of ELV, at the EC level because of poor data consistency and in the UK in particular due to the metal content assumption. Legislation at a European level was hampered by the automotive sectors' political influence and requirement for gradual long-term goals. Use of more long-term but ambitious goals might be important therefore as articulated in the Circular Economy to shape industry and wider society expectations.

The lack of involvement by OEMs in developing the CE package and in recycling efforts in general was also a barrier. At the UK level, the UK government appeared limited in its influence because many car firms in the UK are not UK-owned and particularly vulnerable to being moved overseas, negatively impacting GDP and local employment. The length of the automotive supply chain was seen as a significant barrier to their introduction because of the difficulties of co-ordinating information and all stakeholders along its length.

Drivers

A number of factors which might be defined as landscape issues, including increased electrification of cars and more technology within cars such as autonomous vehicles were seen to add to long-term "landscape" technological pressures to lightweight the car. Thus far this pressure has mostly manifested itself in increased research into and use of light-weight metals, given their long-standing use. Bio-based materials could offer a solution to this issue given further processing improvements. The potentially unlimited supply was also attractive to the car industry, but car makers were reluctant to consider a feedstock from recycled waste, given the variability in processing and need for a regular and guaranteed supply. Imports from overseas based on virgin crops were preferred given the regularity and consistent quality of this material.

7.5.3 RQ3 Are there legislative barriers to the use of bio-based materials and in regulation of their end of life impacts for the automotive sector at the European and UK level?

The emphasis on quantity of waste in the ELV reporting structure and CE packages rather than the quality, together with mass recycling targets rather than material specific ones means that there is an unconscious failure to recognise the potential of this sector. The lack of compulsory segregation of bio-waste was particularly pronounced at the UK level, where there also appeared to be lack of representation to the EU of the UK recycling industry's concerns.

The CE package focus on recycling and hierarchy of materials also does not encourage the separate collection of food waste and thus a guaranteed cheap supply of bio-based materials. The analysis suggested differences in expectations in that UK legislators tended to consider more long-term and societal factors affecting development, i.e landscape factors whilst UK industry tended to consider legislative proposals. This contrasts with research on expectations of German car manufacturers considering fuel cells (Budde *et al*, 2012). This suggests that those seeking to promote bio-based materials in the car industry need to specifically focus on legislative development and expectations rather than more long-term socio-technical factors.

The analysis also illustrated how much the ELV and CE package are linked in a number of ways. The CE package proposes minimal amendments to existing ELV legislation but there are no explicit sector incentives to the car industry, or other high polluting industries, to amend their material policies. A key issue is the poor implementation of existing legislation such as ELV. This weakens the effectiveness of the EU; means that there is a façade of compliance which injures genuine attempts to develop a CE or bio-based economy in the most optimal sustainable way. This also obscures information, distorting the market and means that not all stakeholders can participate effectively. But whilst these larger firms may enjoy the resources to act in the most sustainable manner (Hitchens *et al.*, 2005), they may not be the most innovative.

7.5.4 RQ4. How could EU legislation be modified to support sustainable technologies in this sector?

The research has confirmed that the automotive sector appears that the automotive industry is inertintroduction to the thesis highlighted how the EU has addressed the lifecycle of cars to reduce the amount of emissions in use and a growing issue of lifecycle impact, in particular from manufacturing. This means that legislative change to introduce a new material will be required along the whole length of the value chain to produce a more sustainable product. Unless this is consistently done, manufacturers can push environmental cost into another part of the chain or export the problem to another part of the world.

Light-weighting might be more explicitly encouraged by the use of metrics on the weight or size of cars rather than emissions produced. Adjusting the value limit curve gradually and setting a long-term target to eliminate it might encourage those heavier, more luxury cars to innovate more quickly. ELV targets might be more materials rather than weight-focussed with reduced insistence on recycling of materials into an open market, rather than re-use in closed loops. Increased investment in recycling technologies and separation of materials are required to develop the market further. Under the CE , separate food waste collection and banning bio-based waste from landfill would encourage business to find alternative uses and grow the supply chain.

Independent testing under the WVTA system at the European level would prevent national agencies competing to provide this service to car firms and permit better scrutiny of testing than that currently afforded by the commercial national testing agencies. Clarifying European wide definitions for re-use would help to prevent the issue of missing ELVs and a shared method of data analysis of ELV, rather than the use of the MCA, would provide more information on the end of life of cars and permit

7.6 Overall research aim: How can transitions theory to foster sustainable innovation be improved by taking account of legislation?

The literature review identified that transitions theories have rarely explicitly considered the legislative framework and the opportunities it offers for sustainable innovation.

There were three main ways in which the transition framework aided analysis. The transitions approach is also a developmental theory and studies of innovation processes are increasingly drawing on this approach to derive policy and assert the role of legislative authorities.

Early SNM looked at how niches might develop on a small scale and that they would grow to encourage the regime. But that hasn't happened on a significant scale. If there needs to be more rapid adaptation given rising CO2 rather than waiting for the regime to change, need to be more proactive and change the regime itself.

The literature review developed in chapter 2 highlighted how politics and legislation are not taken into account in much of the sustainability transitions literature. The focus of this study, the car industry, was recognised as a particular sector which has an urgent need to innovate sustainably but which is also heavily constrained by legislation.

Strategic Niche Management, an early form of sustainability transitions literature, focussed attention on policymakers to foster sustainable innovation, by orchestrating a range of measures. This thesis contributes to the sustainability transitions literature by refocusing attention back onto state and intranational actors, particularly the EC and re-purposing strategic niche management to strategic regime management approach. This refocus is necessary in order to persuade existing actors and sectors to move towards sustainability more rapidly, since market actors currently do not provide the necessary stimulus.

This refocus puts attention back on policymakers and state actors. The study offers explanations of why many sustainable innovations fail to develop sufficiently to overcome the inertia of existing sectors. The inconsistency between legislative design at the European level and implementation at the national acts as a disincentive to manufacturers to invest in sustainable innovation, since it is cheaper and less risky to avoid compliance. This also hampers timely investment in capital technology to recycle. More independence in testing regimes with transparency of data would also encourage this investment.

This suggests that transitions study needs not only to consider the design of legislation but also the context and nuances of implementation. For EU legislation in particular, the varying degrees of national implementation can create distortions to the incentives and barriers to sustainable innovation, creating a "patchwork" effect (Garcia Quesada, 2014). For example in the emissions case, the preferential car tax rate for diesel vehicles in the UK, created a market incentive which elevated the technological case for incremental improvement of diesel engines. The resulting effect on JLR for example was such that their product line and increased sales are skewed towards this knowledge, thus acting as a regime barrier to other innovations. On ELV, the differences in data collection methodologies, including use of the MCA, the metal content analysis, means that whilst there is an appearance of compliance, a significant portion of ELVs in reality are not accounted for.

Yet for EU policymakers, CO_2 emissions and waste both are international, but EU can address the car market. In encouraging innovation, it faces a challenge in that the transition process will create winners and losers but established firms wield the lobbying power to frame the legislative process.

The research adds to the growing international literature that argues that policy has had a significant impact on sustainable automotive innovation (Berggren, 2012, Lee, 2011). Which contradicts the general industry view that regulation is not required as the market will drive innovation. The particular design features which make one policy more successful than another are open to debate however. Bergren and Magnusson (2012) but the effectiveness of the regulation as compared to the voluntary standard seems clear (as discussed in chapter 4).

The analysis indicates that rapid transition to a more sustainable innovation will require significant reform of existing legislation, to ensure coherent encouragement and prevent unintended consequences. This is challenging however given the political power of existing industry, but also the way that existing structures, networks and political alignments fit together to act as barriers. Not involving the public in debate on car manufacturing decisions means that no wider landscape or public pressure is brought to bear on legislators thus retaining the technological model approach to innovation.

Calls for an innovation principle to be enshrined in legislation however are difficult to achieve given the lack of clear definition, or how it can be operationalized or measured. It is also possible that this can be used as another barrier to the formation of any legislation, complicating the issue and deterring involvement by legislative authorities and wider stakeholders.

7.7 Limitations of the research and future research directions

There are a number of limitations to the research, some of which are due to the ambition and changing nature of the initial research design. However the trade-off between the comparative study of three policy measures against a more in-depth case study of one measure was not appropriate as the research sought to cover the whole life-cycle of the car. Focusing attention on only one measure, ignores the interconnectivity and mutual relationship between the different life-cycle phases, potentially shifting the environmental impact on to another groups of stakeholders.

Although the interviews took place over an extended period of four years which was a limitation, in some aspects this afforded the researcher an opportunity to monitor the evolution of the CE package in particular. Interview questions were also modified as the researchers knowledge grew and new issues emerged. A particular challenge was the initial lack of contacts within the automotive sector at a sufficiently expert level to provide meaningful information. A lack of access to EU actors within the Commission also weakens the primary data obtained. Interviewees were also easier to identify and access for the more recent Emissions and CE sections meaning that the interview data is not evenly spread across all three case studies. The ELV section however enjoyed the benefit of more secondary data to draw upon.

A comparative view is useful however to gain a more holistic understanding of the cumulative impact of the different policy measures and understand how they may contradict each other, despite sharing the same goal. Comparative study with eg Italy, or the US might shed light on how differing interpretations and implementation of EU policy may affect the developing bio-based materials paradigm. Since the technology is in its infancy there is potential to trace its development and further interactions with other industrial sectors or parts of the transport sector, such as the aerospace industry, which also prioritises fuel-savings and light-weighting.

The research also highlights that there is an urgent need to address the end of life scenarios for both bio-based and mixed materials. Currently there do not appear to be the facilities to treat these materials apart from incineration for energy, but this is problematic because it maintains the linear mode of handling materials, and integrates bio-based materials into ever-increasing amounts of consumption. This is also an urgent matter because of the current long-lead time to construct the infrastructure to process.

There is nothing inherently more sustainable about the use of bio-based materials as opposed to petroleum based products, although they enjoy a renewable supply. Need to consider how we evaluate the processes around our consumption since perhaps the recent leasing model for cars might encourage car manufacturers to retain resources in a CE model. There will be increasingly heterogenous mixes of materials utilised in cars in order to satisfy growing demand for cars but if the EU wishes to shoulder its role as an environmental leader it may need to consider which processes may most effectively treat these wastes to avoid future environmental impacts.

7.8 Conclusion.

This chapter has gathered together data from the previous empirical chapters to answer the research questions generated from the literature review with the aim of understanding

The research has revealed a number of inconsistencies in the legislation which impairs its effectiveness and may impede sustainable innovation in this sector. The analysis also showed that an understanding of the processes of knowledge, network formation and expectations can be used to understand how regime actors and processes sustain the status quo in a mutually reinforcing pattern which can act as a barrier to the introduction of new materials. The review suggests that regime actors knowledge, networks and expectations work to maintain the status quo and a " business as usual" approach, meaning that new materials and sustainable innovations have increasingly higher standards to meet in order to adjust to, never mind to transform or replace the status quo.

The analysis has also highlighted the ways in which the national political context in a member state, the UK, can blunt or limit the effectiveness of an EU policy measure, particularly through the use of market instruments, such as car tax, which produce a powerful effect on the market, which can interfere with the policy measure. The variability of national implementation measures, such as the differing VCAs, and definitions of terms, means that national subsidiarity can interfere and effectively block EU policy measures with a sustainability goal.

Analysis also implies that the promotion of sustainable innovation at a sector level in the EU requires attention to the supranational legislative level because of the power of the larger EU, rather than national, market. Study at the EU level is also appropriate because of its influence world-wide. Yet since transitions are an on-going process, this also implies that the policy measures may need continual monitoring, adjusting and updating. As such, it repositions regulatory authorities as important and under-appreciated actors within the transitions process. It also suggests that there is under-utlised space within the policy measures to support niches, but also to enact "creative destruction" (Kivimaa and Kern, 2016) to shift the regime away from ongoing unsustainable activities.

Appendix 1. Interviewee Consent form

- I agree to take part in the University of York PhD research specified above. I have read and understand the information sheet, which I can keep for my records, explaining the above research and I have had the opportunity to ask questions. YES/NO

- I understand that my participation is voluntary, that I can choose not to participate in part or all of the project and that I am free to withdraw at any time (prior to the publication of any research) without giving any reason and without any negative consequences. YES/NO

- I understand that my responses will be kept confidential and that no information that could lead to the identification of any individual will be disclosed in any reports or to any other party YES/NO

- I understand that reports based on the interview(s) will be kept in secure storage and that the reports held by the University will be destroyed after completion of the research. YES/NO

- I understand that the information I provide may be used as part of publications of research on the topic. YES/NO

- I agree to be interviewed by the PhD student Anne Kildunne YES/NO

Participants name:____

Signature____

Date____

Interviewer name: Anne Kildunne

Appendix 2. Project Information Sheet

<u>Legislative opportunities and barriers to biobased materials in the UK automotive sector</u>

You are being invited to take part in a research project. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully. If there is anything that is unclear or if you would like more information, please ask.

The research forms part of my PhD on sustainable innovation in the UK automotive sector (especially biomaterials, lightweight materials and electric vehicles) to understand how existing automotive legislation, particularly at the European level, effects their development.

The information you provide will be used to guide research for my PhD and subsequent academic publications. I would like to discuss this topic with you because of your expertise and background.

If you decide to take part, you will be given this information sheet to keep and asked to sign a consent form. You are still free to withdraw at any time (prior to the publication of any research) and without giving any reason.

I will be asking you questions around the development of sustainable transport and automotive policy. The interview should not last more than an hour. All data provided will be stored securely and all information will be confidential. Any direct quotes used in publications or my PhD will be anonymised. I would be happy to send you the finished research project, should it be of interest. After the interview I do not expect there to be a need to contact you again.

I would like to record the interview, this will only be used for transcription and no other use made of it. No-one apart from myself and my supervisor will be allowed access to the original recording. This research has been given ethical approval by the University of York Environment department.

Should you wish to contact me, my name is Anne Kildunne and my email address is ak846@york.ac.uk. My supervisor is Dr Charlotte Burns, who can be contacted at charlotte.burns@york.ac.uk.

I hope that you will be willing to participate in my research.

Thank you for your co-operation.

Abbreviations

ACEA	European Automobile Manufacturers Association (Association des Constructeurs Européens d'Automobiles)
ASR	Automotive Shredder Residue
ATF	Authorised Treatment Facilities
BEIS	Department Business, Energy, Industry and Skills (UK)
BIS	Department for Business, Innovation and Skills (UK)
BPF	British Plastics Federation
CAFE	Corporate Average Fuel Economy (US)
CE	Circular Economy
CO_2	Carbon dioxide
DECC	UK Department of Energy and Climate Change (UK)
Defra	Department for Environment, Food and Rural Affairs(UK)
DVLA	Driver Vehicle Licencing Agency (UK)
EA	Environment Agency (UK)
EC	European Commission
EEA	European Environment Agency

ELV	End of Life Vehicles Directive
EP	European Parliament
EU	European Union
EV	Electric Vehicle
HSS	High strength steel
ICE	Internal Combustion Engine
IDIS	International Dismantling Information Service
IMDB	International Materials Database
I.T.	Information Technology
MEP	Member of the European Parliament
MVDA	Motor Vehicle Dismantlers Association
NEDC	New European Driving Cycle
NGO	Non-governmental organisation
NOx	Nitrogen Oxide
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer

OICA	Organisation Internationale des Constructeurs d'Automobiles
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
SME	Small and medium enterprises
SMMT	Society of Motor Manufacturers & Traders (UK)
ULEV	Ultra-low emission vehicle
US	United States of America
VCA	Vehicle Certification Agency
WEEE	Waste Electrical and Electronic Equipment
WLTP	Worldwide harmonised light vehicles test procedure
WRAP	Waste Resources Action Programme

g/cc	grammes per cubic centimetre

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