WEATHERING THE STORM:

MANAGING PHYSICAL CLIMATE RISKS IN THE ELECTRICITY SECTORS IN THE UNITED KINGDOM AND FRANCE

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This thesis includes work from one academic article, corresponding to chapter 4:

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As lead author on this publication I designed the methodology, collected and analysed the data underlining this article, developed the hypotheses and narratives and wrote as well as well revised the manuscript. I also submitted the article to the peer-reviewed journal and revised the manuscript according to the reviewers' feedback. My supervisors were co-authors of this work, providing guidance on the methodologies, and feedback and edits on the manuscript.

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ABSTRACT

Recent flooding of substations or droughts reducing hydropower brought the brittleness of electricity infrastructures to the attention of engineers, scientists and policy-makers. As future climate change is projected to affect extreme weather events, ensuring critical infrastructure reliability is vital for any society's survival. Whilst governments lead climate adaptation planning, engaging private organisations in adaptation is paramount when they provide critical services. This research explores how electricity companies manage the climate risks they are exposed to and what drives them to do so in two countries. The UK and France were chosen because of the marked differences in the structure and governance of their electricity sectors. The research takes a qualitative multi-method approach, consisting in a systematic literature review and content analyses of policy and corporate documents as well as of interviews with electricity company employees, policy-makers and third-party practitioners. This thesis makes several contributions. First, in the long term, climate change will impact negatively on thermal electricity generation and positively on some renewable generation in parts of Europe. Second, climate risks in both countries are mostly mainstreamed through policies aiming to ensure future generation capacity. Third, the electricity sectors in both countries are well-prepared for short- and medium-term climate risks but less so for the longer term. Corporate climate adaptation is largely driven by financial and regulatory policy instruments, but existing instruments are not conducive to building climate-resilient electricity sectors in the long term. Fourth, the electricity sector governance is changing in both countries. Whilst the UK is traditionally market-based, government interventions are more frequent. In contrast, France moves from a state-centred towards a more market-based governance. In this context, a window of opportunities opens for governments to explore more innovative policy processes that consider the longer term and for companies to adopt decision-making approaches that accommodate the deep-uncertainties intrinsic to future climate change.

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ACRONYMS AND ABBREVIATIONS

ARENH:	French regulated access to historical nuclear energy (Accès Régulé à l'Electricité Nucléaire Historique)
BACLIAT:	Business Areas Climate Impact Assessment Tool (UKCIP)
CCA:	Corporate Climate Adaptation
CCC:	Power plants with Closed-Circuit Cooling
CLARA:	Climate Adaptation Resource for Advisors (UKCIP)
CNR:	Compagnie Nationale du Rhône
CPI:	Climate Policy Integration
CRE:	French energy regulator (Commission de Régulation de l'Energie)
CSP:	Concentrated Solar Power (Chapter 2)
CSP:	French public service contract between the State and EDF (Contrat de Service Public)
CV&C:	Climate Variability and Change
DECC:	UK Department of Energy & Climate Change
DNO:	Distribution Network Operator
EC:	European Commission
EC:	End of the 21st century (Chapter 4)
EDF:	Électricité de France
EEA:	European Environment Agency
EMR:	Electricity Market Reform
E.ON:	Energy On
ETGG:	French Energy Transition for Green Growth Act (i.e. Loi relative à la transition énergétique pour la croissance verte; n° 2015-992))
ETR:	Engineering Technical Report
EU:	European Union
EU BASE:	Bottom-Up Climate Adaptation Strategies Towards a Sustainable Europe (EU FP7 project)
GB:	Great Britain

GHGs: Greenhouse Gases

IEA: International Energy Agency

IHACRES: Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow

IPCC: Intergovernmental Panel on Climate Change

NGET: National Grid Electricity Transmission plc.

NGO: Non-Governmental Organisation

NOME: French new organisation of the electricity market (Nouvelle Organisation du Marché de l'Electricité)

NT-MC: Near term to mid-21st century (Chapter 4)

OFGEM: UK Office of Gas and Electricity Markets

OTC: Thermal power plant with Once-Through Cooling

PDCA: Plan–Do–Check–Adjust

PPE: French pluriannual energy program (Programmation Pluriannuelle de l'Energie)

PV: Photovoltaic

R&D: Research and Development

RCPs: IPCC Representative Concentration Pathways

RDM: Robust Decision Making

RIIO: Revenue = Innovation + Incentives + Outputs (UK OFGEM)

RTE: Réseau de Transport d’Electricité

RWE: Rheinisch-Westfälische Elektrizitätswerke

SHEM: Société Hydraulique du Midi

SLR: Systematic Literature Review

SNBC: French national low-carbon development strategy (Stratégie Nationale Bas Carbone)

SoES: Security of Electricity Supply

SSE: Scottish and Southern Energy

STARS: STatistical Analogue Resampling Scheme

SWIM: Soil and Water Integrated Model

TOPKAPI: TOPographic Kinematic APproximation and Integration

UK:	United Kingdom
UK ARP:	United Kingdom Adaptation Reporting Power
UK BEIS:	UK Department for Business, Energy & Industrial Strategy
UK CCA:	UK Climate Change Act 2008
UKCIP:	UK Climate Impacts Programme
UKCP09:	UK Climate Projections
UK DEFRA:	UK Department for Environment, Food & Rural Affairs
UK Met Office:	UK Meteorological Office
UN:	United Nations
UNFCCC:	United Nations Framework Convention on Climate Change
WaterGAP:	Water Global Assessment and Prognosis

“Success is not final.

Failure is not fatal.

It is the courage to continue that counts.”

Winston Churchill

1. INTRODUCTION

Infrastructures provide the critical lifelines of our societies: communication, energy, food supply, health services, transportation, water and many more. Protecting and ensuring the reliability of these infrastructures against known and unknown threats are paramount for any society's survival. The current variability in climate has already brought the brittleness of critical infrastructures to the attention of engineers, scientists and policy-makers.

In 2007, for example, flooding in the southwest of England affected water treatments plants and electricity distribution substations and left hundreds of thousands of people without water or power (Pitt, 2008). During the winter of 2013/14, storms in the United Kingdom (UK) led to over 150 000 homes losing power for prolonged periods of time, the closure of Gatwick Airport, the complete severance of the South Devon Main Rail Line in Devon for two months and to general damages to buildings and other infrastructure assets (Chatterton et al., 2016). A year later, more floods disrupted electricity supplies for tens of thousands of people, caused a number of bridges to collapse and affected mobile and broadband communication networks (Marsh et al., 2016). The importance of infrastructure and the significance of the disruptions caused by extreme weather events are echoed around Europe and the world (Salagnac (2007); Chang et al. (2007); McEvoy et al. (2012); Ziervogel et al. (2014)).

Future climate change is projected to alter average weather conditions and the nature and intensity of extreme weather events across the world (Wigley (2005); Intergovernmental Panel on Climate Change (IPCC) (2014b)). Gradual shifts in long-term climate elements (e.g. air temperature, precipitation and solar radiation) could reduce the capacity and efficiency of some infrastructures, lead to increase disruption of infrastructures, alter the design life of infrastructures and diminish the effectiveness of the services they provide (Dawson et al., 2018). Globally, $2.5tn is spent on infrastructure annually (Woetzel et al., 2016). In the UK alone, the Treasury plans to spend £300 billion across all sectors of infrastructure by 2020/21 (HM Treasury and Cabinet Office, 2016). Infrastructure is typically associated with large capital costs, lifetimes of 30-200 years and limited flexibility once built. Given the sensitivity of infrastructure performances to extreme weather events and the cascading implications that potential disruptions to critical infrastructure could cause to society, assessing and managing climate risks for these infrastructure must be priorities, making climate adaptation unavoidable (Moss et al., 2013).

Sufficient climate change evidence emphasises the need to take swift actions to reduce current and future climate-related damages (Intergovernmental Panel on Climate Change (IPCC), 2014a). The climate debate has now moved on from "do we need to act now" to "how to act now in order to best adapt to climate change" (Costello et al., 2009). But understanding the implications of climate variability and change (CV&C)[1] for individuals, businesses and society, is no easy task. Simple advice like "save energy" or "use public transport" are useful to reduce greenhouse gas (GHG) emissions but no equivalent exists to adapt to CV&C. Climate adaptation is indeed characterised by high degrees of spatial diversity, controversy, complexity and uncertainty, and therefore requires difficult, non-evident and often contradictory solutions as well as large scale environmental and social change, involving many actors in society (Lorenzoni et al. (2007); Driessen et al. (2013)). And yet adaptation is nothing new; societies have adapted autonomously to their environments to alleviate climate-related risks throughout history. The complexity, range and magnitude of potential future climate-related risks will however overwhelm autonomous adaptation and require planned adaptation and the coordination of various public and private actors if damages are to be minimised. Private sector organisations have significant economic

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[1] In this thesis, the term "climate variability and change" (CV&C) is used. This is to emphasise the point that changes in climate variability, without changes to mean temperature or rainfall variables, may also be the result of climate change. However, strictly speaking, the definition of climate change encompasses climate variability.

weight in global and national economies and how they rise to the climate challenge will have societal consequences beyond the companies' boundaries. However, to date, corporate climate adaptation (CCA) is not well-understood in existing literature and needs to be explored further.

Section 1.1 provides the background of the research and underpins the focus of this dissertation on the issue of corporate climate adaptation. Section 1.2 elaborates on the research aim and objectives. This chapter concludes with section 1.3, which provides an outline of the thesis.

1.1. BACKGROUND AND PROBLEM OUTLINE

The scientific debate on the governance of adaptation to CV&C

As extreme weather events intensify, societies as a whole have to start making provisions for climate risks. However, according to the existing adaptation literature, the development of adaptation policies and the implementation of adaptation measures is hampered because the responsibilities for climate adaptation often remain rather vague, fragmented and/or ambiguous (Storbjörk (2007); Termeer et al. (2013); Wamsler and Brink (2014)). This lack of clarity over who is responsible for adaptation is problematic as it could lead to under-adaptation, increased climate risks and if adaptation actions are delayed, a substantial rise in costs for adaptation in the medium or long term (Stern, 2007).

Traditionally, public actors (i.e. national or local governments) take responsibility for adaptation action to secure sufficient levels of preparedness for present and future generations (Osberghaus et al., 2010). However, if governments are over-ambitious, it may lead to over-adaptation and a waste of resources. On the other hand, responsibilities for adaptation could be left with private sector actors, such as businesses and individuals. But although this arrangement might appear to be more efficient (Mendelsohn, 2006), private actors may exclude other actors and may act to the detriment of others. The importance of governance arrangements where both public and private actors are involved in adaptation starts to be acknowledged, but little is still known on what enabling environments or policy instruments are needed to foster private sector adaptation.

This PhD research will contribute to the above policy debate. Adaptation to CV&C is a new and emerging environmental policy field, in which the boundaries between public and private sectors have not yet been completely defined and in which public and private responsibilities still remain unclear. This context is highly problematic when private companies are responsible for the provision of public services critical for any economy and when unforeseen crises such as natural disasters, civil unrest, extreme economic fluctuations, etc. can affect their ability to function. Chapter 5 sets out to inform the above debate by exploring how governments in the UK and France facilitate (or incentivise) adaptation to CV&C in electricity companies to ensure that the lights stay on in the shorter and longer terms.

The importance of corporate climate adaptation

Businesses have significant economic weight in global and national economies, and how they rise to the challenge of climate change will have societal consequences beyond the companies' boundaries. Corporate responses to CV&C have been documented in academic and grey literature (Kolk and Levy (2001); Levy and Egan (2003); Hoffman (2005); Kolk and Hoffmann (2007); Lash and Wellington (2007); Okereke (2007)) but this literature has largely focused on climate mitigation responses (e.g. strategies to reduce greenhouse gas emissions and carbon disclosure practices and carbon reporting).

Only in more recent years have scholars become more engaged with understanding climate adaptation responses and literature on corporate climate adaptation is an emerging field of research that is still largely unexplored (Agrawala et al. (2011); Averchenkova et al. (2016)) and not well-understood (Fisher and Surminski, 2012). Also, recognising that companies are vulnerable to climate risks is relatively new in organisation research and as such, little insight still exists on how CV&C impacts companies and what private sector organisations do to manage climate risks. This is especially relevant when firms are responsible for the provision of services critical to any economy such as electricity.

Chapter 6 contributes to this academic debate by exploring how electricity companies in the UK and France manage CV&C risks in the short and longer terms and by unearthing the factors that influence corporate decisions to implement climate adaptation measures.

1.2. Research aim, rationale and questions

Reflecting on the gaps outlined above, the overarching aim of this thesis is to explore corporate climate adaptation in a sector of critical importance, the electricity sector. It follows a multi-level approach, examining corporate climate adaptation, explicitly considering the policy and climatic contexts within which electricity companies operate.

This thesis sets out to answer four research questions (RQs), (Figure 1-1):

RQ1: What do we know about the impacts of CV&C on electricity systems in Europe?

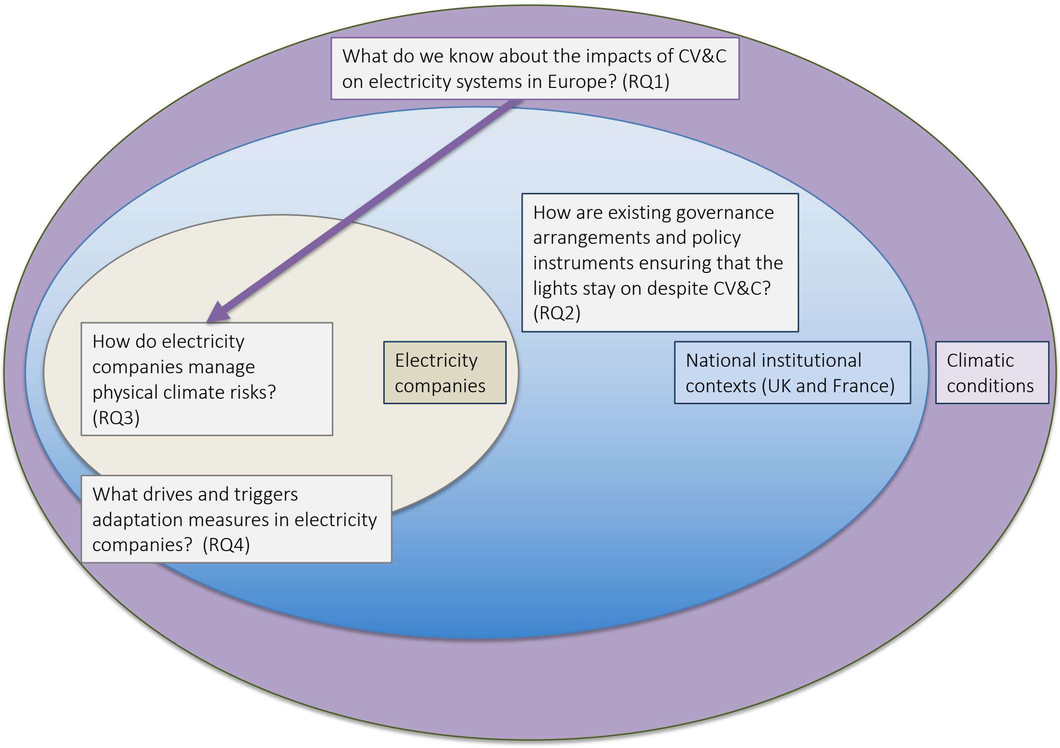
RQ2: How are existing governance arrangements and policy instruments ensuring the lights stay on despite CV&C in the United Kingdom and France?

RQ3: How do electricity companies manage physical climate risks?

RQ4: What drives and triggers adaptation measures in these companies?

Chapter 3 details the overarching research strategy employed to answer these research questions.

Figure 1-1: Research questions (RQs) the thesis covers



1.3. Thesis Outline

The remaining of this thesis is organised as follows. Chapter 2 introduces the theoretical literature that underpins the research in this thesis: section 2.2 starts by documenting the theories supporting climate adaptation governance with a particular emphasis on interactive governance and the division of roles and responsibilities between public and private actors for adaptation to climate change; section 0 follows, by reviewing the still nascent literature on corporate responses to CV&C risks; section 0 explores the scarce literature on adaptation to CV&C in the electricity sector. Chapter 3 presents the interpretive philosophy underpinning the research and outlines the qualitative multi-method approach to data collection, consisting in a systematic literature review, a multi-case study and third-party conversations. Chapters 4, 5 and 6 are the three empirical chapters of this study. Chapter 4 identifies the physical impacts of climate variability and change (CV&C) on electricity systems in Europe. Chapter 5 explores what policy instruments governments in the United Kingdom and France use to ensure that the lights stay on in the shorter and longer terms amid physical climate risks. Chapter 6 investigates how electricity companies in the UK and France manage physical climate risks, what drives and triggers them to adapt and whether adaptation-specific regulations make a difference to the way they adapt. Chapter 7 provides a synthesis of the previous empirical chapters, discusses research findings as well as presents the limitations of the study and reflections and avenues for further research. Chapter 8 concludes the thesis.

Chapters 4, 5 and 6 report on different aspects of the research. Indeed, corporate climate adaptation cannot be dissociated from the physical climate impacts that it tries to manage or the institutional/policy contexts that it operates in. Although these three elements of a) physical climate impacts, b) institutional contexts and c) corporate climate adaptation are three pieces of the same puzzle they are better tackled separately in the first instance. The exploration of each of these three elements also required different empirical data and methods of analysis (Figure 3-2) and has called for different groundings within the existing literature. They also contribute to different academic debates. These reasons motivated to report this research in three separate chapters, in their relevant contexts, rather than combined in a methodology chapter and a results chapter.

2. LITERATURE REVIEW

2.1. INTRODUCTION

This chapter introduces the theoretical concepts that underpin this thesis. In order to better understand whether and how electricity companies in the UK and France manage CV&C risks, this chapter explores existing literature across four sections. Section 2.2 first outlines governance arrangements for climate adaptation. Section 0 then synthesises the existing literature on corporate climate adaptation. Section 0 discusses how central the notion of time is to organisational responses to environmental issues such as climate change. Section 2.5 then summaries the nascent literature on firm-level adaptation in the electricity sector. Whilst this chapter outlines some of the literature underpinning this research, more extensive descriptions of the research supporting each aspects of the study are given in each of the empirical chapters 4, 5 and 6.

2.2. GOVERNANCE ARRANGEMENTS FOR CLIMATE ADAPTATION

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects." (Intergovernmental Panel on Climate Change (IPCC) (2014a); p.5). Climate adaptation has for a long time been seen as "taboo" because it was perceived to hinder mitigation efforts. Former US vice-president Al Gore forcefully declared in 1992, that adaptation represents a "kind of laziness, an arrogant faith in our ability to react in time to save our skins" (Pielke Jr et al. (2007); p. 597). Until recently, adaptation was largely seen as an issue mainly relevant to low-income countries (Biesbroek and Lesnikowski, 2018). Since the years 2000s however, perspectives evolved when it was politically acknowledged that some degree of climate change was unavoidable as greenhouse gas emissions were not reduced quickly enough.

This lack of focussed political attention to adaptation at international level has resulted in state and non-state actors across the globe implementing adaptation in autonomous, bottom-up and self-organising ways (Berrang-Ford et al. (2011); Berrang-Ford et al. (2014)). To date, twenty-five European Union (EU) Member States and three other European Economic Area member countries have adopted a national adaptation strategy (European Environment Agency (EEA), 2019). Regarding concrete policy actions, Lesnikowski et al. (2016) note an increase of eighty-four per cent of reported adaptation work amongst high income countries (Annex I) between 2010 and 2014. These concrete actions however are not initiated as a result of monocentric steering but instead actors seem to be driven by, for example, experiences of local climate impacts, entrepreneurship, cooperative learning and policy diffusion (Biesbroek and Lesnikowski, 2018).

Consequently, the current adaptation landscape is highly fragmented and shows unequal progress across contexts. However, the UNFCCC Paris Agreement, in force since 2016 (i.e. the "Paris Agreement"), detracts from this observation. Indeed, the Paris Agreement presents more prominently, and for the first time, climate adaptation alongside mitigation and pushes for a stronger coordinated and globalised adaptation efforts by setting a global adaptation goal. Whilst mitigation started from a centralised mode of governance and climate adaptation from a "bottom-up" mode of governance, both now seem to be gradually converging towards a more polycentric model of climate governance (Biesbroek and Lesnikowski, 2018), a form of governance with multiple centres of decision making, where each of which operates with some degree of autonomy (Ostrom, 2005). This is very prominent in the Paris Agreement where a strong emphasis is put on the social responsibility of multiple (non-)state actors across different scales and the necessity for these actors to join forces, self-organise and implement mitigation and adaptation measures.

An examination of the adaptation governance literature indicates that most studies on the governance of adaptation build on three different but related strands of theory: adaptive governance, multilevel governance and interactive governance. Adaptation research adopting an adaptive governance theory assumes "that the inherent uncertainties and dynamic complexities associated with adapting to climate change impacts require governance systems to be highly flexible, with embedded redundancies that increase resilience to system shocks" (Biesbroek and Lesnikowski (2018); p. 308). The multilevel strand of adaptation governance focuses on the mismatch between the level(s) at which policy problems manifest themselves and the level(s) at which they are managed and responds to the strong emphasis on "localism" that dominates much of the adaptation literature. The third strand of adaptation governance literature is directly concerned with exploring the relationships between public and private actors and seeks to address how different network configurations increase trust among different stakeholders. This thesis, and the section that follows, explore the interactive adaptation governance literature more extensively.

Some studies adopting an interactive governance approach investigate for example the types of governance arrangements that bring together different public and private actors with vastly different tasks and responsibilities (Tompkins and Eakin, 2012). Such studies emphasise the need for national governments to create a sound institutional foundation and knowledge base and to foster networks to connect public and private actors. Indeed, climate change adaptation is not just an environmental problem in need of technical and managerial solutions; adaptation is a political issue too where a variety of actors (e.g. state agencies, private sector[2] companies, industry associations, non-government organisations, etc.) engage in contestation as well as collaboration. But unlike the highly centralised and government-driven rhetoric of climate change mitigation, adaptation is more decentralised and is likely to take place beyond the

[2] The "private sector", although made up of a wide spectrum of actors (from small firm with few employees to large multi-national companies with staff numbers and balance sheets equivalent to small countries) is understood here as the set of activities in society that are mainly driven by market logic, following: Benzie, M. and O. Wallgren (2014). Initiating and sustaining adaptation in the private sector (Chapter 6.3) In Climate Change Adaptation Manual. A. Prutsch, T. Grothmann, S. McCallum, I. Schauser and R. Swart, Routledge. London, UK: 78-83pp. ISBN: 9780415630405

official 'adaptation decisions' of the nation-state or the United Nations Framework Convention on Climate Change (UNFCCC) (Agrawala and Fankhauser, 2008).

Governance as a new way of steering is a popular concept in social sciences. (Environmental) governance theorists and political scientists expressed various views on how the state, market and civil society should share responsibilities for public issues and recognise that boundaries between public and private sectors in such governing styles are often blurred (Stoker, 1998). If a general consensus exists about the need to involve non-state actors in environmental governance, divergent opinions remain about what governance arrangements between state and non-state actors are the most effective in dealing with the complexity, uncertainty and ambiguity that characterise climate adaptation (Mees et al., 2013).

Adaptation governance arrangements range from top-down governance at one end of the scale to societal self-governance at the other end. In existing literature, scholars distinguish between three perspectives of environmental governance. The earliest identified are the hierarchical (i.e. hierarchies, top-down government; governments as the main governing actors) and market governance arrangements (i.e. self-governance; the initiative to implement adaptation measures is left to private actors and civil society) (Lindblom (1977); Williamson (1979)). Davies (2005) sees the hierarchical and market governance arrangements as forming the foundations of the nation-state. Meanwhile, interactive governance arrangements emerged in recent years (i.e. interactive arrangements in which governments and private actors jointly govern) (Thompson (1991); Kjaer (2004); Griffiths et al. (2007)). These three governance arrangements are summarised in Table 2-1 and then outlined in more details in the text that follows.

Table 2-1: Hierarchical, interactive and market models of governance

Dimension	**Hierarchical governance**	**Interactive governance**	**Market governance**
Actor	Predominantly public responsibilities	Shared responsibilities between public and private actors	Predominantly private responsibilities
Rationales	Ensuring a comprehensive approach to adaptation Ensuring national security in face of CV&C Ensuring fairness in distributional consequences of climate impacts or adaptation action Overcoming market failures Coordinating and engaging with various stakeholders	Sharing knowledge on climate information and practices Interacting on environmental / climate adaptation policy making (contention and cooperation)	Implementing private adaptation actions for private and localised benefits Self-coordination of autonomous actors
Policy instruments	All instruments (legal, economic and communication) but predominantly regulations	Mostly communicative instruments and negotiated agreements	Predominantly economic and voluntary instruments

Hierarchical governance arrangements depend on chains of command and control with power as the medium of exchange (Mees et al., 2013). In hierarchical governance, public actors, i.e. government bodies at various institutional levels and sectors, are responsible[3] for steering adaptation. Several reasons support government-led adaptation. First, governments are responsible for elaborating adaptation policies to comprehensively (1) protect those least able to cope (by addressing the causes of vulnerability); (2) provide information to non-state actors for planning and stimulating adaptation; (3) safeguard important public goods such as ecosystem services and

[3] In this thesis, responsibilities are understood as being tasks that an organisation or actor has, whether public, private or a public-private network, and for which it/s-he can be held accountable.

public resources, and (4) harness the possible benefits arising from climate change (Tompkins et al. (2010), McCallum and Isoard (2014)). Second, governments are ultimately responsible for matters of national security. Indeed, in many countries the building of dikes and levees for flood protection for example are seen as typical tasks belonging to the public domain (Berkhout (2005); Brooks and Adger (2005); Heltberg et al. (2009); Aakre and Rübbelke (2010); Osberghaus et al. (2010)). Third, governments can ensure fairness in terms of the distributional consequences of climate impacts or adaptation actions. A key governance challenge is that climate impacts are spatially diverse and might impact certain groups or regions more severely than others. As adaptation measures for one group or region might also have negative consequences for other groups or regions, governments can decide to compensate those groups that are the most vulnerable or affected by climate impacts or adaptation measures (Berkhout (2005); Stern (2007); Osberghaus et al. (2010)). Additionally, climate change risks generate broad social and economic externalities, which might not fully be considered by the private sector (Pricewaterhouse Coopers, 2010). Fourth, governments have a crucial role to play in introducing adaptation regulations, incentives or policies to avoid societal costs from mal- or under adapted business operations (especially if private operations provide public goods, manage common resources or are financed through public funds) or to correct market failures (Prutsch et al., 2014). An example is a public policy encouraging lenders to provide capital to firms for high-risk investments in R&D, leading to the development and implementation of new technologies to adapt to CV&C. However, the complex nature of the climate adaptation problem constrains the capacity of governments to hierarchically steer effective responses to CV&C. Hamann and Börzel (2013) for example, cite the motivation and the coordination gaps that governments experience when trying to coordinate effective responses to climate change. The motivation gap on one hand, occurs because many governments are still grappling with the climate change issue, trying to understand the costs and benefits of diverse policy options. The coordination gap on the other hand, emerges when governments have agreed on broad adaptation strategies but have limited knowledge and means available for actually achieving these. Recognising the limitations of the hierarchical governance arrangements to efficiently coordinate adaptive response to CV&C, interest in "bottom-up" adaptation by businesses, community groups and even social movements starts to emerge.

At the other end of the governance arrangement spectrum, market governance operate through competition and rely on prices as the medium of exchange (Mees et al., 2013). In market governance, the private sector regulates itself; private actors assume responsibility and initiate policy to regulate competition and pre-empt public policy. Climate action is left with the market, because the benefits of adaptation actions are relatively localised and private, compared to mitigation efforts aiming to reduce global GHG emissions that would have large benefits for all (Berkhout (2005); Agrawala and Fankhauser (2008)). Under this mode of governance, government is minimised. Individualism is preferred as this maximises utility, while public bureaucracies are seen as inefficient "rent-seekers" (Roe, 2013). Markets are spontaneous orders that emerge from the self-coordination of autonomous actors. Market governance is multi-centric, consisting of a virtually infinite number of independent actors. Resources are distributed to the firms and companies that are the most profitable (Porter, 1990) and competition between groups leads to innovation (McGahan and Porter, 1997). However, market-failures could lead to non-adaptation, mal-adaptation (unintended actions which are counterproductive, such as the building in flood plains as a result of insurance coverage of house owners) and under- (at lower than optimal levels of action, so that considerable climate risk remains) or over-adaptation (at higher than optimal levels of action, so that considerable costs incurred that could have been minimised) (Mees et al., 2012).

As CV&C cut across all economic sectors and geographical scales (from the local to the national and international levels), adaptation calls for a governance system that moves away from hierarchical or market structures and goes towards a more interactive approach (Brunner and Lynch, 2010). Interactive arrangements are conditioned by dialogue, deliberation and collaboration between public and private stakeholders with trust and reciprocity as a medium of exchange (Mees et al., 2013). In interactive governance, responsibility for climate adaptation is more of a joint public-private effort and climate adaptation is a balancing act between public and private actors.

The theoretical premise behind interactive governance lies in treating societies or institutions as assemblages of a large number of actors and their structure that either limit or facilitate their actions (Kooiman et al., 2008). Polycentric governance (or polycentricity) and network governance, two theoretical streams of interactive governance, both involve multiple, dispersed points of decision making. However, both approaches contrast in their set-ups, what they can achieve, their suitability to tackle certain problems and the place of government as an actor. Indeed, firstly, whereas polycentric governance implies the existence of multiple centres of decision-making at various scales, who self-organise and take part in decentralised initiatives, network governance involves coordinators and facilitators (Ludwig and Kok, 2018). Secondly, polycentric governance is characterised by coordination of activities (collective action), effective problem-solving in complex situation and internal conflict resolution whereas capacity building, learning and scaling up of efforts and rule-setting are the main functions of network governance. In polycentricity, the government is one of many actors within global governance that play an important role, but is not always best-suited to address complex problems; the other actors involved are from different sectors, such as civil society, the private sector and at different administrative levels, from national to local (Ostrom, 2010a). In network governance on the other hand, governmental rules are needed to control for “free-riders and leakages” (Abbott, 2012).

Interactive arrangements for climate adaptation can already be seen in practice. For example, the exchange of climate-related information is one area where public and private actors interact on adaptation. On one hand, governments are responsible for ensuring that businesses have sufficient information to identify adaptation strategies (Benzie and Wallgren, 2014) and that knowledge on climate impacts is distributed as a public goods (Berkhout (2005); Stern (2007); Aakre and Rübbelke (2010); Osberghaus et al. (2010)). Governments then become information providers to businesses. On the other hand, businesses can provide governments with information supporting national strategies. For example, under the UK Adaptation Reporting Power, critical infrastructure and services providers, many of whom are private actors, report on their existing and future climate risks and adaptation plans to the UK government. The UK government then uses the information collated to update its national climate change risk assessment.

Another area where public and private interests overlap is in climate adaptation policy-making. Although adaptation planning often appears to be government-led (Johnson and Priest (2008); Storbjörk (2010); Wilson and Termeer (2011)), in the last decade, private sector companies have been increasingly influencing adaptation policy-making (Falkner (2003); Levy and Newell (2005); Clapp and Meckling (2013)). How private sector organisations impact on environmental policies and governance varies according to the circumstances under which their activities aim at shaping the process in place. According to Clapp and Meckling (2013), the history of corporate involvement in global environmental politics and governance so far points towards a trend ranging from business opposition to environmental regulations to business shaping the regulator options, style and rules of governance arrangements. Though often private sector organisations are spoken about as a monolithic interest group, different business actors hold diverging policy preferences and these differences might lead to undermining business influence over policy processes (Falkner, 2008). In the realm of environmental politics and regulations, private sector organisations could also build alliances to leverage and pool resources together, thus giving them a strategic form of power over policies and governance (Clapp and Meckling, 2013).

Whilst one area of adaptation governance literature has focussed on characterising the hierarchical, market and interactive governance arrangements , another debate has emerged on the issue of public versus private responsibilities for adaptation to climate change. Although some scholars have argued that climate adaptation is a government's mandate, others maintain that the governance of adaptation requires the actions of both public and private actors (Allman et al. (2004); Füssel (2007); Storbjörk (2007); Hinkel et al. (2010)). Indeed, Börzel and Risse (2010) for example, noted that the State capacity to regulate private actors' behaviours is often weak. In addition, companies' responses to CV&C will inadvertently or even purposefully influence the institutional field, which they are part of and in which they are active.

However, Preston et al. (2011) show that in adaptation policy planning a clear allocation of roles and responsibilities between public and private actors is often lacking. This vagueness surrounding the roles and responsibilities for adaptation is often cited as a barrier to adaptation actions (Biesbroek et al. (2010); Dovers and Hezri (2010)).

Exploring existing as well as potential dynamic interactions between public and private adaptation is therefore particularly important (Hamann and Börzel, 2013) and even more so when the continuity of services critical to society needs to be ensured in the face of CV&C. An early examination of this literature reveals that the type of relationship between public and private sector actors has a noteworthy influence on adaptation outcomes and how the private sector is engaged is of significance (Fisher and Surminski, 2012). But engaging the private sector to act and mobilise resources for tackling CV&C is no easy task.

To date, little knowledge is still available on the enabling environments or policy instruments needed to foster private sector adaptation and climate resilience. Stenek et al. (2013)'s analysis reveals that short of one single "silver bullet", five areas need to be considered in an integrated manner to successfully enhance private sector adaptation, namely: data and information, institutional arrangements, policies, economic incentives, and communication, technology and knowledge. Stenek et al. (2013) further found that, in different countries, each of these five areas did not have the same weight in fostering favourable conditions for climate adaptation in the private sector. Such observations highlight the value of taking a closer look at what conditions enable/incentivise and create barriers to adaptation actions in different institutional contexts. This research will contribute to the above debate by exploring how governments engage electricity companies in climate change adaptation and what arrangements exist between public and private actors in the governance of adaptation in the electricity sector in two different countries.

2.3. CORPORATE CLIMATE ADAPTATION

Existing research on climate change and the private sector has mainly focussed on how companies reduce GHG emissions (mitigation), respond to climate mitigation policies and create business opportunities related to both (Levy and Kolk (2002); Kolk and Pinkse (2007); Pinkse and Kolk (2009); Sullivan (2017)). By contrast, literature on private sector adaptation is still sparse (Tompkins et al. (2010); Linnenluecke et al. (2013)) and organisations' adaptation behaviours not well-understood (Sussman and Freed (2008); Pinkse and Kolk (2012)). Cross-disciplinary work integrating findings from studies on how climate change integrates into business thinking, despite starting to filter through the business management and organisational theory literature, still remains limited (Berkhout et al. (2006); Nitkin et al. (2009); Winn et al. (2011); Okereke et al. (2012)). As Berkhout (2012) further points out, corporate adaptation is a difficult process for firms to tackle and for scholars to understand.

Yet, businesses have significant economic weight in global and national economies, and how they rise to the challenge of climate change will have societal consequences beyond the companies' boundaries. For example, a business already internalising CV&C impacts now, will provide reliable and relevant services in an environment of physical, regulatory and commercial changes (Carbon Disclosure Project, 2012). Governments also increasingly realise the potential of business organisations' funding to support climate-related actions. Schneider et al. (2000) reiterate further the importance of corporate adaptation, especially where companies provide critical goods and services (e.g. food, water, electricity, medical care, etc.). As around the world, private sector companies deliver more than eighty per cent of critical infrastructure to the public, national security often depends on how private organisations adapt to CV&C (Schneider et al., 2000). A private company is deemed to provide critical infrastructure if the "systems or assets are so vital to a country that any extended incapacity or destruction of such systems would have a debilitating impact on security, the economy, national public health or safety, or any combination of the above" (Dunn-Cavelty (2008); p. 40). Infrastructure sectors range from unregulated and regulated competitive markets, private sector monopolies to stateprocured public goods. The private sector is deeply involved in these infrastructure sectors, assuming the roles of investor, owner, operator, lender, insurer and as a major user of economic infrastructure. The private sector therefore has a key role in addressing the risks of climate change and ensuring the resilience of economic infrastructure (Pricewaterhouse Coopers, 2010).

Several definitions of risks exist. Originally the idea of risk was strongly linked to the notion of certainty or statistical probability. It was a way to show that the future could be anticipated and, in a certain way, controlled. The notion of risk then was intimately linked to the idea of a modern State able to protect its population against any arising menaces (Borraz, 2008). Nowadays, the notion of risk is often associated with uncertainty and a menacing future where control over threats is actually limited (Borraz, 2008). The definition of risk also varies according to the domain of study. For example, in health and safety, risk is often used interchangeably with hazard and danger whereas in finance, an upside risk is the uncertain possibility of gain, which would be beneficial to investors (Demeritt, 2014). In recent years, “surprises” and “black swans” have emerged to characterise risks and especially climate risks. An event is commonly considered as a “surprise” when it occurs unexpectedly and also runs counter to accepted knowledge (Gross, 2010). Taleb (2011) refers to a “black swan” as a surprising extreme event relative to the present knowledge/beliefs. Hence the concept of risks, surprises and black swans must always be viewed in relation to whose knowledge/beliefs we are talking about, and at what time (Aven, 2014). In this thesis, Haigh and Griffiths (2012)’s characterisation of climate risks as “climatic surprises” will be adopted. According to these authors, climatic surprises occur when organisations are surprised that “climate is becoming more unpredictable at a pace sufficient to increase business uncertainties, directly affecting operations (i.e. impact closer to home than expected) and challenging long-held assumptions about climatic pattern and the ability to project trends on the basis of historical data” (p. 91).

Considering firms as vulnerable to climate risks instead of responsible for climate change is still fairly novel (Linnenluecke and Griffiths (2010); Berkhout (2012); Tashman et al. (2015)). To date the relationship between climate change and organisations has mainly been considered in existing literature through the perspective of how firms' activities impacts upon the climate ("inside-out") rather than in terms of how the changing climate may affect companies ("outside-in") (Porter and Reinhardt (2007); Weinhofer and Busch (2013)). But besides affecting countries and communities, physical climate risks also pose major challenges to companies (Weinhofer and Busch, 2013), leaving them vulnerable when they are not able to cope with these changes (O'Brien et al. (2007); Busch (2011)). Sectors that rely on specific temperature and seasonal conditions, such as agriculture and forestry, have facilities located in climate-sensitive areas, such as coastal areas and floodplains or depend on / own large scale infrastructure, such as the energy, automotive and transportation sectors are particularly vulnerable to climate risks (Intergovernmental Panel on Climate Change (IPCC) (2007); Winn et al. (2011)). Major new forces, such as globalisation and information technologies, can periodically reshape the business world but climate change, in its complexity and potential impact, may rival them both (Porter and Reinhardt, 2007). In particular, physical climate risks can pose challenges so major to business companies that they can lead to a reconsideration of the relationship between organisations and their ecological environment, which until now was supposed to be stable (Winn et al., 2011).

Corporate climate adaptation (CCA, or corporate adaptation for short) refers to a gradual, continuous change process of an organisation as a response to or in anticipation of a stress or shock from the organisations' operating environment (Linnenluecke and Griffiths, 2010). Other definitions suggest that adaptation can involve both building adaptive capacity (thereby increasing the ability of individuals, groups, or organisations to adapt to changes) and implementing adaptation decisions, (i.e. transforming that capacity into action). Both dimensions of adaptation can be implemented in preparation for or in response to impacts generated by a changing climate (Adger et al., 2007). When applied to business organisations, the latter definition suggests that adaptation includes "adjustments and modifications that are being undertaken in expectation of and in response to environmental changes, which cover a wide range of attitudinal, cognitive and behavioural aspects at organisational and individual levels, and which also reflect and interact with the broader institutional or social context of the firm" (Linnenluecke et al. (2013); p. 399). This study adopts the latter definition of corporate climate adaptation.

Nitkin et al. (2009) found that although adaptation has emerged in the business discourse, it is still often being confused with mitigation and is interpreted in a wide variety of ways by a wide variety of actors. Haigh and Griffiths (2012) further note that although organisations have started to identify climate risks in regions where they operate, there was still a "lively disagreement among managers within the organisations about whether changes in local climatic conditions were attributable to global climate change, and there was a reasonable amount of scepticism among them about the rigor of the climate science" (p. 90). Understanding how private sector organisations form their beliefs on the issue of climate change is of paramount importance given the key role that beliefs and cognitive characteristics have in triggering and shaping corporate adaptation processes. A study by Pelling and High (2005) also points towards the importance of perceptions, problem-solving and social learning by different actors in understanding corporate adaptation. Bleda and Shackley (2008) for example developed a computer simulation of how businesses develop an organisational "belief" in climate change aiming to equip users with a very general template that allows them to explore the dynamics of belief for different types of business organisations. Although Bleda and Shackley (2008) made a start in providing an explorative tool on the dynamics of beliefs to climate change in organisations, much work remains to be done.

Different typologies of adaptive actions have been proposed in existing literature (Smit et al. (2000); Burton (2009)). One way, existing literature frames adaptation is to classify adaptation processes according to the types of adaptation actions implemented, i.e. "soft" or " hard" adaptation measures (Agrawala et al., 2011). "Soft" or no regret adaptation measures characteristically address current climate variability concerns and are co-beneficial to existing operations, while also supporting resilience to climate variability and risks. In some cases, they can be undertaken irrespective of predicted climate change impacts (Agrawala et al., 2011). By contrast, "hard" adaptation measures typically have a specific adaptation purpose and entail actions such as adjusting infrastructure and technology, often requiring significant investments (Markandya et al., 2014). “Soft” and “hard” adaptation measures are not mutually exclusive and can be implemented simultaneously.

Another way to conceptualise corporate adaptation is to place adaptation strategies along a “time-related” spectrum of reactive[4] to proactive[5] actions or of short-term coping to longer-term transformational actions. On the one hand, Haigh and Griffiths (2012) for example, point out that the inclusion of climate considerations within businesses’ strategic environments occurred as a response to impacts experienced and as such is reactive. On the other hand, several references argue for the need to develop proactive adaptive solutions in organisations in response to anticipated impacts, taking for granted that this response will be rewarded (e.g. European Environment Agency (EEA) (2003); Boiral (2006); Sussman and Freed (2008)). Being proactive supposes implementing actions intended to cause changes, rather than just reacting to change. How organisations perceive time also conditions adaptation behaviours in organisations. Slawinski and Bansal (2012) suggest that a company’s time perspective forms an important aspect of its character and therefore its response to CV&C. On one hand, organisations that adopt a linear timeline (i.e. that use the continuum of actions from reactive to proactive to plan adaptation) can move quickly and efficiently to work on technological solutions to CV&C but they might not address the problem in a holistic way, focussing instead on one single dimension of the problem. On the other hand, organisations that adopt a cyclical perspective of time, viewing the past, present and future as connected (i.e. organisational learning shaping adaptation responses) are likely to coordinate and learn but the solutions they develop might be slower and incommensurate with the temporal realities of CV&C (Slawinski and Bansal, 2012). Another gap in literature relates to how companies consider future climate change or how organisations responses to climate impacts may change over time.

[4] coping with the consequences of an extreme event

[5] planning ahead of the potential extreme event

A more recent strand of literature on corporate climate adaptation use conceptual frameworks based on organisation theories (e.g. Linnenluecke and Griffiths (2010); Winn et al. (2011)). Indeed, literature starts to emerge considering business adaptation to climate change as "organisational learning". Berkhout et al. (2006) argue that adapting to CV&C is similar to other corporate adaptation and learning processes but distinctive features make climate adaptation more challenging; "the long time-scales and uncertainties inherent to climate change sets it apart from more conventional drivers of change such as competition, technological change or market demand" (Berkhout et al. (2006); p. 153). A useful framework to consider climate adaptation is the "Act - learn- and act again", the on-going process of evaluating current decisions and actions in view of newly available information and re-adjusting them if necessary. Along the lines of this framework, Berkhout et al. (2004) developed a four-stage learning model of corporate adaptation to climate change: Stage 1: Signalling and Interpretation, Stage 2: Experimentation and Search, Stage 3: Knowledge Articulation and Codification and Stage 4: Feedback and Iteration. Moser and Ekstrom (2010) outline another framework where the adaptation process follows three phases: understanding the problem, planning adaptation options and implementing the selected options. No single adaptation approach is likely to fit any organisation. Consequently an organisation will have to screen through a set of possible adaptation paths that will be relevant for its particular setting. This choice will however be restricted by cognitive, organisational and contextual factors. Pelling et al. (2008) also outline a learning model of corporate adaptation but one that considers the broader social context in which organisations make decisions, and by which they are influenced; understanding organisation adaptive capacity is through the lens of six adaptive pathways[6].

[6] "Pathways 1 and 2 acknowledge that the adaptive capacity of an agent is in part expressed through the collective action of which the agent is a part. Pathway 1 speaks to adaptive pathways that result in internal institutional change, Pathway 2 to actions on the external environment. Three pathways connect adaptive capacity to material action by the agent. Pathway 3 describes non-reflexive realignments of resources used to make adaptations in response to top-down command and control. Pathway 4 is an intermediary learning pathway where the agent self-learns from experience to refine the selection of assets with which to enable established adaptive trajectories. Pathway 5 is a reflexive pathway where the goals as well as the mechanisms for adaptation are reviewed and potentially changed. Reflexivity is also present in Pathway 6 where the target of adaptation is the institutional

Existing literature describes three rationales for corporate climate adaptation: the utility-maximising, the behavioural and the institutional approaches (Berkhout, 2012). First, adaptation in organisation can be motivated by economic returns. Literature following this perspective describes adaptation behaviours as the result of optimal choices between a set of clear alternatives whose costs and benefits are known over time. “Utility-maximising organisations” will tend to choose inaction when that is economically optimal, whilst making timely investments in adaptation when it is economically justified (Berkhout, 2012). Although this approach is being criticised for bringing forward invalid assumptions about the nature of the climate impacts (Schneider et al., 2000) or for misunderstanding actors’ adaptation decision-making processes (Risbey et al., 1999), its validity is still worth exploring as increasingly some evidence emerge that points towards the economic benefits of strong and early actions to mediate the effects of CV&C far outweighing the economic costs of not acting (e.g. Stern (2007); Jakob et al. (2012)). Second, adaptation decisions in organisations can be conditioned by the organisations’ perceptions and capabilities; indeed, the strategies that organisations will choose to adopt will be less driven by objective economic assessments like cost and benefit analysis and based more on “messy processes of sense-making, learning and organisational adjustment” (Berkhout, 2012). Third, corporate adaptation can also be shaped and constrained by external social, cultural, political, and economic structures and processes (Berkhout, 2012). Smit and Wandel (2006) reiterate the importance of the institutional environment within which adaptation occurs. This approach offers a major concern linked with the flexibility offered to organisations by institutionally framed rules when they define and implement adaptation actions. External incentives (or disincentives) then become the critical determinants for adaptive actions in organisations.

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architecture of the canonical or shadow systems that constrains or enables future material adaptations” From: Pelling, M., C. High, J. Dearing and D. Smith (2008). Shadow spaces for social learning: a relational understanding of adaptive capacity to climate change within organisations. Environment and Planning A **40**(4): 867-884. https://doi.org/10.1068/a39148 (p. 15-16)

However, this literature on corporate climate adaptation, although informative, remains quite generic and does not refer to any particular type of organisation or sector. This thesis will build on this emerging literature by providing empirical evidence on how business organisations in the electricity sector adapt in the face of CV&C and what factors may support or undermine adaptation decisions in these organisations.

2.4. A MATTER OF TIME: MANAGING EXTREME WEATHER EVENTS AND BUILDING RESILIENCE FOR CRITICAL INFRASTRUCTURES

Time and climate change are indissociable elements. Whilst climate experts suggest that the worst effects of climate change will not be felt for another fifty years (Intergovernmental Panel on Climate Change (IPCC), 2007), urgent actions are needed to mediate the adverse effects of extreme weather events already taking place across Europe. Climate change is a multi-faceted time issue, which is particularly challenging for corporations who face unrelenting pressures to focus on the short-term. Time is therefore central to corporate climate adaptation.

The notion of time has been touched upon in existing research on corporate climate adaptation as this literature typically categorises responses to environmental issues along a time continuum from reactive to proactive (Buysse and Verbeke, 2003). Reactive companies are myopic because they resist acting on social and environmental issues despite the potentially negative consequences of inaction, whilst proactive firms are farsighted, anticipating future needs and regulations (Slawinski and Bansal, 2012). This continuum, however, imposes a rather simplistic view of time, where companies' actions lie somewhere along a single continuum from short- to long-term orientation. Yet in reality, corporate climate adaptation requires companies to balance urgency with long-term impacts. An emerging literature on organisations and time offers a more nuanced view of time, one that asserts different perceptions of time to a number of organisational outcomes and behaviours (e.g. Ancona et al. (2001); Bluedorn (2002)). Mosakowski and Earley (2000) further argue that perceptions of time are important for understanding individual and collective behaviours. Schein

(2010) even asserts that ‘there is probably no more important category for cultural analysis than the study of how time is conceived and used in a group or organization” (p. 134).

Two perspectives on time have dominated social sciences: clock time and event time (Orlikowski and Yates, 2002). Clock time refers to a view of time that is discrete, linear, measurable, divisible, precise, deterministic, and subject to only one interpretation (Mosakowski and Earley, 2000). This view of time has contributed to scientific progress and ultimately helped spur the Industrial Revolution (Ancona et al., 2001). In event time however, different episodes acquire meaning through time (Mosakowski and Earley, 2000). “Events, as with the seasons and weather, will not occur in a completely haphazard way but there will be an irregularity, novelty and multiplicity of events reinforcing the non-linearity of the time scale.” (Butler (1995); p. 934). It is subjective, open, organic, and cyclical (Ancona et al., 2001). Whilst clock time has greatly contributed to progress in the last 200 years, it has also contributed to environmental problems such as resource depletion and climate change. Much remains to be explored about time and organisations’ behaviours but existing research highlights that time is central to organisational responses to climate change and time is therefore an underlying thread throughout this thesis.

Protecting infrastructures against known and unknown threats is crucial to prevent failures and support the recovery of services that are critical to any society’s survival, such as electricity provision. Stressors affecting critical infrastructure are characterised by various degree of uncertainty, ranging from known stressors with known probabilities and quantifiable impacts to the completely unknown. Stressors thus not only include point-in-time influences, such as events and accidents, but also slowly developing conditions that could results in potential failure of the infrastructure. Traditional risk analysis and management focus on those stressors that can be sufficiently characterised and described in terms of frequency of occurrence, size, duration and impacts on the system. The management of this type of stressors is based on the quantitative assessment and evaluation of these stressors as well as the decision-making process to find mediating measures (Aven and Renn, 2010). However, traditional risk management approaches are inadequate “when the uncertainty of stressor characteristics, in terms of frequency and size, or the uncertainty regarding the impacts and damages from stressors, or the dynamics of the structural changes of the system under management, or the interdependence with other systems is growing” (Goessling-Reisemann and Thier (2019); p.122), then it is recommended to complement traditional risk management approaches with resilience management. Resilience-building can be understood as a strategy to deal with deep uncertainty or uncertainty that cannot be reduced by statistics or predictive modelling. Resilience-building and traditional risk management are not mutually exclusive; they complement each other. Instruments to build resilience can be characterised in four broad phases: i) prepare and prevent, ii) implement robust and precautionary design, iii) manage and recover from crises and iv) learn for the future. Table 2-2 outlines more details about each of these resilience approaches. This thesis will explore which of these approaches, if any, electricity companies in the UK and France use to manage extreme weather events and build resilience to future climate change.

Table 2-2: The four phases of resilience management (adapted from Goessling-Reisemann and Thier (2019))

Resilience management phase	Description
Prepare and prevent	After a crisis or near accident, remediation measures should be documented and evaluated to learn about the stressors that caused them and the context in which they occurred or were avoided. Further analysis should cover those stressors that have not yet occurred but are likely to occur in the near future, known from example, from trend extrapolation.
Implement robust and precautionary design	The central elements of resilient systems must comprise robustness, adaptive capacity, innovation capacity and improvisation capacity. These resilience-enhancing capabilities can be achieved by strengthening the vulnerable elements in a system. Exploring alternative solutions to enhance diversity could also help in preparing for unknown future stressors. Attention should also be drawn to components and structures in the system that have not yet been affected but that are crucial to the functioning of the system. Vulnerabilities emerging from coupling between systems should also be analysed.
Manage and recover from crises	If failures of a system lead to crises, these should be kept to the smallest possible areas or sub-system and be overcome as quickly as possible. To reduce the extent of such crises, emergency planning must be devised and implemented. Flexible coupling between systems as well as decentralisation of the system into sub-systems could increase the restorative capacity of a system to deal with crises.
Learn for the future	Mastered or averted crises should be used to learn and increase the adaptive capacity of the system. This can be achieved by documenting and analysing past crises and events thus identifying the weaknesses that led to their occurrence or reversely identify the strengths that led to their avoidance or recovery. Improvisation capacity can be increased by confronting actors with simulations combining external threats and internal failures or equipment.

2.5. CLIMATE ADAPTATION IN THE ELECTRICITY SECTOR

As private sector organisations are often deeply involved in managing critical infrastructure, understanding how they perceive and manage climate risks in the short and longer terms is of paramount importance for any societies. Infrastructures are labelled as critical as they are deemed essential for vital societal functions, including the health, safety, security, economic and social well-being of people (European Council Directive 2008/114/EC, 2008).

Energy infrastructures form the central nervous system of all economies; interruption of electricity provision can have consequences reaching far beyond the electricity systems themselves. History has shown that energy critical infrastructure can and do fail due to extreme weather events or accidental failures with high consequences for society and the economy (Kyriakides and Polycarpou, 2014). Additionally, modern infrastructure operate as a "system of systems" with many interactions, interconnections and interdependencies between them. As such, damages to one infrastructure system can cascade and results in failures onto all related and dependent infrastructure.

Recent extreme weather events across Europe highlighted the urgency to adapt to the unavoidable consequences of climate variability and change. Even if global GHG emissions are stabilised to the 2°C Global Temperature Target (Gao et al., 2017), climate projections point towards higher temperatures and sea levels, changes in sea surface conditions and coastal water quality, increased weather variability, and more frequent and extreme weather events (Intergovernmental Panel on Climate Change (IPCC), 2014a). Already the entire energy supply chain is significantly vulnerable to changing weather patterns (Table 2-3), with extreme weather events (e.g. earthquakes, tsunamis, hurricanes, floods…) found to be globally responsible for 63% of blackouts (Bompard et al., 2013).

Table 2-3: Potential impacts of extreme weather events on the electricity system

Weather patterns	Extreme temperature (heat & frost)	Increase frequency and /or intensity of… …storms, cyclones	…droughts	…floods	Changes in precipitation
Electricity generation					
Thermal power	Decreased power plant efficiency due to higher temperature of cooling water	Decreased generation if infrastructure is affected	Decreased generation due to lack of water for cooling and other operations	Decreased generation if power plants are flooded	
Hydropower	Reduced generating capacity (increased reservoir evaporation / high temp.)	Same as floods	Decreased generating capacity due to reduced runoff and increased surface water evaporation	Reduced generating capacity (forced storage and / or spills) Infrastructure damaged	Changed generating capacity (changes in runoff, reduced storage)
Wind	Decreased power output (decreased air density)	Decreased generating capacity (forced shutdowns if strong winds)	None	Generating capacity lost (physical damage of infrastructure)	Decreased generating capacity (stability of wind towers challenged)
Solar	Decreased efficiency	Reduced generating capacity (infrastructure damaged)	Potential increase in generating capacity of existing units	Local impacts on distributed systems due to local flood damage	Reduced generating capacity
Energy transmission and distribution					
Energy transmission and distribution	Capacity utilisation changed	System reliability reduced due to physical damages	System reliability reduced due to forest fire damages	System reliability reduced due to physical damages	See floods

In general terms, adaptation to climate risks in the electricity sector can take three overarching forms: i) technological, whereby electricity companies invest in new or adapted technologies or improve existing assets; ii) behavioural, whereby utilities relocate their assets or modify their emergency, maintenance and operating plans or iii) institutional, whereby companies and regulators adopt climate change adaptation strategies, assign staff responsibility, incorporate climate risk management into existing systems and standards, or disclose information on climate change impacts and adaptation (Audinet et al., 2014). Table 2-4 presents some generic examples of each of these three types of adaptation actions (adapted from Ebinger and Vergara (2011)).

Table 2-4: Generic examples of adaptation responses in the electricity sector (adapted from Ebinger and Vergara (2011))

	Technological		**Behavioural**			**Institutional**
	"Hard"- structural	"Soft" – technological and design	(Re)location	Anticipation	Operational and maintenance	
Electricity Supply						
Thermal power plants	Flood-proof installations	Improve design of gas turbine	(Re)locate in areas with lower flooding risks	Emergency planning	Manage on-site drainage and runoff Adapt regulations to allow discharge of higher water temperature	Adopt an internal adaption strategy Review internal codes of practice and manuals
Hydropower	Increase dam height	Change in reservoir management	(Re)locate based on changes in flow regimes		Consider water re-use in processes	
Wind power		Improve design of turbines for higher wind speeds	(Re)locate (account for changes in wind speeds)			
Solar power		Improve design of panels to withstand storms	(Re)locate (account for changes in cloud cover)			
Transmission and distribution						
	Improve robustness of infrastructure (withstand extreme events Bury cables					

But whilst some literature on climate adaptation in organisations has started to emerge, it remains scarce in sectors of critical importance to society such as energy, transportation and health (Fankhauser, 2017) and how electricity organisations respond to climate risks is still not well-understood (Linnenluecke et al., 2012). The handful of studies on firm-level adaptation in the electricity sector focus on risk identification, assessment and response in firms (Weinhofer and Busch, 2013), analyse how companies respond to specific climate risks, such as rising temperature, water availability, and extreme weather (Haigh and Griffiths, 2012) or drought (Gasbarro et al., 2016), report empirical insights into the capabilities electricity companies need for climate adaptation (Busch, 2011) and explore the role of organisational learning in adaptation (Orsato Renato et al., 2017). More recently Gerlak et al. (2018) reviewed the existing literature on climate risk management in the electricity sector, focusing on: a) climate change impacts; b) measurement of risks; c) stakeholder engagement and cross-sectoral collaboration, and; d) adaptation actions. Although Audinet et al. (2014) review initiatives to assess climate risks and manage climate impacts in electricity companies in the developed world, they do not consider what drives electricity sector organisations to adapt to climate risks, of which little is still known (Averchenkova et al., 2016). Additionally, whilst some of the studies in the electricity sector are concerned with climate risk management, they are largely documenting how companies managed past climate risks and often do not consider how companies prepare for future climate change or how they appreciate the uncertainties associated with future climate projections. It is also noteworthy that none of the studies on climate change adaptation in the electricity sector explores the interplay between corporate adaptation and the institutional setting within which the companies operate. This thesis will bring new contributions to this nascent literature on corporate climate adaptation in a sector of critical importance.

2.6. SUMMARY

The current variability in climate has already brought the brittleness of critical infrastructures to the attention of engineers, scientists and policy-makers. Future climate change is projected to alter average weather conditions and the nature and intensity of extreme weather events across the world (Wigley (2005); Intergovernmental Panel on Climate Change (IPCC) (2014b)). Gradual shifts in long-term climate elements (e.g. air temperature, precipitation and solar radiation) could reduce the capacity and efficiency of some infrastructure, lead to increase disruption of infrastructure and alter the design life of infrastructure and the effectiveness of the services they provide (Dawson et al., 2018). Given the sensitivity of infrastructure performances to extreme weather events and the cascading implications that potential disruptions to critical infrastructure could cause to society, assessing and managing climate risks for these infrastructure must be priorities, making climate adaptation unavoidable (Moss et al., 2013).

But ensuring the continuity and reliability of critical services, such as electricity supply, amid climate variability and change (CV&C) is not only a technical and managerial challenge but also a political one. Indeed, during the last decades many critical infrastructure sectors have faced substantial reorganisations (Cedergren et al., 2017). As a consequence to these changes, responsibility for operation and maintenance of the services provided by these critical systems have been divided across a multitude of public as well as private actors.

According to existing literature, a lack of clarity about responsibilities for climate adaptation hampers the development of adaptation polices and the implementation of adaptation measures (Storbjörk (2007); Termeer et al. (2013); Wamsler and Brink (2014)) and could lead to under-adaptation, increased climate risks and if adaptation actions are delayed, a substantial rise in costs for adaptation in the medium or long term (Stern, 2007). Traditionally, public actors (i.e. national or local governments) take responsibility for adaptation action to secure sufficient levels of preparedness for present and future generations (Osberghaus et al., 2010). However, if governments are over-ambitious, it may lead to over-adaptation and a waste of resources. On the other hand, responsibilities for adaptation could be left with private sector actors, such as businesses and individuals. But although this arrangement might appear to be more efficient (Mendelsohn, 2006), private actors may exclude other actors and may act to the detriment of others.

Adaptation to CV&C is a new and emerging environmental policy field, in which the boundaries between public and private have not yet been completely defined and in which public and private responsibilities still remain unclear. This context is highly problematic when private companies are responsible for the provision of public services critical for any economy and when unforeseen crises such as natural disasters, civil unrest, extreme economic fluctuations, etc can affect their ability to function.

This highlights the importance of governance arrangements where both public and private actors are involved in adaptation and raises questions on what enabling environments or policy instruments exist to foster private sector adaptation and what infrastructure companies do to manage CV&C risks and ensure the continuity and reliability of critical services. These questions will be answered in this thesis, focussing on the electricity sectors in the United Kingdom and France.

3. METHODOLOGY

Section 2.2 looked at the emergent climate adaptation governance, reviewing what roles and responsibilities are outlined in existing literature for public and private sectors in adaptation to climate change. The review suggests that although risks have traditionally been linked to governments being able to protect their populations against any arising menaces, adaptation to climate risks requires a more decentralised approach involving both state and non-state actors. As private sector organisations are often deeply involved in managing critical infrastructure, understanding how they understand and manage climate risks in the short and longer terms is of paramount importance for any economies.

This section will now consider the most appropriate way to investigate how electricity companies perceive and manage climate risks and what drives corporate climate adaptation. It presents the interpretive philosophy underpinning the research and outlines the qualitative multi-method approach to data collection, consisting in a systematic literature review, a multi-case study and third-party interviews. Some reflections on the questions of research ethics and trustworthiness complete the chapter.

3.1. THE RESEARCH PHILOSOPHY

The previous sections contained terms, such as “understand”, “beliefs”, “long-held assumptions”, “interpretation” and “exhibit” that point to the interpretive nature of this study. In contrast to a positivist approach that argues that reality exists external to the researcher and must be investigated through the rigorous process of scientific inquiry, the interpretivism approach “looks for culturally derived and historically situated interpretations of the social world” (Crotty (1998); p. 67). Interpretivists believe that social reality is not objective; instead, it is extremely subjective as it is formed by people’s perceptions (Collis and Hussey, 2013).

This thesis adopts an interpretivist approach for four reasons. First, in interpretive research emphasis is placed on understanding how participants make meaning of a phenomenon, process, or perspective views (Merriam, 2002). Interpretivism as a theoretical perspective allows the researcher to learn more about the multiple constructions and interpretations of reality at a particular point in time and in a particular context. This study calls for a research approach that recognises that multiple understandings of climate risks exist, and that how climate risks are perceived by decision-makers will influence whether and how corporate climate adaptation takes place. Second, the interpretivist approach emphasises the importance of context. Including the institutional contexts the electricity companies operate in is of importance for this study as, as Linnenluecke et al. (2013) point out "firm and industry adaptation will always be strongly influenced by the context in which firms and industries are embedded" (p. 407). Third, this study does not aim to generate cause-effect relationships but rather, the process of interviews and interpretive data analysis lead to deeper understandings of human behaviours, intentions, and experiences in everyday life (Orlikowski and Baroudi, 1991). Fourth, this research is by nature exploratory as literature on corporate climate adaptation is still scant. In keeping with interpretivism, this work followed an inductive approach, beginning with a topic, and then developing empirical generalisations and identifying preliminary relationships as the research progressed.

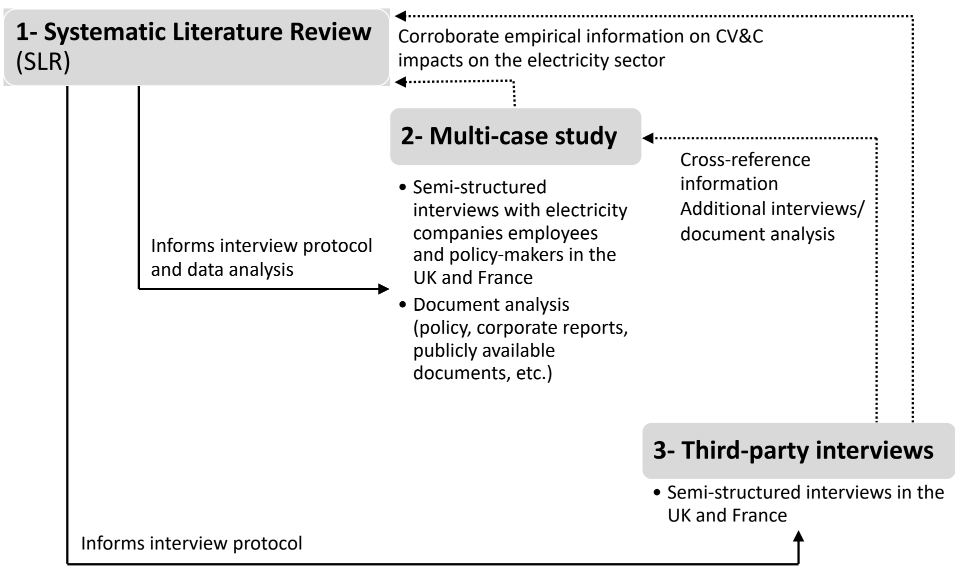
3.2. THE RESEARCH APPROACH

The decision to pursue a qualitative, rather than quantitative approach, follows directly from the nature of the research aim. Indeed, this research is not concerned with developing cause-effect relationships like in quantitative research but rather to understand organisational behaviour and particularly corporate climate adaptation. A multi-method approach to data collection, consisting in a systematic literature review, a qualitative multi-case study and third-party conversations was employed to make sense of corporate climate adaptation, a new phenomenon where little is known (McKeown, 2004).

Using a multi-method approach to studying climate corporate adaptation has several advantages. First, “different research methods (…) focus on different aspects of reality and therefore a richer understanding of a research topic will be gained by combining several methods together in a single piece of research or research program.” (Mingers (2001); p. 241). Second, it allows for data to be triangulated (Hammond, 2005). Third, it makes allowance for the discovery of paradoxes and the discovery and confirmation of unexpected outcomes (Hoyles et al., 2005).

Figure 3-1 presents how the three elements of the multi-method approach are connected to each other’s. It is to be noted that the SLR was carried out first. The multi-case study and third-party interviews were then carried out simultaneously in the United Kingdom and in France.

Figure 3-1:Flows between each component of the data collection



How the data collection fits into the broader research design is presented in Figure 3-2. Further descriptions of the methods of data collection and analysis are outlined in chapters 4, 5 and 6. Chapter 4 (and Appendix C in section 10.3) describes in detail the systematic literature review. Chapters 5 and 6 (and respectively Appendix D in section 10.4, and Appendix A in section 10.1 and Appendix B in section 10.2) give detailed accounts of the documents included in the study as well as of their analyses and of the interviews with electricity company employees, policy-makers and third-party practitioners. Consequently, the following sections will only expand on the rationales behind the choice of the multi-case study approach and the third-party interviews.

Figure 3-2: Overview of the research questions (RQs) and the respective data needs and methods of data collection and analysis

Research Questions (RQs)	Data needs	Data collection	Data analysis
RQ1: What do we know about the impacts of CV&C on electricity systems in Europe?	Peer-reviewed articles on the impacts of CV&C on electricity generation, distribution and transmission in Europe	Systematic Literature Review of peer-reviewed articles	
RQ2: How are existing governance arrangements and policy instruments ensuring the lights stay on despite CV&C in the United Kingdom and France?	Information on what policy instruments national governments in the UK and France use to ensure electricity supply reliability and resiliency despite CV&C	Multi-case study (UK and France): - Purposive sampling of policy documents on electricity supply continuity and reliability	Content analysis of policy documents through inductive category development
RQ3: How do electricity companies manage physical climate risks?	Information on how electricity companies perceive climate risks and how they manage them	Multi-case study (UK and France): - Semi-structured interviews with electricity company employees and third-party practitioners to explore how climate risks are perceived and managed in companies and the triggers or barriers to climate adaptation are. Semi-structured interviews with policy-makers to uncover policy instrument influence on corporate adaptation - Literature search on publicly available corporate documents and reports, UK ARP reports and policy documents.	- Content analysis of interview transcripts and documents through inductive category development - Personal reflections during the research process using a research diary
RQ4: What drives and triggers adaptation measures in these companies?	Information on the drivers and barriers for climate risk management in electricity companies		

The multi-case study

This component of the qualitative approach seeks to obtain and understand organisational perceptions (of climate risks), practices (i.e. how companies adapt or not to climate risks) and motives (i.e. internal and external factors). The case study method is considered appropriate for generating and testing theory about previously understudied topics (Yin, 2014) and is therefore well-suited to the under-researched topic of corporate climate adaptation.

Applying a multi-case study technique is particularly relevant for answering “how” and “why” questions (Hagg and Hedlund (1979); Eisenhardt (1989); Yin (2017)). Additionally, multi-case study can help overcome some of the potential analytical challenges that may arise from the localised and context-dependent nature of climate change and corporate responses to it.

Following Gasbarro (2013)’s underlying reasons for selecting case studies, cases in this research were chosen “in order to allow an analytical generalisation of findings through a literal and theoretical replication, ensuring the possibility of discovering similarities among the cases, and to predict contrasting results for predictable reasons” (p.115).

The former is achieved because all the companies included in this study have:

a) existing sensitivity to climate variability and change, but are able to overcome many climate issues;
b) the ability (economically and technologically) to significantly tackle climate change directly and indirectly;
c) a big influence on society and economy as critical infrastructure providers.

To allow the latter, two different countries were chosen for case-study analysis, whereby a degree of variation exists between:

a) the national institutional and regulatory environments (i.e. modes of governance) the companies operate in;
b) the national sectoral structure the companies are part of.

The choice of companies in the electricity sector as objects of analysis was motivated by several factors (i.e. the similarities described above). First, the energy sector is already confronted with extreme weather events and is becoming increasingly aware of the risks that CV&C pose for its operations and reputation (e.g. “Energy company bosses to be summoned to appear before Members of Parliament over Christmas power cuts[7]"; "Climate change – a new risk reality for utility companies[8]"). Second, the energy sector is already gearing up towards mediating current and future risks (e.g. Électricité de France adopted in 2010, a Sustainable Development Strategy that includes a concrete commitment towards adapting its generation fleet and customer offers to climate change - (Électricité de France (EDF), 2010)). Third, electricity provision is critical for any economy.

The EU BASE project[9] provided the funding for this research, thus delimiting its geographical focus to Europe. For the contrasting element of the study, the United Kingdom and France, two western democratic countries in Europe with different economic, political and cultural contexts, were selected. Table 3-1 summarises each country unique characteristics in regard to the mode of governance and the sectoral structure electricity companies operate under / are part of. These unique characteristics were used to provide structural variables to explain any potential differences in patterns of organisations' responses to climate change.

7 From: http://www.telegraph.co.uk/finance/newsbysector/energy/10542870/Energy-company-bosses-to-be-summoned-to-appear-before-MPs-over-Christmas-power-cuts.html, [Accessed 29/03/2014]

8 From: http://www.worldenergy.org/documents/congresspapers/411.pdf., [Accessed 29/03/2014]

9 For more information, see http://base-adaptation.eu/

Table 3-1: Summary of the case studies' contrasting characteristics

	National institutional and regulatory environments (mode of governance)	National structure of the electricity sector
UK electricity sector	State-Centric mode of governance, whereby the state is at the centre of the process, but institutionalises its relationships with social actors (Pierre and Peters, 2005). As such it tries to connect planned strategies with openness for actor's initiatives.	The British electricity sector evolved into a market involving producers from large multinationals to small family businesses running a single site. In 2014, 70% of generation capacity was owned by the "Big Six" companies[10] (Ofgem et al., 2014). Transmission is dominated by National Grid Electricity Transmission plc, Scottish Power Transmission Limited, Scottish Hydro Electric Transmission plc. Fourteen licensed distribution network operators (DNOs)[11] are each responsible for a regional distribution services area.
French electricity sector	Étatist mode of governance where "the government is the principal actor for all aspects of governance and can control the manner in which the social actors are permitted to be involved, if they are at all. (Pierre and Peters, 2005). This means that the political institutions are the ultimate locus of authoritative power and they therefore largely determine the contents and the organisation of policies; crucial resources are controlled by the state and other than state actors are placed in a dependent position and have limited access to decision-making.	Although the French generation sector is entirely open to competition, in 2014 three companies generate most of the domestic electricity: Électricité de France (EDF) (French, 78%), Engie (French, 8%) and E.ON (German, 2%) (Levallois, 2015). Réseau de Transport d'Electricité (RTE) is the transmission operator and Enedis operates 95% of the distribution grids. Both are fully-owned subsidiaries of EDF.

10 The "Big Six" companies include Électricité de France (EDF) (that owns EDF Energy UK) (French), E.ON (German), RWE (that owns Npower) (German), Iberdrola (that owns Scottish Power) (Spanish), Centrica (that owns British Gas) (UK) and Scottish and Southern Energy, SSE (UK).

11 The UK distribution network operators (DNOs) are owned by six different groups: Electricity North West Limited, Northern Powergrid, Scottish and Southern Energy, Scottish Power Energy Networks, UK Power Networks and Western Power Distribution.

To explore corporate climate adaptation, an approach looking at organisations in their institutional contexts was preferred to an approach favouring inter-companies comparison. This choice was motivated by several factors. First, given the heterogeneity of the electricity companies included in this study (i.e. different sizes, ownership arrangements, activities, geographical coverage, exposure to climate risks etc.), a rigorous comparison of organisation behaviours in the face of climate risks would not be possible as too many factors would have to be taken into consideration to offer any meaningful insights. Rather, this study is more concerned with understanding the electricity companies' collective behaviour than comparing their practices. Second the institutional context is of paramount importance for the study for three reasons:

a) electricity companies, like any other organisations, are embedded in a historical, sociocultural, economic and political context which shapes the norms, values and expectations that in turn influence the structures and processes of the electricity system (Suddaby et al., 2010),
b) context is not simply a stage on which action takes place. The context of an organisation is fluid and dynamic, influencing and in turn shaped by organisational events (Dopson and Fitzgerald, 2005),
c) the institutional context is also responsible for reinforcing and perpetuating organisational characteristics, and for maintaining patterns of continuity that could support or hinder organisational activities (Buchanan and Fitzgerald, 2011).

To better understand the institutional contexts electricity companies operate in, in the UK and France, policy documents on electricity supply continuity and reliability were sourced and analysed (chapter 5).

To capture true accounts of the companies climate perspectives and practices, semi-structured interviews were conducted with electricity companies employees selected based on their roles in assessing and managing climate risks. One participant was typically interviewed per electricity sector organisation unless the company had different sub-units for assessing and managing climate risks. If this was the case, two or more interviews were carried out with representatives of the same organisation. Semi-structured interviews were also carried out with national policy-makers to better gauge the influence existing policy instruments have on corporate climate adaptation in the French and UK electricity sector. The semi-structured interview format allows for qualitative and open research questions, tied to an interview protocol which may also provide structured prompts for respondents to construct a narrative account of their experiences ("tell me about a time when…"), as a valid way for respondents to frame their understanding of the issue. When several respondents frame their experiences consistently, this supports consistent analysis.

As behaviour may be best understood if observed by more than one method (Darlington and Scott, 2002), analyses of publicly available corporate documents and reports, including the UK ARP reports supplemented the semi-structured interviews with electricity companies employees (chapter 6). Such "triangulation" by multiple methods increases validity and reduces bias (Flowerdew and Martin, 2008).

Third-party interviews

In order to better understand corporate decision-making and cross-reference the information gathered through interviewing electricity company employees and policy-makers, interviews with "third-party" practitioners were also carried out using the same interview procedures. Participants were individuals who provide specialist advice on a consultancy basis to corporate businesses and investors (e.g. consultant), who provide support and advice to businesses and Government through practice-based research (e.g. researchers) and who run supports networks or forums on climate change in critical infrastructure (e.g. the UK Infrastructure Transitions Research Consortium).

3.3. Ethical considerations in the research

Ethical considerations are paramount in any research involving participants. When interviewing electricity company employees, policy-makers and practitioners on the sensitive topic of risks, it was necessary to keep in mind the potentially unfavourable consequences they might face of being put in a difficult position vis-à-vis employers, co-workers or others.

In line with current practice at the University of Leeds, ethical considerations were carefully thought through at the onset of the research and addressed with care. These included among others, to secure voluntary participation, to inform participants about the research and to ask them to sign a consent form prior to the interview taking place, to be careful not to put participants at risk in any ways, to respect confidentiality and to present respondents' views accurately. Interviewees' anonymous profiles can be found in Section 10.1.

The interviewees' identities were concealed and as such interviewees remained anonymous and care was taken that when quoted, the statement could not be traced back to the interviewees. Respondents were also given assurance that their statements would remain confidential, and that data would be stored securely. Audio and transcribed data are to be destroyed on completion of the research project; and transcriptions and other work-in-progress analyses were themselves stripped of any identifying features. For research integrity, original data remained open to research supervisors' access whilst the research was ongoing and the thesis written up.
The Environment and Leeds University Business School (AREA) Faculty Research Ethics Committee of the University of Leeds, granted ethical for the research in October 2014 (AREA 14-029).

3.4. Research trustworthiness

The value of findings generated by research adopting the interpretive paradigm is determined by the degree to which it fits and works with the perspectives of the participants (Glaser, 2017). In judging the quality of qualitative research, trustworthiness is the term that is often used. Trustworthiness simply poses the question of whether the findings can be trusted. Several definitions and criteria of trustworthiness exist (Korstjens and Moser, 2017), but the best-known criteria are credibility, transferability, dependability, and confirmability as defined by Lincoln and Guba (1985).

Research credibility

Credibility is the confidence that can be placed in the truth of the research findings. Credibility establishes whether the research findings represent plausible information drawn from the participants' original data and is a correct interpretation of the participants' original views (Lincoln and Guba, 1985). Data triangulation was the strategy chosen to ensure credibility of the research. The findings from the systematic literature review on the impacts of CV&C on the European electricity sector corroborated the answers provided by all the interview participants when asked about climate risks in the electricity sector. The analysis of the policy documents to ensure continuity and reliability of electricity supply was supplemented with interviews with policy-makers. The interview data gathered with electricity companies employees were triangulated with the analyses of publicly available corporate documents. Interviews with third-party practitioners further cross-checked some of the statements gathered during the interviews with electricity company employees and policy-makers.

Credibility and researcher-induced bias

Bias is commonly understood as being any influence that provides a distortion in the results of a study (Polit and Beck, 2014). For example, interviewer bias arises when the interviewer's appearance or behaviour influences the interviewee's responses (Saunders et al., 2012).

Some qualitative researchers believe that researcher's bias and values hinder the outcomes of a study (Merriam, 1998) and that the relationship interviewee-interviewer is the greatest underlying threat to research outcome credibility (Roller and Lavrakas, 2015).
However, others such as Peshkin (1988) points out that "one's subjectivities could be seen as virtuous, for bias is the basis from which researchers make a distinctive contribution, one that results from the unique configuration of their personal qualities, and joined to the data they have collected" (p. 18). As such an honest and open disclosure of the researcher's positionality[12] can help in establishing the credibility of the research findings. A statement of positionality does not attempt to minimise bias but rather aim to recognise that a bias does exist but if openly discussed can help the reader to make his/her own judgement on the truthfulness of the research. The following paragraphs outline the researcher's positionality.

I have spent the five years before the beginning of my PhD working in the field of climate adaptation as a senior consultant. The projects I led or was involved in then were mainly in the developing countries context. Although very interesting and enriching these projects touched on adaptation to climate change from a development perspective. I was however increasingly aware that little existed in research and practice on climate adaptation in the private sector in developed countries. These gaps in research and a strong personal interest in climate adaptation motivated the choice of topic for this study.

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[12] Positionality recognises that researchers are part of the social world they are researching. Positionality both describes an individual's world view and the position he/she has chosen to adopt in relation to a specific research task (Foote, M. Q. and T. G. Bartell (2011). Pathways to equity in mathematics education: how life experiences impact researcher positionality. Educational Studies in Mathematics **78**(1): 45-68. https://doi.org/10.1007/s10649-011-9309-2; Savin-Baden, M. and C. H. Major (2013). Qualitative research: the essential guide to theory and practice, Routledge. ISBN: 9780415674782).

The design for this research was also very much influenced by my prior knowledge and views on the different framings of climate adaptation. For example, I strongly believe that uncertainties in climate projections should not be a reason for inaction or to delay action to mediate climate variability and change. Climate projections are certainly important evidence but are only a part of the evidence-base needed to make adaptation decisions.

I also had experience in carrying qualitative interviews before starting my doctoral studies. However, the fact that most of my interviewees were in influential positions in electricity companies, government or other institutions (e.g. Head of Sustainability, Climate Change and Sustainability Director, General Secretary of a Government Department, Director and Advisory Board Member…) positioned me in an inferior position in the researcher–researched relationship. This position of inferiority favoured openness from the interviewee as they assumed I had limited knowledge in the area researched and as such shared information that they might have concealed, had I been interviewing them not as a doctoral researcher but as a senior consultant. It is to be noted however that care was taken not to deceive participants about myself, as I systematically disclosed my background and previous professional experiences to the interviewee before conducting the interviews.

Research transferability

Transferability is about the degree to which the study has made it possible for the reader to apply the findings in the situations investigated to such other similar situations (Lincoln and Guba, 1985). In this study the researcher took care in providing much details on the conditions (i.e. the context in which the research was carried out; its setting; sample size, strategy, characteristics; inclusion and exclusion criteria; interview procedures and topics; etc) surrounding each of the research processes in the empirical chapters. That way the readers could assess whether the research findings are transferable to their own settings and meaningful to them.

Research dependability and confirmability: the audit trail

Dependability is the stability of findings over time. Dependability involves participants' evaluation of the findings, interpretation and recommendations of the study such that all are supported by the data as received from participants of the study (Lincoln and Guba, 1985).

Confirmability on the other hand is the degree to which the findings of the research study could be confirmed by other researchers. Confirmability is concerned with establishing that data and interpretations of the findings are not figments of the inquirer's imagination, but clearly derived from the data (Lincoln and Guba, 1985).

The strategy needed to ensure dependability and confirmability is known as an audit trail (Korstjens and Moser, 2018). Formal assessment after 12 months (the transfer stage), together with supervision meetings provided further scrutiny of the research design and practices. During these meetings, the researcher outlined to the supervisors and assessors the decisions made during the research process as well as reflective thoughts, sampling, research materials adopted, emergence of findings and information about data management. This enabled the auditors to make sure of the transparency and comprehensiveness of the research path.


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Is the UK's energy infrastructure resilient to the power of nature?
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World's energy systems at risk from global warming, say leading firms
Energy grids, power stations and distribution networks are vulnerable to storms, flooding and heatwaves caused by climate change, say World Energy Council
LIVE
Floods and power loss after storm
Impacts on energy
The Met Office has been working closely with UK energy companies on EP2, an innovative project looking at the effects of climate change on the energy industry.

4. A SYSTEMATIC REVIEW OF THE IMPACTS OF CLIMATE VARIABILITY AND CHANGE ON ELECTRICITY SYSTEMS IN EUROPE

Published as Bonjean Stanton, M. C., Dessai, S. and Paavola, J. 2016. A systematic review of the impacts of climate variability and change on electricity systems in Europe. Energy 109: 1148-1159. DOI: http://dx.doi.org/10.1016/j.energy.2016.05.015

4.1. INTRODUCTION

Devastating consequences of extreme weather are repeatedly making the front pages of the media across Europe, as they challenge the provision and security of critical services (e.g. BBC (2015); Gayle (2015); BBC (2016)). Understanding the impacts of climate variability and change (CV&C) on electricity systems[13] is increasingly important not only for electricity companies providing such critical services, but also for policy-makers in charge of ensuring the security of a country's electricity supply. As energy infrastructures form the central nervous system of all economies, interruption of electricity provision can have consequences reaching far beyond the electricity systems themselves.

Although the global impacts of CV&C on the energy sector have been explored in the literature (Ebinger and Vergara, 2011, Bruckner T. et al., 2014), the impacts of CV&C on the electricity systems have received less attention and regional, national and local assessments are still rare (Chandramowli and Felder, 2014).

Existing studies of impacts of CV&C on electricity systems can be divided into three strands. First, some studies use the findings from empirical literature to assess the

[13] Electricity systems are defined here as networks of physical assets used for electricity generation, transmission and distribution

impacts of CV&C beyond electricity systems. For example, Mideksa and Kallbekken (2010) examine the impacts of CV&C on demand and supply in the electricity markets whilst Rayner and Jordan (2013) investigate the impacts of global warming on trade in electricity between European countries and on national electricity prices. Schaeffer et al. (2012) explore the literature on the impacts of CV&C on resource endowments, energy supply, and energy use and infrastructure.

Second, some assessments, such as Klein et al. (2013), construct indices to assess the susceptibility of the energy sector to the impacts of CV&C: they compare the impacts on energy systems in twenty-one European countries using an index based on variables such as summer temperature increases, discrepancies between production and consumption and the volume of imports and exports. Bardt et al. (2013) in turn compute risks and opportunities posed by changing climatic conditions for energy sectors in France, Germany, Norway and Poland on the basis of expert interviews.

Third, some assessments focus on the statistical relationships between climatic and energy variables. They use the outputs of climate modelling experiments as inputs in electricity generation and network impact models. Peer-reviewed articles using this approach were the objects of this systematic review. Only the articles from this latter strand of literature were selected for the review as the assessment approaches they use are more homogeneous and as such their results can be more consistently put in the context of each others'. The systematic review approach was used in order to collate, evaluate and interpret all the results of such research.

This review aims to identify the impacts of CV&C on electricity systems in Europe to answer the questions: i) what patterns of impacts of CV&C on electricity systems can be identified by collating the results of peer-reviewed articles? ii) are any of these patterns robust?

The rest of the chapter is divided into four sections. Section two describes the method used in the systematic review and the data. Section three presents the results of the systematic review, including robust patterns of impacts of CV&C on electricity systems in Europe. The final two sections discuss the implications of the results for further studies and for decision-making and conclude.

4.2. METHOD AND DATA

4.2.1. Method

The peer-reviewed articles included into this study were selected using a systematic literature review (SLR, see Berrang-Ford et al. (2015)). A literature review is "systematic" when it is based on a clearly formulated question, identifies relevant studies, appraises their quality and summarises their evidence (Khan et al., 2003). The SLR methodology is explicit and contains enough information to be reproducible. SLRs collate, evaluate and interpret all research available and relevant to a particular question, topic area, or phenomenon of interest. SLRs are widely used in medical research but they are still under-utilised in other disciplines including in climate science (Porter et al., 2014).

The well-defined methodology makes SLRs less likely to be biased. SLRs can also provide information about the effects of a phenomenon across a wide range of settings and empirical methods; if the studies yield consistent results, the reported effects can be considered robust. If, on the other hand, the SLR yields inconsistent results, these dissimilarities can be analysed further (Biondi-Zoccai et al., 2011).

SLRs have also their shortcomings. They are time-sensitive snapshots of the literature on their subject. Another drawback is closely linked to the type of evidence commonly used in SLRs: significant results published in peer-reviewed articles, which leads to under-representation of non-significant results.

The results of the reviewed articles were collated to assess whether robust patterns of impacts of CV&C can be identified at regional, national or sub-national scales on any parts of the electricity systems. The term "robust" does not refer here to "statistical robustness" as is sometimes done in climate science where future changes are considered robust "when i) present-future model ensemble mean difference is significant at the 95 % confidence level according to the Wilcox-Mann–Whitney test applied to the whole model ensemble (adapted from Jacob et al. (2014)) and ii) at least 12 models out of 15 agree on the sign of change" (Tobin et al., 2015). In this SLR we use Lloyd (2015) definition of robustness as "the standard convergence of predictions/retrodictions of multiple instantiations of variants of the model-type, as well as exploration and empirical confirmation of an array of empirical model assumptions, which can be seen as aspects of random, well-supported experiments when a variety of evidence inferences to support the core structure are used". This is a more qualitative take on robustness, in which the convergence of the results of independent empirical studies corroborates a given phenomenon.

The SLR was carried out in four successive steps: 1) search for peer-reviewed articles in Scopus using different keyword combinations; 2) high-level screening of the returned articles by applying four inclusion criteria; 3) further screening of the retained articles using a star-rating scorecard; and 4) collation and analysis of the results from the subset of included articles.

Scopus was chosen over Web of Science (WoS) as a search database because it covers four times more journals. The search included records from 1960 (i.e. "all years" in Scopus) to mid-2015 (i.e. 19th of July 2015). When selecting the search keywords, care was taken to use both generic and specific terms (Egan et al., 2012) and to include relevant word variants related to climate variability and change and climate data (i.e. climat*, climat* change, climat* project*, climat* model*, climat* condition*, weather, stochastic simulation, change, project*, model*, condition*), impacts and vulnerability (i.e. impact*, ?ffect*, sensitivity, susceptibility, availability, potential*, performance, vulnerab*, assessment, consequence*, *plication) and electricity or power (i.e. energy, power, electric*, hydropower, hydro*, *energy, *lectric*).

First the accuracy of the search strategy was ensured by comparing the returned articles resulting from searches in Scopus to a benchmark collection of relevant studies collated from previous work (Bonjean Stanton et al., 2016a). Then, 734 searches were run in Scopus using the improved keyword combinations. The searches yielded a total of 24463 articles (including duplicates). Once imported into the EndNote software, the articles were first screened using four high-level inclusion criteria and only the articles complying with all of these criteria were retained. These four criteria specified that articles needed to be 1) with European coverage (as defined by the United Nations Statistics Division) and 2) in peer-reviewed journal and 3) in English and 4) focusing on the impacts of CV&C on electricity generation and networks in the near-, medium- and long-term (no reviews).

Following Porter et al. (2014), the retained articles (n= 57) were then screened using a scorecard to differentiate between rigorous and less rigorous publications. The scorecard's star-rating scheme ranges from zero to five stars. In a five star article the study design and methods are highly appropriate for the research question and they are clearly outlined and justified. Several climate models and scenarios are used for assessing impacts for several time-periods, annually and seasonally. The information on the calibration and validation of the climate and impact models used is explicit. The results are triangulated and set in the context of other studies (e.g. Finger et al. (2012); Majone et al. (2015); See Appendix C in section 10.3). In a four star article, the methods are clearly justified and several climate models and scenarios are used in the assessment but information on model calibrations, study limitations, or result triangulation is missing. In a three star article, the chosen method is appropriate for the assessment to be carried out. Information on the number and types of climate scenarios and climate and impact models used and their calibration is mentioned but not explained in detail. The results are clearly presented but their implications are not outlined explicitly nor triangulated against other studies. Articles using a single climate scenario, one/two climate model(s) and pre-compiled climate variable datasets were also classed as three star articles. Articles scoring less than three stars were excluded; such articles provided too little information on the method and the datasets used in the assessment and hence the results of such studies were not considered to be sufficiently rigorous to be included in this review.

Out of the 50 peer-reviewed articles retained for review, 9 were classed as five star, 29 as four star and 12 as a three star. Using the latest climate models or scenarios (e.g. the Representative Concentration Pathways, RCPs) did not automatically qualify the article as five star; all the scorecard attributes were considered conjointly to assign an article to a star category.

4.2.2. Data

There were 50 articles scoring three stars or more. They were retained for further analysis and labelled #1-50 (See Table 4-1). Their publication dates range from 1997 to 2015: there are more publications for years 2012 and onwards compared to the earlier years (Figure 4-1; 1a). A third of the articles are on hydroelectricity generation, followed by articles on wind electricity (28%), thermal electricity (14%), solar electricity (13%), bioenergy (7%), and wave energy (3%) (Figure 4-1; 1b). One article focused on the electricity networks (2%) (Figure 4-1; 1b).

Table 4-1: Data included in this study

Identifier #	Paper reference
1	Aronica, G. T. and B. Bonaccorso (2013). "Climate change effects on hydropower potential in the Alcantara River basin in Sicily (Italy)." Earth Interactions 17(19).
2	Baltas, E. and M. Karaliolidou (2010). "Land use and climate change impacts on the reliability of hydroelectric energy production." Strategic Planning for Energy and the Environment 29(4): 56-63.
3	Barstad, I., A. Sorteberg and M. D. S. Mesquita (2012). "Present and future offshore wind power potential in northern Europe based on downscaled global climate runs with adjusted SST and sea ice cover." Renewable Energy 44: 398-405.
4	Bellarby, J., M. Wattenbach, G. Tuck, M. J. Glendining and P. Smith (2010). "The potential distribution of bioenergy crops in the UK under present and future climate." Biomass and Bioenergy 34(12): 1935-1945.
5	Bloom, A., V. Kotroni and K. Lagouvardos (2008). "Climate change impact of wind energy availability in the Eastern Mediterranean using the regional climate model PRECIS." Natural Hazards and Earth System Sciences 8(6): 1249-1257.
6	Burnett, D., E. Barbour and G. P. Harrison (2014). "The UK solar energy resource and the impact of climate change." Renewable Energy 71: 333-343.

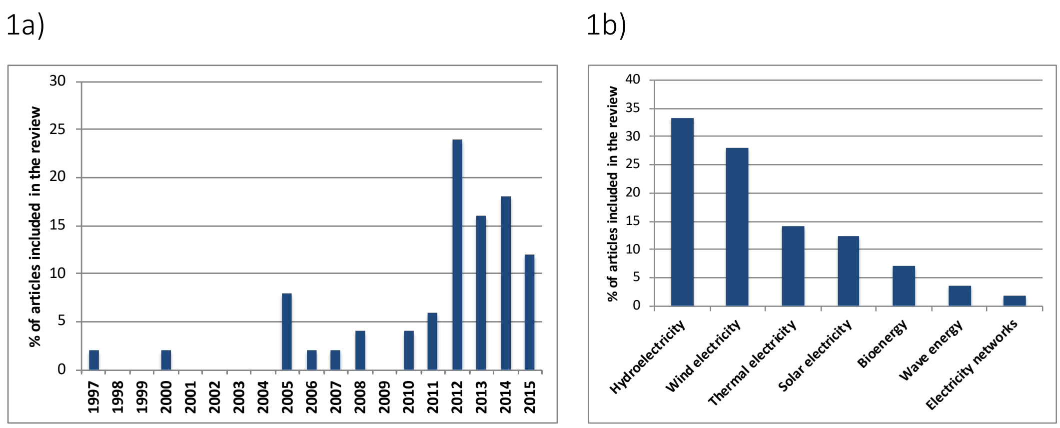
Identifier #	Paper reference
7	Carless, D. and P. G. Whitehead (2013). "The potential impacts of climate change on hydropower generation in Mid Wales." Hydrology Research 44(3): 495-505.
8	Chernet, H. H., K. Alfredsen and Å. Killingtveit (2013). "The impacts of climate change on a Norwegian high-head hydropower system." Journal of Water and Climate Change 4(1): 17-37.
9	Cosentino, S. L., G. Testa, D. Scordia and E. Alexopoulou (2012). "Future yields assessment of bioenergy crops in relation to climate change and technological development in Europe." Italian Journal of Agronomy 7(2): 154-166.
10	Cradden, L. C., G. P. Harrison and J. P. Chick (2012). "Will climate change impact on wind power development in the UK?" Climatic Change 115(3-4): 837-852.
11	Crook, J. A., L. A. Jones, P. M. Forster and R. Crook (2011). "Climate change impacts on future photovoltaic and concentrated solar power energy output." Energy and Environmental Science 4(9): 3101-3109.
12	Dowling, P. (2013). "The impact of climate change on the European energy system." Energy Policy 60: 406-417.
13	Finger, D., G. Heinrich, A. Gobiet and A. Bauder (2012). "Projections of future water resources and their uncertainty in a glacierized catchment in the Swiss Alps and the subsequent effects on hydropower production during the 21st century." Water Resources Research 48(2).
14	Flörke, M., I. Bärlund and E. Kynast (2012). "Will climate change affect the electricity production sector? A European study." Journal of Water and Climate Change 3(1): 44-54.
15	Gaetani, M., T. Huld, E. Vignati, F. Monforti-Ferrario, A. Dosio and F. Raes (2014). "The near future availability of photovoltaic energy in Europe and Africa in climate-aerosol modeling experiments." Renewable and Sustainable Energy Reviews 38: 706-716.
16	Gaudard, L., F. Romerio, F. Dalla Valle, R. Gorret, S. Maran, G. Ravazzani, M. Stoffel and M. Volonterio (2014). "Climate change impacts on hydropower in the Swiss and Italian Alps." Science of the Total Environment 493: 1211-1221.
17	Golombek, R., S. A. C. Kittelsen and I. Haddeland (2012). "Climate change: Impacts on electricity markets in Western Europe." Climatic Change 113(2): 357-370.
18	Gunderson, I., S. Goyette, A. Gago-Silva, L. Quiquerez and A. Lehmann (2015). "Climate and land-use change impacts on potential solar photovoltaic power generation in the Black Sea region." Environmental Science and Policy 46: 70-81.
19	Hamududu, B. and A. Killingtveit (2012). "Assessing climate change impacts on global hydropower." Energies 5(2): 305-322.

Identifier #	**Paper reference**
20	Harrison, G. P., L. C. Cradden and J. P. Chick (2008). "Preliminary assessment of climate change impacts on the UK Onshore wind energy resource." Energy Sources, Part A: Recovery, Utilization and Environmental Effects 30(14-15): 1286-1299.
21	Harrison, G. P. and A. R. Wallace (2005). "Climate sensitivity of marine energy." Renewable Energy 30(12): 1801-1817.
22	Hoffmann, B., S. Häfele and U. Karl (2013). "Analysis of performance losses of thermal power plants in Germany - A System Dynamics model approach using data from regional climate modelling." Energy 49(1): 193-203.
23	Hueging, H., R. Haas, K. Born, D. Jacob and J. G. Pinto (2013). "Regional changes in wind energy potential over Europe using regional climate model ensemble projections." Journal of Applied Meteorology and Climatology 52(4): 903-917.
24	Koch, H., S. Vögele, F. Hattermann and S. Huang (2014). "Hydro-climatic conditions and thermoelectric electricity generation - Part II: Model application to 17 nuclear power plants in Germany." Energy 69: 700-707.
25	Koch, H., S. Vögele, F. F. Hattermann and S. Huang (2015). "The impact of climate change and variability on the generation of electrical power." Meteorologische Zeitschrift 24(2): 173-188.
26	Lehner, B., G. Czisch and S. Vassolo (2005). "The impact of global change on the hydropower potential of Europe: A model-based analysis." Energy Policy 33(7): 839-855.
27	Majone, B., F. Villa, R. Deidda and A. Bellin (2015). "Impact of climate change and water use policies on hydropower potential in the south-eastern Alpine region." Science of the Total Environment.
28	Maran, S., M. Volonterio and L. Gaudard (2014). "Climate change impacts on hydropower in an alpine catchment." Environmental Science and Policy 43: 15-25.
29	McColl, L., E. J. Palin, H. E. Thornton, D. M. H. Sexton, R. Betts and K. Mylne (2012). "Assessing the potential impact of climate change on the UK's electricity network." Climatic Change 115(3-4): 821-835.
30	Mimikou, M. A. and E. A. Baltas (1997). "Climate change impacts on the reliability of hydroelectric energy production." Hydrological Sciences Journal 42(5): 661-678.
31	Naughton, M., R. C. Darton and F. Fung (2012). "Could climate change limit water availability for coal-fired electricity generation with carbon capture and storage? A UK case study." Energy and Environment 23(2): 265-282.
32	Nolan, P., P. Lynch, R. McGrath, T. Semmler and S. Wang (2012). "Simulating climate change and its effects on the wind energy resource of Ireland." Wind Energy 15(4): 593-608.

Identifier #	Paper reference
33	Panagea, I. S., I. K. Tsanis, A. G. Koutroulis and M. G. Grillakis (2014). "Climate change impact on photovoltaic energy output: The case of Greece." Advances in Meteorology 2014.
34	Pašičko, R., Č. Branković and Z. Šimić (2012). "Assessment of climate change impacts on energy generation from renewable sources in Croatia." Renewable Energy 46: 224-231.
35	Pereira-Cardenal, S. J., H. Madsen, K. Arnbjerg-Nielsen, N. Riegels, R. Jensen, B. Mo, I. Wangensteen and P. Bauer-Gottwein (2014). "Assessing climate change impacts on the Iberian power system using a coupled water-power model." Climatic Change 126(3-4): 351-364.
36	Pryor, S. C., R. J. Barthelmie and E. Kjellström (2005). "Potential climate change impact on wind energy resources in northern Europe: Analyses using a regional climate model." Climate Dynamics 25(7-8): 815-835.
37	Pryor, S. C., J. T. Schoof and R. J. Barthelmie (2005). "Climate change impacts on wind speeds and wind energy density in Northern Europe: Empirical downscaling of multiple AOGCMs." Climate Research 29(3): 183-198.
38	Reeve, D. E., Y. Chen, S. Pan, V. Magar, D. J. Simmonds and A. Zacharioudaki (2011). "An investigation of the impacts of climate change on wave energy generation: The Wave Hub, Cornwall, UK." Renewable Energy 36(9): 2404-2413.
39	Reyers, M., J. G. Pinto and J. Moemken (2015). "Statistical-dynamical downscaling for wind energy potentials: Evaluation and applications to decadal hindcasts and climate change projections." International Journal of Climatology 35(2): 229-244.
40	Richert, C. N. and A. Matzarakis (2014). "The climatic wind energy potential — present and future: GIS-analysis in the region of Freiburg im Breisgau based on observed data and Regional Climate Models." Central European Journal of Geosciences 6(2): 243-255.
41	Santos, J. A., C. Rochinha, M. L. R. Liberato, M. Reyers and J. G. Pinto (2015). "Projected changes in wind energy potentials over Iberia." Renewable Energy 75: 68-80.
42	Schaefli, B., B. Hingray and A. Musy (2007). "Climate change and hydropower production in the Swiss Alps: Quantification of potential impacts and related modelling uncertainties." Hydrology and Earth System Sciences 11(3): 1191-1205.
43	Seljom, P., E. Rosenberg, A. Fidje, J. E. Haugen, M. Meir, J. Rekstad and T. Jarlset (2011). "Modelling the effects of climate change on the energy system-A case study of Norway." Energy Policy 39(11): 7310-7321.
44	Tobin, I., R. Vautard, I. Balog, F. M. Bréon, S. Jerez, P. M. Ruti, F. Thais, M. Vrac and P. Yiou (2014). "Assessing climate change impacts on European wind energy from ENSEMBLES high-resolution climate projections." Climatic Change 128(1-2): 99-112.

Identifier #	**Paper reference**
45	Torssonen, P., A. Kilpeläinen, H. Strandman, S. Kellomäki, K. Jylhä, A. Asikainen and H. Peltola (2015). "Effects of climate change and management on net climate impacts of production and utilization of energy biomass in Norway spruce with stable age-class distribution." GCB Bioenergy.
46	Tuck, G., M. J. Glendining, P. Smith, J. I. House and M. Wattenbach (2006). "The potential distribution of bioenergy crops in Europe under present and future climate." Biomass and Bioenergy 30(3): 183-197.
47	Van Vliet, M. T. H., S. Vögele and D. Rübbelke (2013). "Water constraints on European power supply under climate change: Impacts on electricity prices." Environmental Research Letters 8(3).
48	Van Vliet, M. T. H., J. R. Yearsley, F. Ludwig, S. Vögele, D. P. Lettenmaier and P. Kabat (2012). "Vulnerability of US and European electricity supply to climate change." Nature Climate Change 2(9): 676-681.
49	Wachsmuth, J., A. Blohm, S. Gößling-Reisemann, T. Eickemeier, M. Ruth, R. Gasper and S. Stührmann (2013). "How will renewable power generation be affected by climate change? The case of a metropolitan region in Northwest Germany." Energy 58: 192-201.
50	Westaway, R. (2000). "Modelling the potential effects of climate change on the Grande Dixence hydro-electricity scheme, Switzerland." Journal of the Chartered Institution of Water and Environmental Management 14(3): 179-185.

Figure 4-1: Retained articles by publication year (1a) and by electricity system focus (1b)



Information was collated on the authorship, assessment methods, results, limitations and research gaps of each retained article by using a qualitative record sheet template. In particular, it was discerned: i) what are the projected impacts of CV&C (positive, negative, no significant impact) on the electricity systems for the period of assessment in the articles? and ii) whether these results are in agreement with results of other articles, i.e. can robust patterns be identified from the results?

A total of 43 articles on the impacts of CV&C on hydro-, wind, thermal and solar electricity generation were analysed and the results are reported in the next section. Results from the articles focusing on bioenergy, wave energy and electricity networks (n=7) were not included in the analysis because of the limited and conflicting evidence base they provided but are presented in the Appendix C in section 10.3.

The remaining 43 articles had assessment periods chosen for reasons of their own (See Appendix C in section 10.3). In some articles, the choice was justified by invoking the electricity infrastructure lifespan, whereas others provided little or no justification for the chosen assessment period. The heterogeneity of used assessment periods made it difficult to gain an overall view of the results. To address this challenge, we re-mapped the articles and their results onto two time periods, near term to mid-21st century and the end of the 21st century. Near term to mid-21st century (NT-MC) covers the period from the present until 2070, while the end of the 21st century (EC) covers the period from 2061 until 2100. There were 22 articles covering near term to mid-21st century and 10 articles covering the end of the 21st century. Both periods were covered by 11 articles. These periods were chosen for NT-MC and EC assessments as the earliest and latest assessment years across the subset of studies are respectively 2008 and 2070 for the NT-MC and 2061 and 2100 for the EC.

Each article was scrutinised for its results, and an individual result was chosen as the unit of analysis. A result is “individual” if the article outlines it explicitly and its interpretation is not left to the discretion of the reader. An individual result can be explicitly outlined in a table (e.g. Table 2 in Lehner et al. (2005)), a figure (e.g. Figure 4 in Crook et al. (2011)) or in the text (e.g. Baltas and Karaliolidou (2010)). Some articles have several individual results (e.g. Van Vliet et al. (2013)) whereas others only have a single one (e.g. Baltas and Karaliolidou (2010) (See Appendix C in section 10.3).

Individual results from the 43 articles were organised by i) the type of electricity generation (hydro-, wind, thermal and solar electricity generation), ii) geographical coverage (regional, national and sub-national scale) and iii) assessment period (near term to mid-21st century or the end of the 21st century). Each combination could have more than one individual result, one individual result, or no result. A pattern of impacts of CV&C was identified when all relevant individual results were consistent, with the pattern direction of change (positive or negative) reflecting the envelope of individual results. When the individual results were inconsistent, no pattern was attributed. If a single individual result existed, a pattern was attributed only if several climate models or scenarios were used in the generation of the individual result. In total the sample contained 498 individual results.

Some limitations remain in the reported systematic review. We used the UN Statistics Division's clustering of countries to define European regions (Northern, Western, Eastern and Southern Europe). However, as some articles give limited information on their spatial coverage, the exact match of the results with the UN Statistics Division's clustering of countries cannot be fully guaranteed. Also, some articles cover a long time span including both near term to mid-21st century and the end of the 21st century: this makes it difficult to distinguish which impacts to allocate to which assessment period. Therefore, these individual results were allocated to both assessment periods (e.g. #11: 2010-2080; #29: 2020-2080; #30: 1990 – 2080/2100). Articles on the same type of electricity generation were collated regardless of some differences in addressed generation technology and infrastructure. For example, articles on hydroelectricity generation included impact assessments for run-of-the-river and storage reservoir plants. Additionally, articles focusing on thermal electricity generation produced from fossil fuels, gas, biomass or nuclear energy were grouped as thermal electricity generation. CV&C is projected to affect the generation cycle efficiency and cooling water requirements of thermal power plants. Some divergences of opinions do exist however as to the water cooling quantities required by different thermal electricity generation technologies. For example Goldstein and Smith (2002) and Delgado Martín (2012) show that water requirements differ by fuel source, plant and cooling system type whereas (World Nuclear Association, 2019) points out that:

"there is no real difference in the amount of water used for cooling nuclear power plants, relative to coal-fired plants of the same size" (web-page, no page number). The different thermal electricity generation technologies covered in the articles retained for analysis had to be grouped together for the following reasons. Only 14% of the data (8 articles) reported results on thermal electricity. The majority (5) of these articles did not report results separately for nuclear and non-nuclear thermal generation. One article focus on nuclear generation only (#24) and another one on coal fired generation only (#31). Thus the separation of the results by thermal electricity generation technology was not possible. This is a gap in research, considering the importance of understanding the potential differences in the climate change impacts on thermal generation technologies. Furthermore, the statistical significance of individual results was indicated in some articles but not in others; individual results with no mention of their statistical significance were still included, but non-significant results were not when explicitly characterised as such. Finally, all the reviewed articles are in English, disregarding results reported in other languages. Funding information, where available, revealed that the European Commission, national research councils and ministries, and academic institutions (e.g. university research departments) financed most of the studies, with the exception of one study (#29), commissioned directly by a national energy association.

4.3. Results

4.3.1. Landscape of methods of analysis

The reviewed articles use quite different methods of analysis. The simplest ones take climate data as proxy for the impacts of CV&C (e.g. # 10), whereas more complex ones use outputs of climate model experiments as inputs to comprehensive impact models (e.g. #27).

The climate data used in the assessments can be taken directly from existing climate change projection datasets (e.g. UKCP09 in #6) or be simulated by 1) combining emissions scenario(s) and climate model(s)/projection(s) (e.g. #2, #13, #27, #43) or 2) by rearranging observed time series with respect to a given linear trend for a selected variable (e.g. STARS[14] in #24). The statistical measures of climate data (e.g. mean, median, distribution) used as inputs to the impact models, also vary.

The impact models used in the articles vary from validated and widely accepted models (e.g. IHACRES[15]) to models specifically developed for the articles and conveyed by a single equation or more complex computations. Impact models also tend to reflect the dominant impact pathway.

Hydroelectricity generation depends directly on the hydrological cycle. CV&C affect hydroelectricity generation through the availability of excess water (precipitation minus evapotranspiration) and the seasonal pattern of the hydrological cycle in regions where snowmelt is a relevant factor for generation (Schaeffer et al., 2012). The impacts of CV&C on hydroelectricity generation are assessed using hydrological models (e.g. rainfall-runoff models such as IHACRES, TOPKAPI[16] or HBV Model[17], GEOTRANSF[18]) or models simulating hydroelectric power plant operations.

Energy contained in wind is proportional to the cube of the wind speed (Pryor and Barthelmie, 2010) and thus variations in wind speed can have significant effects on generation. Schaeffer et al. (2012) indicate that wind speed varies significantly with

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14 STARS or STatistical Analogue Resampling Scheme (From: https://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/stars [Accessed 09/02/2016])

15 IHACRES or Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow data (From: http://www.toolkit.net.au/tools/IHACRES [Accessed 07/12/2015])

16 TOPKAPI or TOPographic Kinematic APproximation and Integration (From: http://www.progea.net/prodotti.php?p=TOPKAPI&lin=inglese [Accessed: 07/12/2015])

17 HBV Model (From: http://www.geo.uzh.ch/en/units/h2k/services/hbv-model/ [Accessed 07/12/2015])

18 Majone, B., A. Bertagnoli, A. Bellin and A. Rinaldo (2005). GEOTRANSF: a continuous non-linear hydrological model. AGU Fall Meeting Abstracts. From: http://adsabs.harvard.edu/abs/2005AGUFM.H23C1441M

height and that little is known about likely future wind speeds at the hub height of a wind turbine (above 50 m). In the reviewed articles, the impacts of CV&C on wind electricity generation is assessed either by taking future wind projections (e.g. GCM geostrophic wind) as proxy for wind power production, or by extrapolating wind speed for the specific height of the hub of the analysed wind turbine model.

Thermal electricity generation using coal, natural gas, nuclear isotopes, geothermal energy and biomass depends on the availability and temperature of cooling water. Its efficiency depends on the heating and cooling needs of both Rankine and Brayton cycles, which in turn vary according to the average ambient conditions such as temperature, pressure, humidity and water availability (Schaeffer et al., 2012). Reliability of supply can also be threatened by water abstraction and regulations on discharge water temperature (Naughton et al., 2012). Water use models (e.g. WaterGAP3[19]), eco-hydrological models (e.g. SWIM[20]), hydrological models and specific models of thermal electricity generation were all used.

Solar electricity generation can be impacted by extreme weather events, changes in snow and cloud cover and air temperature increases. Changes in air temperature not only modify photovoltaic (PV) cell's efficiency and reduce generation (Pasicko et al., 2012), but also negatively affect temperature-sensitive Concentrated Solar Power (CSP) systems. The impacts of CV&C on solar electricity generation are assessed by using the delta change method, assessing the differences between simulated current and future climate conditions, by developing models of PV power generation, or by deriving the power output from irradiance and ambient temperature data.

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[19] Water Global Assessment and Prognosis or WaterGAP (Eisner, S. and M. Flörke (2015). Benchmarking the WaterGAP3 global hydrology model in reproducing streamflow characteristics. EGU General Assembly Conference Abstracts. From: http://adsabs.harvard.edu/abs/2015EGUGA..1711049E

[20] SWIM model or Soil and Water Integrated Model (From: https://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/swim [Accessed 07/12/2015])

Some of the reviewed articles explain the rationale for the choice of the assessment period(s) and used climate and impact models but most do not. Many articles develop their own methods of analysis, combining a unique set of climate data and impact models. Most articles (with the exception of e.g. Hoffmann et al. (2013)) also assess the impacts of CV&C on the basis of climate signals only, and neglect to consider feasible adaptation measures or future change in policies and regulations. Impact models developed in some of the reviewed articles are based on the existing types of electricity infrastructure, designed on the basis of historical meteorological records and not future climate projections. The articles also assume that no new electricity infrastructure will be built and that generation capacity will remain constant. Moreover, all but a few articles consider only one technology for a given type of electricity generation. Lehner et al. (2005) do consider both run-off-the-river and reservoir solutions for hydroelectricity generation, Crook et al. (2011) include in their analysis the two most widely installed solar technologies for large-scale electricity generation, namely photovoltaic (PV) and concentrated solar power (CSP)) and Van Vliet et al. (2013) assess different types of thermal electricity generation plants. As a consequence, the methods of analysis were not examined further in the analysis.

4.3.2. Consistent patterns of impacts of CV&C

This section explains the consistent patterns of impacts of CV&C on hydro-, wind, thermal and solar electricity generation at the regional and national scales. The robustness of the patterns of impacts of CV&C is indicated for the regional and national scales, for which there were more often more than one individual result available (in bracket and in italic; NT-MC: near term to mid-21st century and EC: end of the 21st century). We use the number of available and consistent individual results as a proxy for robustness; a pattern of impacts of CV&C identified from four or more individual results is considered more robust that one derived from a single result. Robustness is not considered at the sub-national scale because only single individual results were available at this scale.

At sub-national scale, impacts were mostly derived from one individual results per location, not allowing for any pattern to be extrapolated. As such, sub-national scale impacts of CV&C are only discussed in Appendix C (section 10.3).

4.3.2.1. Consistent patterns of impacts of CV&C on hydro-, wind, thermal and solar electricity generation at regional scales

Figure 4-2 summarises the annual consistent patterns of CV&C on hydro-, wind, thermal and solar electricity generation at regional scales. Positive patterns can be observed for renewable electricity generation in Northern Europe and negative patterns for both renewables and traditional electricity generation for the Western, Eastern and Southern Europe.

Hydroelectricity generation

Hydroelectricity generation from the installed hydropower capacity is expected to drop from 10% of the EU27 electricity generation in 2013 to less than 6% by 2050 as the result of future changes in rainfall (#12).

Hydroelectricity generation will increase in Northern Europe (2 individual results available for NT-MC and 1 for EC) and decrease in Western (NT-MC: 1; EC: 1) and Southern Europe (NT-MC: 2; EC: 2) by near term to mid-21st century and by the end of the 21st century. In Eastern Europe, hydroelectricity generation will decrease in the near term to mid-21st century (1).

Hydroelectricity generation is projected to increase in winter in Northern Europe (1) and decrease in summer for Southern Europe (1) for the end of the 21st century.

Wind electricity generation

No consistent patterns of impacts of CV&C on wind electricity generation are projected for Northern Europe for the near term to mid-21st century (3). For Northern

Europe, an annual increase (3) and an increase for the winter months (1), and a decrease for the summer months (1), are predicted for the end of the 21^{st} century. For Southern Europe, wind electricity generation is predicted to decrease in the near term to mid-21^{st} century and for the end of the 21^{st} century (NT-MC: 1; EC: 2). A decrease in generation is also predicted for summers in Western Europe (1) and summers (1) and winters (1) in Southern Europe for the end of the 21^{st} century. The decrease for Southern Europe is consistent with a decrease in annual wind electricity generation in the Mediterranean Sea for the near term to mid-21^{st} century and the end of the 21^{st} century (NT-MC: 2; EC: 2).

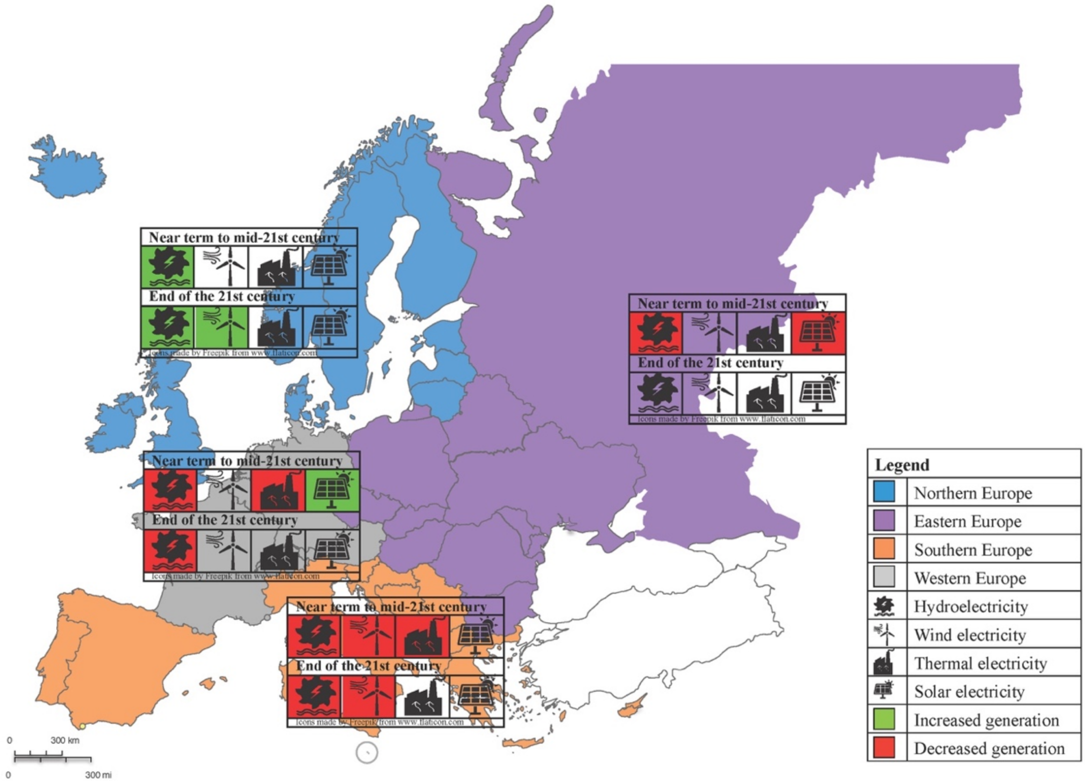
Thermal electricity

Annual thermal electricity generation is projected to decrease in Southern Europe and Western Europe (1) for the near term to mid-21^{st} century (2). This projection resonates with the projections for decreasing precipitation and higher air temperature leading to evapotranspiration for Southern Europe (Kovats et al., 2014), thus reducing the volume of runoff available for use as cooling water. For Western Europe, changes in drought severity that in turn could affect the availability of water for cooling, have also been attributed to climate change (Blenkinsop and Fowler, 2007).

Solar electricity generation

Annual solar electricity generation is projected to increase in Western Europe (1) and to decrease in Eastern Europe for the near term to mid-21^{st} century (1).

Figure 4-2: Annual consistent patterns of impacts of CV&C on hydro, wind, thermo- and solar electricity across the four European regions



4.3.2.2. <u>Patterns of impacts of CV&C on hydro-, wind, thermal and solar electricity generation at national scale</u>

Figure 4-3 and Figure 4-4 present the annual patterns of impacts of CV&C on hydro-, wind, thermal and solar electricity generation at the national scale and in the Baltic and Mediterranean seas and Iberian Peninsula for the near term to mid-21st century and the end of the 21st century, respectively. The figures also indicate where no pattern could be identified.

Figure 4-3 and Figure 4-4 indicate that national scale assessments of impacts of CV&C are still largely missing for wind, thermal and solar energy generation for the near term to mid-21st century and the end of the 21st century. More individual results are available for the near term to mid-21st century than for the end of the 21st century. There is more agreement between individual results for the end of the 21st century than for the near term to mid-21st century, resulting in more consistent patterns of impacts of CV&C for the later period. This is consistent with stronger climate signals towards the end of the century.

Figure 4-3: Annual patterns of impacts of CV&C on hydro-, wind, thermal and solar electricity generation at national scale for the near term to mid-21st century

(Sources: Hydroelectricity: #25 (1 individual result), #26 (72), #34 (1), #35 (1), #43, (1) and #47 (70); Wind energy: #3(3), #44(2); Thermal electricity: #22(12), #24(1); Solar energy: #6(3), #11(8))

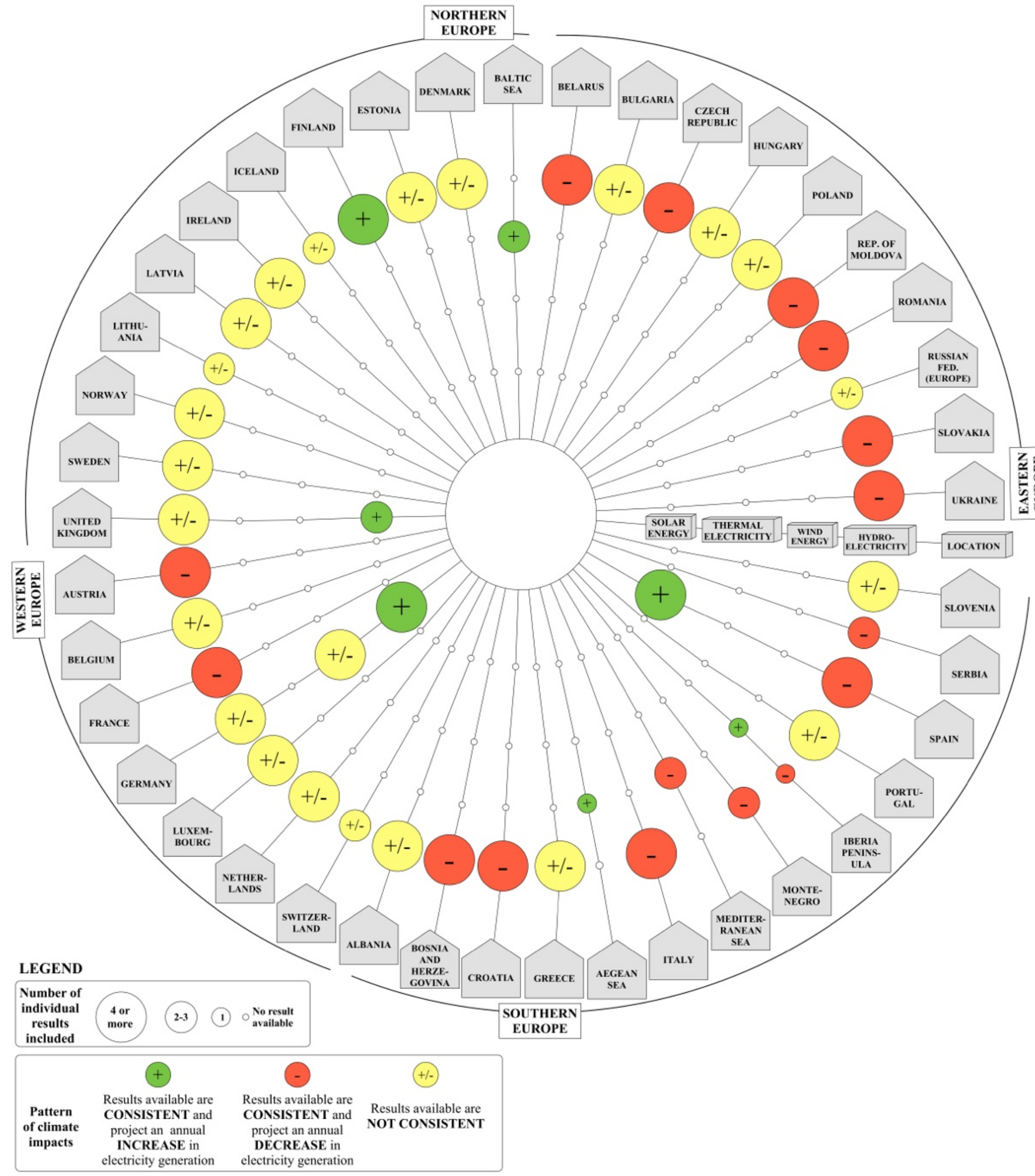
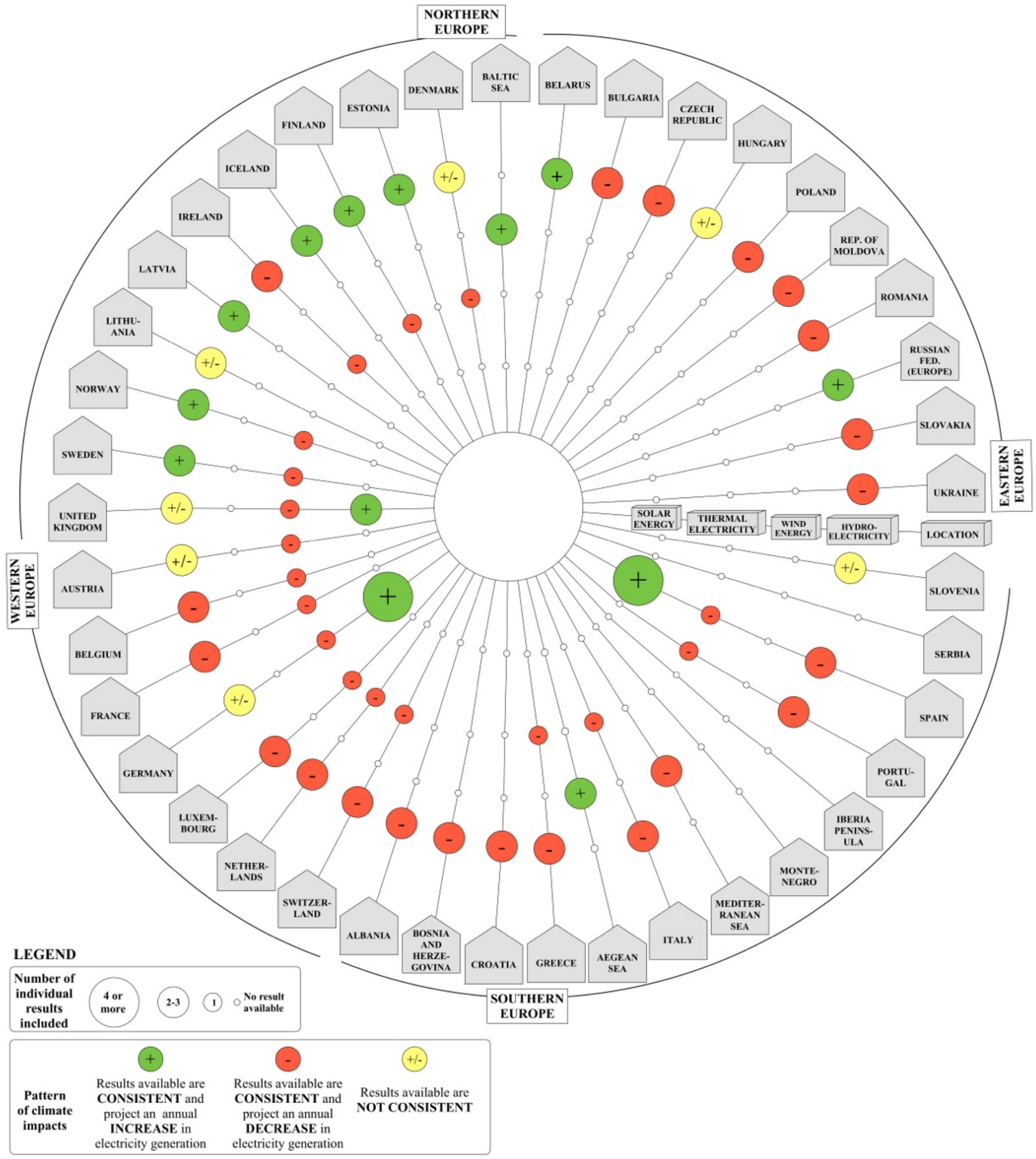


Figure 4-4: Annual patterns of impacts of CV&C on hydro-, wind, thermal and solar electricity generation at national scale in the end of the 21st century

(Sources: Hydroelectricity: #17(16 individual results), #26 (72); Wind energy: #5(1), #23(1), #36(1), #44(3); Thermal electricity: #17(16); Solar energy: #6(3), #11(8))



Hydroelectricity generation

Finland is the only country with a confirmed positive pattern of increased hydroelectricity generation for the near term to mid-21st century (4). Northern European countries of Estonia (2), Finland (3), Iceland (2), Latvia (2), Norway (3) and Sweden (3) and Belarus (2), and the European part of the Russian Federation (2) in Eastern Europe, are also projected to experience an increase in hydroelectricity generation in the end of the 21st century.

Consistent negative patterns of impacts of CV&C on hydroelectricity generation exist for Austria (4) and France (4) in Western Europe, for Belarus (4), Czech Republic (4), Moldova (4), Romania (4), Slovakia (4) and Ukraine (4) in Eastern Europe and for most countries in Southern Europe (Bosnia-Herzegovina (4), Croatia (5), Iberian peninsula (1), Italy (4), Montenegro (2), Serbia (2) and Spain (4)) for the near term to mid-21st century. For the end of the 21st century, hydroelectricity generation is projected to decrease for Ireland (3), and for most Western European countries (Belgium (3), France (3), Luxembourg (2), Netherlands (3), Switzerland (3)), for Eastern Europe (Bulgaria (2), Czech Republic (2), Poland (2), Moldova (2), Romania (2), Slovakia (2) and Ukraine (2)) and for Southern Europe (Albania (2), Bosnia-Herzegovina (2), Croatia (2), Greece (3), Italy (3), Portugal (3), Spain (3)).

Wind electricity generation

There is substantial uncertainty associated with assessing projected changes in wind (Pryor et al., 2005). Despite this, reviewed articles indicate some patterns. An increase in annual wind electricity generation is projected for the Baltic and the Aegean Seas for the near term to mid-21st century and the end of the 21st century (respectively for the NT-MC: 2, 1; EC: 2, 3) and for the Iberian Peninsula (1) for the near term to mid-21st century. An annual decrease is projected for the Mediterranean Sea for the near term to mid-21st century and the end of the 21st century (NT-MC: 2; EC: 2).

Wind electricity generation is projected to increase in summers for the Baltic and Aegean Seas (respectively: 1 and 1) and in winters (November to February) for Germany (1) and Ireland (2) in the near term to mid-21st century, and for the United Kingdom (1) for the end of the 21st century.

A decrease in wind electricity generation is projected for summers for Ireland (2) and Germany (1) in the near term to mid-21st century, and for France (1), the United Kingdom (2), Germany (2) and Poland (1) for the end of the 21st century. A decrease is projected for springs and autumns for the Iberian Peninsula for the end of the 21st century (2).

Thermal electricity generation

Thermal electricity generation is projected to decrease for the near term to mid-21st century and the end of the 21st century across Europe. For near term to mid-21st century Germany, thermal power plants with once-through cooling (OTC) systems are consistently projected to experience a decrease in generation (7) but no consistent pattern of impacts can be identified for power plants with closed-circuit cooling (CCC) systems (6). All individual results project annual decrease in thermal electricity generation for the end of the 21st century (Denmark (1), Finland (1), Ireland (1), Norway (1), Sweden (1), United Kingdom (1), Austria (1), Belgium (1), France (1), Germany (1), Luxembourg (1), Netherlands (1), Switzerland (1), Greece (1), Italy (1), Portugal (1) and Spain (1)).

Solar electricity generation

Annual solar electricity generation is projected to increase for the United Kingdom, Germany and Spain for the near term to mid-21st century ((3), (4), (4)), and for the end of the 21st century ((3), (4), (4)).

4.4. Discussion

Robust negative patterns of impacts of CV&C were identified for thermal electricity generation for the near term to mid-21st century and the end of the 21st century. In contrast, positive patterns were identified for renewable electricity generation; robust positive patterns of impacts of CV&C can be found from the projections for increased generation of hydroelectricity in most of Northern Europe in the near term to mid-21st century and end of the 21st century, for solar electricity in Germany in the near term to mid-21st century and in the United Kingdom and Spain in the near term to mid-21st century and end of the 21st century, and for wind electricity in the Iberian Peninsula in the near term to mid-21st century and over the Baltic and Aegean Sea in the near term to mid-21st century and end of the 21st century.

Future climate projections are in agreement about an increase in temperature throughout Europe, and about increasing precipitation in Northern Europe and decreasing precipitation in Southern Europe (Jacob et al., 2014). Episodes of high temperature extremes are also expected to become more frequent (high confidence) and so are meteorological droughts (medium confidence) and heavy precipitation events (high confidence) (Kovats et al., 2014). These climatic projections resonate with the patterns of impacts of CV&C on electricity systems identified in this systematic review. Increased ambient air temperatures will decrease the efficiency of thermal generating plants and reduce thermal electricity generation across Europe. Higher precipitation will be favourable to hydroelectricity generation in Northern Europe, but decreasing precipitation will reduce hydroelectricity generation in Southern Europe (Figure 4-3 and Figure 4-4).

The results of this review also highlight further the vulnerability to CV&C of more traditional electricity generation technologies such as thermal power plants. The key issue in managing such assets in the face of future changes is that the past can no longer be assumed to be the best guide for the future. As such infrastructure managers should not rely only on past conditions but also consider a range of future scenarios. They should also envisage potential adaptation options for not only climate-proofing traditional technologies but also diversify their electricity generation asset portfolio and encourage the penetration in the energy mix of less climate vulnerable electricity generation technologies such as renewables. Transitioning towards more renewable sources of electricity could also simultaneously support the achievement of the European Union's commitment to reduce GHG emissions from 1990 levels by 40% by 2030 and by 80-95% by 2050, to retain global warming below 2°C (European Commission, 2011). It would also help achieving the binding EU target of covering at least 27% of the European energy consumption from renewable sources by 2030 (European Commission, 2014).

A systematic review of the assessments of impacts of CV&C on electricity systems makes several contributions. First, validation and invalidation of specific results can lower uncertainty and remove barriers from decision-making. Second, as most individual results are not directly transferable to other locations (e.g. Gaudard et al. (2014)) or attributable to other electricity infrastructure assets, a systematic review can help to assemble the puzzle of the future impacts of CV&C on electricity systems. Finally, the envelopes of results represent versions of possible futures that policy-makers and electricity operators will have to prepare for. They can inform policy-makers' plans for a future energy mix capable of withstanding the impacts of CV&C, and interruptions related to them, to ensure the continuity and reliability of electricity provision. Electricity operators can use such evidence to re-think future investments in electricity generation infrastructure, especially those with long-term lifespan such as hydroelectric dams, and thus limiting the risks of stranded assets. Electricity companies, carrying out their own CV&C risk assessments can also use such evidence to triangulate and reinforce their own findings.

This systematic review identified robust patterns of impacts of CV&C from peer-reviewed articles published in English. Although the knowledge frontier in this area has advanced, the evidence available is still sparse. Little robust assessments still exist on thermal generation (combustible fuel and nuclear power plants) for the near term to mid-21st century and the end of the 21st century. As thermal electricity is the main source of electricity in Europe at present[21] and is likely to remain very prominent in the future electricity mix, understanding more consistently the impacts of CV&C on thermal power plants is paramount to better plan for energy security in the future. Some articles also explored the impacts of CV&C on renewable electricity but to the authors' knowledge no study exists looking more holistically at the potential for future renewable installation capacity at European or national levels and at the effects of renewable penetration on future electricity systems. Additionally, most existing articles assess near term to mid-21st century impacts and fewer articles cover end of the 21st century impacts (Figure 4-3 and Figure 4-4). Even fewer articles consider intra-annual or seasonal variations. The spatial coverage of assessments is also uneven. Few assessments focus on the impacts of CV&C at national scale on thermal, wind electricity and solar electricity generation. Sub-national and infrastructure scale assessments are also largely missing, yet they would be key in supporting decision-making. Furthermore, many articles have quite static approach; climate parameters are often the only variables and the energy mix, the commissioning and decommissioning of assets, and the technical parameters for electricity generation are considered constant. Technology innovation is not taken into consideration and nor are future technologies with increased energy efficiencies.

There are inherent cascading uncertainties associated with the climate and impact models used in the assessments, and yet these uncertainties are rarely discussed explicitly in the reviewed articles. There is also little reflection on what the implications of these uncertainties are in practice and how confident the readers and users can be in the results. Future assessments of impacts of CV&C on electricity systems should tailor the communication of results and uncertainties associated with them to specific audiences. Latest literature on communicating climate science would help to better understand the target audiences' needs and preferences, and to tailor the

21 From:

http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_production,_consumption_and_market_overview#Electricity_generation [Accessed 15/02/2016] communication of results accordingly (e.g. EU FP7 Euporias[22]). Furthermore, future assessments should communicate uncertainties and confidence in the results more explicitly (Lorenz et al., 2013). For example, the latest IPCC AR5 report uses two metrics for communicating the degree of certainty in key findings: confidence in the validity of a finding, based on the type, amount, quality and consistency of evidence and a quantified measure of uncertainty in a finding expressed probabilistically (Intergovernmental Panel on Climate Change (IPCC), 2014b).

The articles should also be more explicit about their limitations and outline if possible what the implications of their results are for the stakeholders. For example, few of the reviewed assessments reflect on how to adapt the electricity systems to the impacts of CV&C found in their results.

Assessments of impacts of CV&C on electricity systems often assess the impacts of a single climate variable (a proxy for climate change) on one type of electricity generation or infrastructure asset. To the authors' knowledge, no article has yet looked at the impacts of a climate variable along the whole chain of electricity provision (e.g. the impact of decreasing rainfall on electricity generation and network infrastructure) or investigated the impacts of concomitant weather events on one type of electricity generating technology (e.g. the simultaneous impact of a massive earthquake and a tsunami like in Fukushima in Japan in 2011). Exceptions to the latter are on one hand, Forzieri et al. (2018)'s work exploring multiple climate extremes on critical infrastructures for energy, transport, industrial, and social critical infrastructures and on the other hand Mukherjee et al. (2018)'s study presenting a multi-hazard approach to characterize the key predictors of severe weather-induced sustained power outages. Little is also still known about the impacts of CV&C on sector interdependencies (Dawson et al., 2018). For example, reduced rainfall could lead to droughts, which in turn could translate into not only decreased thermal electricity and hydroelectricity but also into bans and levies on water extraction for irrigation or

[22] From: http://www.euporias.eu/ [Accessed 09/10/2015]

human consumption. Interdependencies assessments (e.g. Hall et al. (2014)) could further the findings from this review by exploring how the impacts of CV&C on electricity systems could have knock-on effects on other sectors such as transport and water, other stakeholders such as consumers or policy-makers or national economies. Finally, another area of importance for future modelling is adaptation. Adaptation options should be included in future assessments of impacts of CV&C on electricity infrastructure and the technological and economical efficacy of such option evaluated for different climate scenarios. Such studies could be invaluable to help infrastructure managers to climate-proof their assets, to ensure national electricity security and to avoid potential maladaptation.

4.5. Conclusion

This systematic review is an early attempt at collating the impacts of CV&C on electricity systems in Europe from peer-reviewed literature published in English. The review indicates that although the evidence base is improving and yields some robust patterns, there is still a need for additional empirical research.

In future assessments there is a need to better contextualise the results against those of earlier assessments. This review can provide a starting point for doing so. Future assessments should also link their results and their implications to user needs and consider how the results are best communicated. Few attempts have been made to date to integrate the assessments of impacts of CV&C on supply and demand of electricity (e.g. Chandramowli and Felder (2014); Ciscar and Dowling (2014)). Such could be the next step in assessment of risks CV&C pose for electricity systems.

This review identified some consistent patterns of CV&C impacts on electricity systems in Europe. As the climate is changing so should energy infrastructure management, policies and the future directions of research. This work could inform not only infrastructure managers trying to climate-proof their assets and avoid resource misallocation but also policy-makers shaping future European Energy policies and the European Commission when shaping the future research and funding programs.

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Rachel Salvidge for the ENDS Report, part of the Guardian Environment Network

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Le Monde.fr | 09.02.2015 à 16h01 • Mis à jour le 09.03.2015 à 11h46 | Par Pierre Le Hir (/journaliste/pierre-le-hir/)

5. KEEPING THE LIGHTS ON AMID CHANGING PHYSICAL CLIMATE RISKS: POLICY INSTRUMENTS FOR CLIMATE RESILIENT ELECTRICITY SECTORS IN THE UNITED KINGDOM AND FRANCE

5.1. INTRODUCTION

A reliable, affordable supply of low carbon power is in the interest of all taxpayers; yet at the same time, the European power system is undergoing a period of dynamic change that entails both threats and opportunities. The electricity sector is highly vulnerable to climate risks with extreme weather events (e.g. earthquakes, tsunamis, hurricanes, floods…) for example, being the biggest threats to power system secure operations (Gündüz et al., 2017) and being globally responsible for 63% of blackouts (Bompard et al., 2013).

Extreme weather events are already challenging the continuity of electricity supply in the short-term in Europe (BBC (2015); Gayle (2015); BBC (2016)). In the absence of measures that would help manage climate risks, climate change is likely to further challenge generation capacity and the continuity and reliability of supply in the future. Thermal electricity generation from the current capacity is projected to decrease throughout the 21st century due to diminishing cooling capacity. In contrast, generation is projected to increase from current capacity of hydroelectric generation in Northern Europe (throughout the 21st century) and so will solar electricity generation in Germany (for the near term to mid-21st century) and the United Kingdom and Spain (throughout the 21st century) due to climate change. Wind electricity generation is projected to increase in the Iberian Peninsula (for the near term to mid-21st century) and over the Baltic and Aegean Sea (throughout the 21st century) (Bonjean Stanton et al., 2016b).

CV&C impacts on the electricity sector are therefore policy-worthy and require attention from decision makers and governments as they challenge the reliability and economic viability and affordability of power systems. As Jordaan (2018) points out, if no policy to improve power systems' resilience to climate change impacts is put in place, today's risky power assets will be left to future generations to manage. Additionally, some opportunities can also come from implementing policies to reduce climate variability in the electricity sector as they could produce important co-benefits that apply to other disruptions, such as cyber-attacks, earthquakes, and tsunamis (Jordaan, 2018).

With more and more evidence suggesting that CV&C affect electricity sectors, do policy instruments exist to safeguard the continuity and reliability of electricity supply in the UK and France? This question will be answered in the following sections. This chapter will first review the literature on governing the electricity sector and point to the lack of evidence on the governance of climate impacts in the electricity sector (section 5.2). Then, section 5.3 introduces the electricity sectors in the UK and France and the material and method of analysis followed in this chapter. Third, section 5.4 outlines the results of the analysis of the policy instruments and governance solutions to ensure continuity and reliability of electricity supply for the two countries. Section 5.5 offers reflections on the future challenges of a change in governance for the UK and France electricity sectors and section 5.6 concludes.

5.2. GOVERNING THE CONTINUITY AND RELIABILITY OF ELECTRICITY SUPPLY

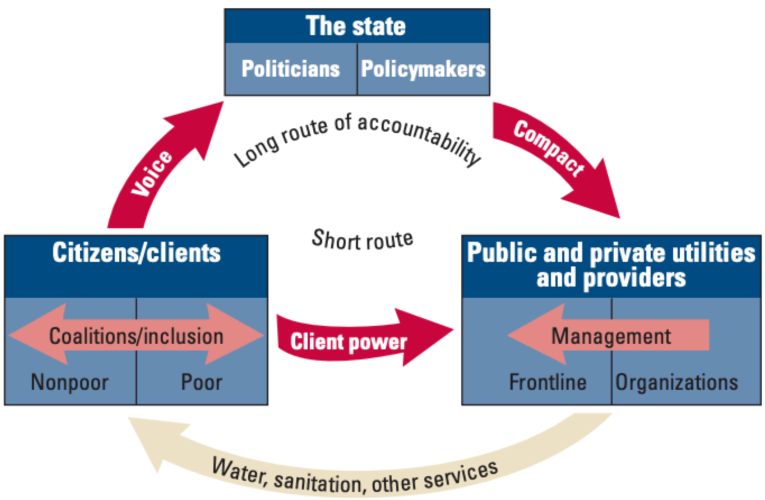
Since the 1990s, governance has known an upsurge of scholarly interest. Yet as the use of the term governance grew, it quickly took on many different meanings (Wurzel et al., 2013). But sufficient agreement now exists on the fact that governance is associated with governments' declining ability to steer and direct societal actors in a hierarchical "top-down" fashion, using "command and control" regulatory instruments (Pierre and Peters, 2000). To date, much of the governance literature has emphasised a strong dichotomy between government and governance. At one end of the spectrum the strong state characterises the extreme form of government in the era of “big government” (Pierre and Peters, 2000) and at the other end lies the “equally extreme form of governance that is the ‘autopoetic self-referential’ system which can no longer be influenced, let alone steered, by top-down government intervention” (Wurzel et al. (2013); p.9). Some scholars argue that governance represents a break from the past (e.g. Stoker (1998)) and is the “new “ method by which society is governed (Rhodes, 1996). The narrative often depicted is that in highly industrialised liberal democracies, top-down structures of government have increasingly given way to new modes of governance that encourage self-organisation by social actors. Traditional tools of government have therefore been supplanted by new modes of governance (Wurzel et al., 2013). However, other literature points out that many of the new policy instruments and new modes of governance flourish in the “shadow of hierarchy” (Héritier and Lehmkuhl, 2011) and thus still require some form of steering from public actors (through regulations for example) or call for co-governing arrangements in which public and private actors cooperate (Jordan et al., 2005). As such, rather than being clearly separated, new modes of governance and traditional tools of government may actually operate in conjunction (Trubek and Trubek, 2007). “Governing” is then the generic term Wurzel et al. (2013) use to subsumes both traditional tools of government and new modes of governance.

In the most general sense, policy instruments are the myriad of techniques the governments have at their disposal to implement their policy objectives (Howlett, 1991). Thus, policy instruments are the tools that policy actors use to attain their goals (Howlett, 2019). Policy instruments are indeed the crucial bridge between the policy frame or “image” that informs how policy-makers act and their actual governing actions (Kooiman, 2003). According to Hall (1993), policy instruments embody particular policy philosophies, goals and outlooks whilst providing concrete policy actions. Policy instruments are also often indicative of a certain period in the political and administrative history of States or of a dominant political and administrative culture (Bemelmans-Videc et al., 2011). However, Jordan et al. (2013) argue that the current academic debate on governance tends to be “over-theorised” and “under-empiricised” and often conducted at too high a level of abstraction. Wurzel et al. (2013) point out that by descending the “ladder of abstraction” (Sartori, 1970) and looking at how governance plays out in relation to specific modes and instruments, it is possible to say something new about governance. Consequently, focussing on policy instruments helps to characterise governance.

Electricity is a service with great social importance. In markets for goods and services, competition makes providers directly accountable to the customers. However, this direct route of accountability works less well for electricity where end-users turn to governments to make electricity providers do what the end-users want; this is the long route of accountability. Figure 5-1 presents a generic governance system for electricity, in which:

- Local and central governments try to make sure that all end-users receive services, and that electricity service providers—whether public or private—deliver a good service and are responsive to consumers,
- Providers deliver services to consumers, who judge that service against their initial expectations and demands, and (if they are unsatisfied) respond by registering complaints with the provider and government,
- Citizens or end-users demand good electricity services from their local and central governments.

Figure 5-1: Accountability in infrastructure services (from World Bank (2003); p.162)



This chapter looks particularly at the relationship between states and electricity providers and what instruments national governments use to ensure the continuity and reliability of electricity supply. The EU Directive 2005/89/EC[23] defines security of electricity supply (SoES) as “the ability of an electricity system to supply final customers with electricity” (Art. 2). Eurelectric (the Union of the Electricity Industry at European level) builds on this definition of SoES and considers that: “security of electricity supply is the ability of the electrical power system to provide electricity to end-users with a specified level of continuity and quality in a sustainable manner, relating to the existing standards and contractual agreements at the points of delivery” (Eurelectric (2006); p.6). In existing literature ensuring security of electricity supply is often framed as ensuring electricity “quantity” or that enough electricity is available to supply final customers (e.g. Chalvatzis and Ioannidis (2017)). To avoid confusion with this framing of SoES, this thesis will use “electricity (supply) continuity and reliability” to mean the uninterrupted availability of electricity, when demanded by end-users, to enable the functioning of the economy.

The ability to keep the lights on in the event of any incidents is a major concern for the electricity sector. But although reliability and resilience are often used interchangeably when talking about keeping the lights on, both terms have slightly different meanings. For the electricity sector reliability is the ability of the electricity system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components and describes the daily challenges faced by system and network operators. Reliability is focused on the electricity system supplying power to the end consumers and businesses, within normal operating conditions and credible contingencies (UK Energy Research Partnership, 2018). Resilience, on the other hand, is the ability of the system to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such events (UK Energy Research Partnership, 2018). So power infrastructures need to be both reliable to high

[23] DIRECTIVE 2005/89/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 January 2006 concerning measures to safeguard security of electricity supply and infrastructure investment

probability, low impact threats (likely to happen and impact small amounts of consumers for a short duration), but also resilient to the high-impact low-probability events (not likely to happen, but effects are widespread locally or nationally, and potentially for longer duration).

Existing literature has sought to categorise risks to electricity continuity and reliability. The European Commission's Green Paper "Towards a European strategy for the security of energy supply", identifies technical (system failures caused by weather, lack of capital investment or poor condition of the energy system), economic (lack of investment or insufficient contracting), political (including regulatory) and environmental (damage or accidents from pollution) risks (European Commission, 2000). Behrens and Egenhofer (2008) identify six groups of risks: import dependence (on producer and transit countries), investment risks, environmental risks (from climate change or pollution, also as a result of accidents), regulatory and political risks (due to inefficient regulation or local market disruptions due to pressure group actions), risks associated with market failure and excessive energy prices. Risks to electricity continuity and reliability have a time dimension: they are very short term (risk of power interruptions, frequency and voltage variations), short term (risks to matching supply and demand over a few hours to a day), medium term (risks to maintaining generation and network assets up to 2 years into the future), long term (risks to investment planning more than 2 years ahead to ensure that sufficient electricity can be generated to match demand and to maintain network reliability) and very long term (risks to demand trends and technological changes 10 or more years ahead) (UK Parliamentary Office of Science and Technology, 2003).

Climate risks affect electricity supply continuity and reliability across all of these timescales. In the short term, extreme weather events have flooded substations leaving 55,000 homes without power for days (BBC, 2015). In the medium and long term, climate risks can severely affect how and where future electricity will be generated. For example, Bonjean Stanton et al. (2016b) indicate that, in the long term, climate change will impact negatively on thermal electricity generation and positively on some renewable generation in parts of Europe.

CV&C are significant risks to electricity continuity and reliability. Indeed, in the past decades, an increase in the number of blackouts all around the world has been observed. Power systems are thus more and more vulnerable to threats. Among these threats, windstorms, rainstorms/thunderstorms, blizzards, cyclonic storms, ice storms, cold storms, heat storms, and lighting, all belonging to “natural threats”, are ones of the most damaging ones (Bompard et al., 2013). Yet to date, few studies have reported results on policies or policy instruments that help manage physical climate risks to electricity supply and build climate resilience in the electricity sector. Indeed, many studies explore the interactions between climate and energy policies but they typically focus on trade-offs and synergies between the two policy areas (e.g. Jonsson et al. (2013); Strambo et al. (2015)) or are concerned with devising optimal policies to reduce greenhouse gas (GHG) emissions (e.g. Brown and Huntington (2008)). While Brown and Huntington (2008) argue for optimal policies that would achieve both GHG emission reductions and energy security, others maintain that the two goals are often at odds (e.g. Watson (2009); Luft et al. (2010)). Reducing GHG emissions is also the main focus of the climate-energy policy nexus literature (e.g. Grubb et al. (2006); Gracceva and Zeniewski (2014)). Additionally, although there are some studies concerned with energy policies and governance across European countries (e.g. Bartle (2002); Thatcher (2007); Teräväinen et al. (2011)), they do not focus on electricity supply continuity and reliability, nor do the studies of energy and climate policy instruments (Oikonomou and Jepma (2008); Oikonomou et al. (2010); Oikonomou et al. (2014)) consider instruments comprehensively across policy fields. This chapter seeks to contribute to filling these gaps by exploring policy instruments for ensuring that the lights stay on amid shorter- and longer-term climate risks in the United Kingdom and France.

5.3. CASE STUDIES, DATA AND METHOD OF ANALYSIS

5.3.1. Case studies

Governance arrangements are highly situation specific and what works in one place will not necessarily work in another. The UK and France were chosen as contrasting case studies on the basis of their electricity sector structures. Indeed, history shaped the diametrically opposite structures of the electricity sectors in the UK and France today, with the UK being more market-led and France more hierarchy-led.

The United Kingdom

To facilitate recovery, post-war government took control over electricity sector companies through nationalisation. In the UK, the 1947 Electricity Act drove the nationalisation process. As a result, the UK electricity sector became very centralised and dominated by state-owned monopolies. The privatisation of the British electricity industry in 1989/90 dramatically changed the sector. The 1989 Electricity Act included six principles for restructuring the electricity sector in England and Wales, and in 2005, the Scottish electricity market was integrated with those of England and Wales (Heddenhausen, 2007). The UK was a pioneer in market liberalisation, serving as an example to the European liberalisation policies.

The British electricity sector evolved into a market involving producers from large multinationals to small family businesses running a single site. In 2014, 70% of generation capacity was owned by the “Big Six” companies including EDF (French), E.ON (German), RWE (German), Iberdrola (Spanish), Centrica (UK) and Scottish and Southern (UK) (Ofgem et al., 2014). Transmission and distribution are dominated by National Grid Electricity Transmission plc (NGET, England and Wales), Scottish Power Transmission Limited (southern Scotland), Scottish Hydro Electric Transmission plc (northern Scotland and the Scottish islands groups) and fourteen licensed distribution network operators (DNOs), each responsible for a regional distribution services area. DNOs are owned by six different groups: Electricity North West Limited, Northern

Powergrid, Scottish and Southern Energy, Scottish Power Energy Networks, UK Power Networks and Western Power Distribution.

<u>France</u>

At the end of the second World War, the French government took control over electricity sector companies through nationalisation. In 1946, more than 200 small private generators and more than 1100 private transmission and distribution companies were nationalised, creating Electricité de France (EDF) (Grand and Veyrenc, 2011). As a result, the electricity sector became very centralised and dominated by a state-owned monopoly in France and has remained so until the European Union pushed for the country to open up its market. Since 1946, EDF was France's main electricity generation and distribution company (Électricité de France (EDF), 2009) but its monopoly formally ended in 1999, when EU directives forced EDF to open up its business to competitors. In 2004, its status changed to that of a limited-liability corporation (société anonyme). The French government floated the EDF shares in 2005, but still retains almost 83.7% of the ownership as of December 2018[24]. Although the French generation sector is entirely open to competition, in 2014 three companies generate most of the domestic electricity: EDF (French, 78%), Engie (which owns the Compagnie Nationale du Rhône (CNR) and the Société Hydraulique du Midi (SHEM), French), 8%)) and E.ON (German, 2%) (Levallois, 2015). Réseau de Transport d'Electricité (RTE) is the transmission operator and Enedis operates 95% of the distribution grids. Both are fully-owned subsidiaries of EDF.

5.3.2. Materials and methods

The documentary material used in this chapter was sourced using purposive sampling (Saunders et al., 2012). It includes binding and non-binding policy documents from January 1970 to December 2017. This period was chosen because it covers both oil

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[24] From: https://www.edf.fr/en/the-edf-group/dedicated-sections/investors-shareholders/the-edf-share/capital-structure [Accessed 08/06/2019]

crises that were turning points for electricity sectors in the two countries and the Rio Summit of 1992, where climate change entered not only the political agenda and discourse, but also the awareness and practices of various economic sectors. The binding policy documents were mainly sourced from official national legal databases (i.e. https://www.legislation.gov.uk for the UK and https://www.legifrance.gouv.fr/ for France). The search was subsequently extended to the websites of national authorities responsible for climate change and for energy and that of energy regulators in both countries. These subsequent searches consolidated the list of the binding policy instruments from the legal databases but also uncovered relevant information in national programme documents, government communications and consultation transcripts. Saturation was considered to be reached when no new reference to further resource was found. A total of 102 documents was identified, obtained and analysed for the UK (sixty documents) and France (forty-two documents) (for a full list, see Appendix D1, section 10.4.1). In the case of policies etc., only their consolidated versions were included, and any updates and changes up to December 2017 were included as well. Further criteria summarised in Table 5-2 below were used to decide whether a document should be included in or excluded from the analysis.

The hundred and two documents included in the analysis were then coded to uncover the policy instruments and their nature (using the qualitative analysis software MaxQDA). At the beginning of the coding process three broad categories were used for the nature of the policy instruments as per Bemelmans-Videc et al. (2011)'s policy instrument typology. However, the coding followed the principles of inductive category development (Mayring, 2000) and the "sermons" instruments (Bemelmans-Videc et al., 2011) got subsequently replaced by procedural, cooperative and persuasive instruments. This typology echoes that of Böcher and Töller (2007)'s (Table 5-1). More information was then collated for each policy instrument identified on its planning review timeline (i.e. a) unknown, not clear; b) Ad hoc / on-going until revoked / under constant review without clear timeline; c) review within the next 4 years (short term review; d) review within the next 4-8years (medium term review) and e) review after 9 or more years (long term review)) and the risk(s) to electricity continuity and reliability it aims to address.

This study initially sought to identify and understand what provisions the UK and French governments use to ensure the lights stay on amid climate risks. An early observation stemming from the sourcing of policy documents to include in the analysis highlighted that climate risks are mainly mainstreamed into policies aiming to ensure the continuity of electricity supply in both countries, rather than being addressed by stand-alone instruments. Thus, all policy instruments covering all risks to electricity supply continuity and reliability were included in the study, as they will also be pertinent to climate risks.

However, both countries differ in how explicitly climate risks are referred to in the policy instruments. Indeed, in British energy policies generic terms that cover climate risks alongside other risk are used, for example, “emergencies”, “unexpected loss of capacity” and “risk of an electricity shortfall”. The only policy instrument explicitly naming climate risks for the utilities sectors is the UK Adaptation Reporting Power but it is not specific to electricity supply. By contrast, the French instruments can in occasion be more explicit about climate risks and their management. For example, the public service contract between EDF and the State (2005) (Contrat de Service Public entre L’Etat et EDF, 2005) outlines clearly EDF’s responsibility to not only understand and study weather forecasts and climate change projections and their consequences for electricity generation and consumption, but also to secure electricity supply amid climate risks.

Table 5-1: Policy instrument typologies

Bemelmans-Videc et al. (2011) instrument typology	Böcher, Michael and Töller, Annette E. (2007) instrument typology (as described in Schmitt and Schulze (2011))
Regulations are commonly referred to as governments' "sticks". They are used to define norms, acceptable behaviours or to limit activities in a given society	Regulatory instruments are rules established by the government (e.g. laws, decrees, orders, standards of performance, codes, licences, regulations).
"Carrots" are financial incentives that the governments use to change citizens' behaviour through either the conditional transfer of funds or charges and fines	Financial instruments can be positive (i.e. incentives, subsidies, funding) or negative (i.e. disincentives, taxation) and also include market-based instruments.
"Sermons" or instruments based on persuasion, refer to a series of discursive strategies aiming to change people's behaviour through providing information or the active exploitation of normative and moral-based arguments.	Procedural instruments aimed at affecting the policy process (Howlett, 2010) and these can be prescriptive or not (e.g. government programmes and plans).
	Co-operative instruments bring electricity practitioners together through information exchange, action plans, development of industry standard.
	Persuasive instruments are suggestions for actions or behaviours.

Table 5-2: Criteria used to decide whether to include or exclude documents

Included	Excluded
- Documents produced or published by the Government - Documents covering one or more of the following aspects of electricity supply continuity and reliability: Long term: a) Access to primary fuels (making sure the policy environment ensures long-term primary fuel supplies whatever primary energy source the generators choose / promote diversity with regard to source, supplier, transport route and transport method of fuels and increase the proportion of energy from politically stable areas); b) System adequacy (generation adequacy & network adequacy, i.e. ensure that that parts of the system function (from production to end users) as an effectively integrated comprehensive system; c) Market adequacy (the ability of the market to establish and maintain an efficient link between producers and consumers of electricity). Short term: Operational reliability of the system as a whole and its assets and the ability to overcome short-term failures of individual components of the system - Documents from January 1970 to December 2017 - Binding and non-binding documents were included. National policies are key binding documents for the sector. Other government documents provide information on the debates that surrounded electricity supply continuity and reliability and clarified content of binding documents.	- Documents not originating from the Government (e.g. electricity company documents were consulted but were not included in the analysis per se) - Documents focusing exclusively on gas, greenhouse gases (GHGs) mitigation, energy demand management, energy efficiency in buildings, decommissioning of energy installations generation, management and disposal of nuclear waste, interconnections with other countries, electricity storage, risk of personal injury or safety of single individuals. - Any document, where the instruments could not be related to one of the aspect(s) of electricity supply continuity and reliability - Documents pre-dating 1970 or published after December 2017

5.4. GOVERNING ELECTRICITY SUPPLY CONTINUITY AND RELIABILITY AMID CLIMATE RISKS IN THE UK AND FRANCE

The analysis yielded both expected and unexpected results. Firstly, in both countries, the instruments aiming to ensure electricity supply continuity and reliability with regard to climate risks stem mostly from policies designed to secure future electricity generation capacity . As such, the climate resilience of electricity sectors seems to be construed as a matter of generation capacity rather than of risk management. Secondly, the policy instruments used to ensure electricity supply reflect the electricity sector governance structures of each country. However, the instruments that have been introduced more recently depart from the established modes of governance in the two countries. Thirdly, in the UK, policy instruments currently in use to ensure electricity continuity and reliability help manage extreme weather events in the short and medium terms but do not necessarily ensure climate resilience longer term. In contrast, a longer-term policy framework is in place in France to ensure the resilience of future electricity supply. A list of the instruments is presented in Appendix D2 (section 10.4.2).

5.4.1. United Kingdom

Before privatisation, the British electricity sector was characterised by extensive vertical integration of generation, transmission, distribution and supply. In England and Wales, one large generation and transmission company, the Central Electricity Generating Board dominated the nationalised industry and sold electricity in bulk to 12 area distribution boards, each of which served a closed supply area or franchise. In Scotland, two vertically integrated boards exercised regional monopolies, but co-operated closely in the use of their generating plant to ensure that demand was met at least cost (Simmonds, 2002).

The Electricity Act of 1989 provided for the restructuring and privatisation of the electricity industry in the UK. It also established a system of independent regulation.

The British electricity policy and regulatory frameworks created a market that for many years provided a secure and reliable supply (UK National Audit Office, 2012). As the sector was very much market-led with little state intervention, the policy instruments used to ensure electricity supply were mainly financial (Figure 5-2). One of the innovations in the UK electricity sector privatisation was the establishment of the electricity “Pool” for England and Wales. The Pool was one of the first mechanisms of its kind; there was limited experience from other countries to draw on when it was created. It provided a rudimentary market mechanism, which the privatised and decentralised electricity industry could use to maintain a balance on the network. Generators were required to bid into a centralised market (the Pool), and the system operator, National Grid Company, scheduled generation to match demand given the bid information.

However, since the year 2000, the UK Government has relied less on a market-based approach and introduced new regulations (Figure 5-2) to help decarbonise and to encourage investments to secure electricity supply. Decisions about the electricity market are increasingly made centrally; the UK Government is for example setting prices for generation technologies such as offshore and onshore winds or nuclear power. As a result, the UK is moving from a competitive market to a “state micro-managed market” for electricity.

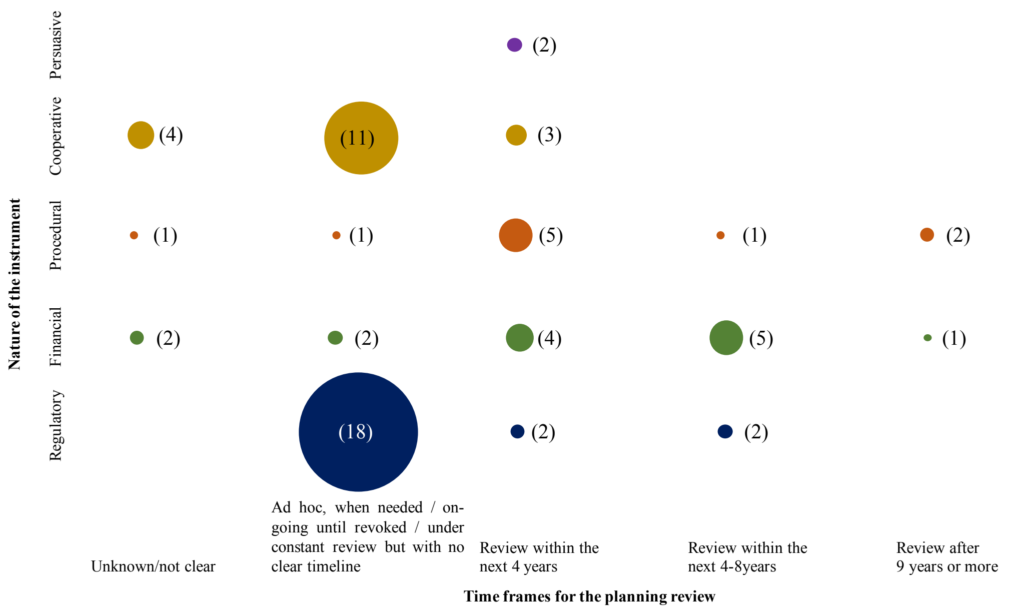
Examples of procedural instruments for electricity supply continuity and reliability in the UK include reporting requirements for electricity companies under the UK Climate Change Act 2008 (UK Climate Change Act 2008) and the UK Energy Act 2011 (UK Energy Act 2011) to produce Adaptation Reporting Power reports and BEIS & Ofgem’s “Statutory Security of Supply Reports”. Electricity supply forecasts such as National Grid’s Winter Outlook Report and the Electricity Ten Year Statement are also procedural instruments. The latter includes the Government’s short-, medium- and long-term response plans for emergencies, climate risks and increasing the share of renewables in the energy mix. Several cooperative instruments also exist. They include focus groups set up to foster discussion between the different actors in the electricity sector as well as standards developed by the electricity sector for itself (e.g. ETR 138 guidance for managing and building resilience against the risk of substation flooding).

Almost half of the UK policy instruments are reviewed within a four-year cycle (Figure 5-2). Short policy cycles can increase uncertainty in the British electricity sector. Political positions are dictated by the 5-year governmental cycle and instruments put in place during a policy cycle might be revoked during the next one. This favours policies that focus on short-term gain rather than long-term planning. This is compounded by the short-term nature of the UK market. Trading can take place bilaterally or on exchanges, and contracts between the generators and suppliers for electricity can be struck over timescales ranging from a few years ahead to on-the-day trading markets. This short-sighted energy policy environment does not increase investors' confidence. Power generating companies are vocal that they cannot commit to any new investments because of the extent of the uncertainty associated with the UK policy and regulatory frameworks (Energy Institute, 2016).

Furthermore, the governance of electricity supply in the UK lacks long-term direction. Half of the policy instruments in the UK are reviewed on an "ad-hoc basis" or have unknown review timeline (Figure 5-2), and do not require consultation of the electricity sector before revision. The electricity sector is subject to both technological change and price volatility. In this dynamic context, lack of information is not favourable for the optimal design of longer-term policies. Instruments with shorter implementation and review periods may be preferred as they help to take newly emerging information into account in the policy framework. But although short-termism increases flexibility, it can also increase uncertainty in a sector that uses the existing policy framework to understand and define its operating environment.

The new financial policy instruments put in place over the last few years such as the Electricity Market Reform and Ofgem RIIO price control are somewhat longer-term with their 4- to 8-year review cycle. They may have the potential to ensure electricity supply continuity and reliability in the future, but their effectiveness is still to be assessed. The only other longer-term policy instruments (review every eight years or less often) are non-binding government plans that are more informative than committal. As a result, the future priorities in the energy sector remain largely unclear.

Figure 5-2: Planning review timeline of the UK policy instruments in force to ensure electricity supply continuity and reliability



5.4.2. <u>France</u>

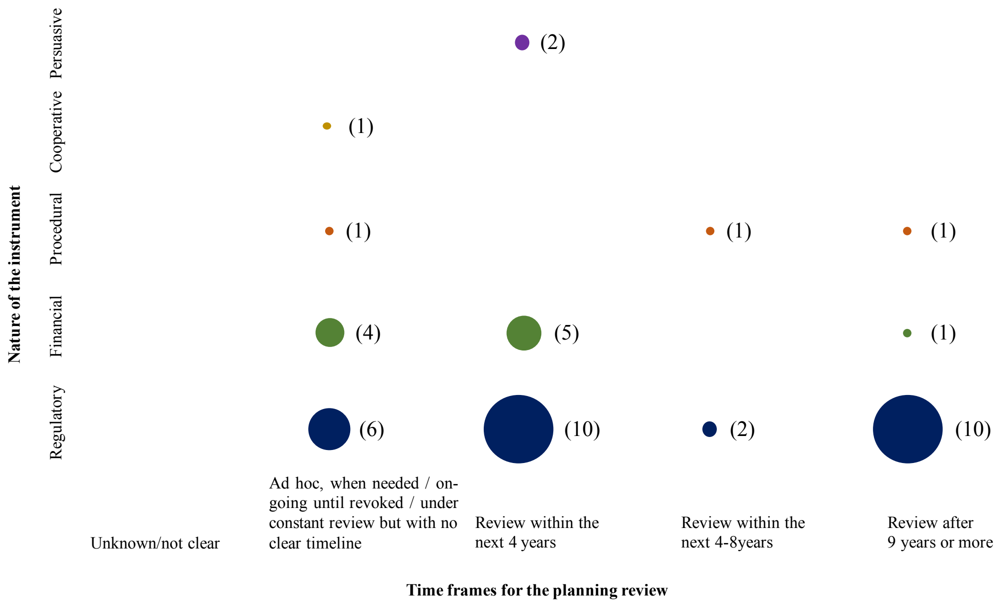
France has limited energy resources of its own and thus depends on imports. Already after the First World War, French energy policy sought to address the nation's dependence on imported coal and petrol and successive governments have made energy security a long-standing priority. World wars, oil crises and long-term electricity supply priorities have shaped the deep and substantial State intervention into the French electricity sector. The policy instruments used in France for electricity supply continuity and reliability are compatible with the state-centric management of the electricity sector. The State has had and still has a stronghold on the main electricity producer EDF as its largest owner. The responsibility for ensuring electricity supply continuity and reliability falls on EDF as the national utility, as outlined in a binding contract between the states and EDF (Articles L. 121-1 et seq. of the French Energy

Code (Code de l'énergie France, 2017) and the Public Service Contract between the State and EDF (Contrat de Service Public entre L'Etat et EDF, 2005)).

However, in the year 2000 and under pressure by the EU, France was forced to liberalise the electricity sector and to open its electricity market for competition. France is now moving towards a more market-led approach with reduced State intervention. It is also adopting new financial policy instruments (Figure 5-3) such as the "capacity mechanisms" which seek to ensure that all actors will contribute to electricity supply continuity and reliability in the new market setting.

By contrast to the UK, France has a set of regulatory and financial instruments that are reviewed at different frequency (Figure 5-3). This provides direction for the electricity sector in the short and longer terms and ensures continuity in the governance of the sector. France has also a long-term framework for the energy transition up to 2030 and 2050. The Energy Transition for Green Growth (ETGG) Act (i.e. (Loi relative à la transition énergétique pour la croissance verte (LOI n° 2015-992)) has binding targets and a carbon price trajectory up to 2030. It established a governance framework based on the National Low-carbon Development Strategy (Stratégie nationale bas carbone, SNBC), five-year carbon budgets and a pluriannual energy program (Programmation pluriannuelle de l'énergie, PPE), to be reviewed every 4-8 years. It covers energy production, energy efficiency, security of supply, and the balance of supply & demand for all energy sources. Because these mechanisms are reviewed periodically, they are flexible over time and ensure that new policies can be re-adjusted to the trajectory of the ETGG Act (International Energy Agency, 2017).

Figure 5-3: : Planning review timeline of the French policy instruments in force to ensure electricity supply continuity and reliability



5.5. Discussion: new eras of electricity supply governance in the UK and France

As highlighted above, literature on electricity continuity and reliability amid climate risks is very scarce. This chapter contributes to fill some of the research gaps. First, this chapter established that in both countries, climate risks are mostly mainstreamed through the policies aiming to ensure future generation capacity. These policies tend to mostly reflect the traditional electricity sector governance in both countries with the exception of newly introduced instruments that detracts from this observation. Second, in the UK and France, although some policy instruments consider climate risks in the short and medium terms, they do not ensure climate resilience in the electricity sectors in the longer term. Lastly, European Union laws still bind the electricity sectors in both countries and condition the governance of electricity supply. As such, the relationship of the two countries with the EU will also play a key role in their electricity supply policy dynamics in the future.

This document analysis uncovered that in both countries, the instruments aiming to ensure electricity supply continuity and reliability amid climate risks stem mostly from policies designed to secure electricity generation capacity; the climate resilience of electricity sectors seems therefore to be construed as a matter of generation capacity rather than of climate risk management. Climate risks are therefore considered alongside other risks to security supply continuity and reliability in existing energy policies. Yet climate risks are different from other risks by their nature and by the scale of their impacts on electricity sectors. Indeed, climate risks are characterised by great scientific and economic complexity, some very deep uncertainties and profound ethical issues, and extreme weather events (e.g. earthquakes, tsunamis, hurricanes, floods…) are the biggest threats to power system secure operations (Gündüz et al., 2017). The UK Adaptation reporting Power (UK ARP), is a step towards recognising the prevalence of climate risks in the electricity sector. The UK ARP is a binding policy instrument developed under the UK Climate Change Act 2008, requiring key sector organisations, such as energy or water companies, to report every four years on what they are doing to adapt to climate risks. Yet, although innovative, the UK ARP is not targeted to a specific sector and stays rather generic.

But mainstreaming climate risks into policies aiming to ensure the continuity and reliability of electricity supply provides a more dynamic policy environment, flexible enough to ensure electricity supply despite shorter- and longer-term climate risks. This resonates with Urpelainen (2013)'s argument that climate change is incompatible with immutable political realities and that policies addressing climate risks need to be dynamic. However, although mainstreaming climate adaptation objectives into existing policies instead of adopting dedicated adaptation policy is widely advocated (Runhaar et al., 2018), more work needs to be done to better understand Climate Policy Integration (CPI) (Adelle and Russel, 2013). For example, Runhaar et al. (2018)'s empirical analysis of climate adaptation mainstreaming found that the operationalisation of mainstreaming is often limited and inconsistent. They also highlighted that an implementation gap of adaptation mainstreaming relates mainly to a lack of a sustained political commitment for mainstreaming of adaptation at higher levels of political decision-making, and to the lack of effective cooperation and coordination between key stakeholders (Runhaar et al., 2018). More explicit definitions and unified frameworks for adaptation mainstreaming are required to foster more informed public policy. This limited understanding on what works for mainstreaming adaptation into sectoral policies and what outcomes could be expected from the mainstreaming process challenge policy-makers, who seek to develop a coherent policy framework that ensures the lights stay on not only in the short and medium terms but also over the longer term. Nierop (2014) offers a potential way forward as he argues for a more collaborative, more “bottom-up” policy framework in which utilities take the lead by not only performing an electrical climate change impact assessment but also devising electrical climate change adaptation plans in cooperation with utility regulators, municipalities and supra-local governments. Sovacool (2011) further supports polycentric approaches – those that mix scales, mechanisms, and actors - for effective climate and energy governance.

As highlighted in the previous section, the governance of climate risks in the electricity sector mirrors the traditional governance of the electricity sectors in both countries as policy instruments to ensure electricity continuity and reliability are mainly mainstreamed in existing policies. However, the introduction of more recent policy instruments show that the electricity sector governance is changing to opposite directions in the UK and France and these changes in governance are symptomatic of a recent transition to a more dynamic (and more uncertain) policy setting for electricity supply. Whilst the UK has traditionally used a market-based approach for governing electricity supply, government intervention has become more frequent. This has happened because British energy policy-makers need to deliver not only on affordability and continuity of electricity supply but also on decarbonising the electricity sector. Doing so in a market setting dominated by private energy companies that have little incentives to decarbonise is a considerable challenge. These observations echo Keay (2016)’s: “The UK is, in energy terms the prisoner of its ideological past – unable to find an effective way of reconciling the 3‘E’s [energy security, environmental growth and environmental protection] because it is stuck in an uncomfortable halfway house between markets and central control…” (p.248). In contrast, France is moving from a state-centred governance strategy towards a more market-based approach. When EDF was the only actor in the energy sector, it was responsible for all aspects of the energy system, from supplying electricity to clients to maintaining existing and investing in new electricity infrastructure. Since 2009, the French Government has taken steps to open up its monopolistic electricity market under EU pressure. Under the 2011 ARENH mechanism (Accès Régulé à l'Electricité Nucléaire Historique or regulated access to historical nuclear energy), following the Act for the New Organisation of the Electricity Market (Loi sur la nouvelle organisation des marchés de l'électricité ou Loi NOME (Loi 2010-1488)), the government granted access to 25% of EDF’s nuclear electricity generation fleet to other suppliers. The almost exclusive concession for electricity distribution given to ENEDIS (EDF’s ENEDIS holds 95% of the distribution network concessions) is also about to expire, which will further open up the sector to competition. But the liberalisation of the French electricity market and the entry of new actors reduces the incentives for maintaining electricity supply continuity and reliability, and to invest in new generation capacity (International Energy Agency, 2017).

Long-term climate change is likely to challenge electricity companies into re-thinking their activities and business models. As regulations are important drivers for action in companies (Averchenkova et al., 2016), governments need to devise policy frameworks and instruments that ensure electricity supply continuity and reliability not only in the short and medium terms but also resiliency in the longer term. However, as this chapter demonstrated, existing policy instruments to ensure electricity continuity and reliability do not provide companies with a policy framework that encourages climate resilience in the electricity sector in the longer-term. In the UK for example, the ARP was a step towards prompting adaptation in the sector, but the improved awareness electricity companies gained from reporting their climate risks is insufficient to make a compelling business case to implement longer-term adaptation measures (Tang, 2016). Additionally, in the UK, frequently changing energy policies have already caused a loss of momentum, created an unstable investment environment and amplified risks to electricity supply continuity and reliability (Castro, 2017). For example, the Electricity Market Reform (EMR) introduced in 2013 included a set of policies to ensure adequate supply capacity and affordability to consumers as well as incentivise low-carbon electricity generation (the energy trilemma). But in 2015, the newly elected UK government announced plans to "reset" the UK energy policy by prioritising only the first two objectives (Department of Environment and Climate Change (DECC), 2015) and deprioritising the decarbonisation of the energy sector. This change of direction and lack of policy continuity potentially declines investor confidence to pursue new projects and where projects do continue they may be priced with higher risk premiums (Castro, 2017). France by contrast does have longer-term objectives and pathways for its electricity sector in place, but their achievability is not clear. As such, France's long-term energy vision might also have to be toned down. In the 2015 Energy Transition Law (Loi relative à la transition énergétique pour la croissance verte (LOI n° 2015-992)), France set medium- (2030s) and long-term (2050s) objectives for national energy production and consumption. One of them was that the share of nuclear electricity generation should be less than 50% by 2025. However, the French Minister for the Environment, in charge at the time, admitted that this target is unrealistic and unlikely to be met (RT News, 2017).

The future relationship each country will maintain with the EU is also likely to condition the governance of electricity supply in both countries and how climate risks will be managed in the sector. The UK decided to leave the EU in the 2016 Referendum, which will have far reaching and unknown implications both for the UK energy policies and the way in which UK policies and markets will relate to those in the EU (Ekins et al. (2016); Pollitt (2017)). The ambiguity of the UK-EU relationships increases uncertainty regarding national energy policy and further dents investor confidence to pursue new projects. When projects do go forward, they may be priced with higher risk premiums (Castro, 2017). While these questions are slowly being addressed both in policy making (UK House of Commons - Energy and Climate Change Committee (2016); Lowe (2017); UK Parliament (2018)), research (e.g. Lockwood et al. (2017)) and in practice (e.g. Vivid Economics (2016); Vaughan (2017)), the implications will remain speculative until when the UK and EU have agreed on Brexit. In contrast, France has been subject to pressure from the EU to liberalise and open up its electricity market. While the EU motivation was at first to break down national monopolies, EDF still controls the French market. As the EU does not have legal power to regulate the ownership of generators, the monopoly might survive for some time (Bauby and Varone, 2007). But the EU will have further initiatives regarding the French electricity market. For example, the EU just adopted a new policy for the EU internal market for electricity (Regulation (EU) 2019/943)[25] that regulates the Union's energy system. This new regulation will have to be transposed into national laws of EU Members States, possibly challenging the governance of electricity supply in France in the future and weakening its investment environment. According to Meritet (2007), the "European construction is making the typically French vision of energy policy" evolve (p. 4767). For example, France has had to adopt new financial instruments (i.e. the capacity mechanisms) to conform with EU requirements and these might not have been necessary to ensure electricity continuity and reliability (Léautier, 2012). One can ask whether being part of the EU is actually detrimental to the French electricity sector. Indeed, the French electricity system functioned well before its liberalisation and new generation capacity might be a bigger priority for the French government than regulating a new market setting with multiple actors as a result of the market liberalisation required by the EU. France will need "to figure out how to be part of the European process while still protecting its national ideas" (Meritet (2007); p.4770).

5.6. CONCLUSIONS AND POLICY IMPLICATIONS

This chapter contributes to the debates on the energy and climate change nexus and on the governance of electricity supply amid CV&C. Energy security has traditionally been governed separately from environmental sustainability, research has similarly tended to focus on one aspect or the other. It is only recently that the relationships between aspects of the energy trilemma (security, affordability and sustainability) have become a matter of interest.

This study examined the governance of electricity supply continuity and reliability in the UK and France across policy fields and over time. This kind of comprehensive

25 From: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943&from=EN, [Accessed 2nd of July 2019]

approach has been missing from the energy and climate change literature. By exploring governance strategies across two geographical settings through the policy instrument lens this work could shed light on how electricity supply is governed and how governance has changed over time, delving deeper into a more operational level of governance rather than staying at a strategic level.

The governance of the electricity sector is changing in the UK and France, bringing both new challenges and opportunities. As the shifts in governance this chapter examined are recent, it is difficult to determine their implications for electricity supply in the two countries. However, these dynamic policy environments provide an opportunity to devise new policy instruments that not only aim to ensure electricity supply continuity and reliability in the short and longer terms but take into account climate risks more comprehensively and favour policy frameworks more conducive to supporting climate resilience in the sectors. These new policy instruments should be re-assessed by future research when they are more established, to deem their implications for electricity supply in the context of climate and other risks. A study covering only two geographical settings is also not sufficient for drawing conclusions on what governance arrangements are best for ensuring future electricity supply and would benefit from a more comprehensive analysis in other EU and non-EU countries.

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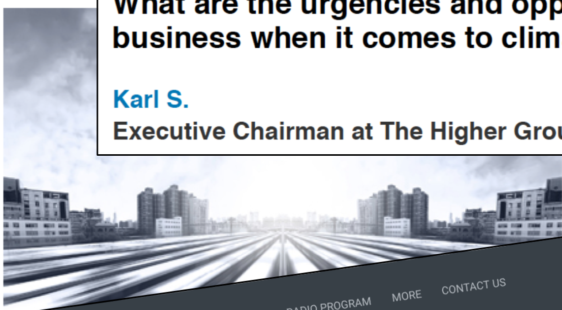

What are the urgencies and opportunities for business when it comes to climate adaptation?

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ARTICLE

As Global Temps Rise, More Companies Begin Adapting to a Warmer World

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hael Coren
ay, July 26, 2011

ections The Washington Post
Democracy Dies in Darkness

Opinions

A climate-change risk assessment

By Michael Bloomberg, Hank Paulson and Tom Steyer October 3, 2013

Michael Bloomberg, an independent, is mayor of New York. Hank Paulson, a former chairman of Goldman Sachs and Treasury secretary in the George W. Bush administration, is chairman of the Paulson Institute, which promotes sustainable economic growth. Tom Steyer is the founder of Farallon Capital Management and co-founder of Next Generation.

If the United States were run like a business, its board of directors would fire its financial advisers for failing to disclose the significant and material risks associated with unmitigated climate change.

CONFERENCE

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Publié le 09 avril 2014

EMPREINTE TERRE

CHANGEMENT CLIMATIQUE : LES ENTREPRISES EN PREMIÈRE LIGNE

L'avertissement du GIEC, lancé la semaine dernière, doit résonner aux oreilles des entreprises. Plusieurs d'entre elles observent déjà les effets du changement climatique sur leur métier et ont déjà décidé de mettre en place une stratégie d'adaptation afin d'assurer leur avenir. Mais l'inertie reste forte au sein de l'immense majorité des acteurs économiques.

6. MANAGING PHYSICAL CLIMATE RISKS IN BUSINESS ORGANISATIONS: AN ANALYSIS OF THE ELECTRICITY SECTORS IN GREAT BRITAIN AND FRANCE

6.1. INTRODUCTION

Keeping the lights on is paramount for all economies. Electricity companies are responsible for ensuring the continuity and reliability of electricity supply and thus need to respond to and be ready for the unexpected. Climate variability and change engender new physical climate risks which electricity companies need to adapt to in order to stay in business and to remain competitive (Bonjean Stanton et al. (2016b); Carvalho et al. (2017); Vagnoli et al. (2018)).

How electricity organisations respond to climate risks[26] is not understood well (Linnenluecke et al. (2012); Averchenkova et al. (2016)). Studies focusing on corporate adaptation to climate change are starting to emerge (Berkhout (2012); Averchenkova et al. (2016)) but to date they have focused on sectors such as insurance (Dlugolecki and Keykhah (2002); Herweijer et al. (2009)), tourism (Bicknell and McManus (2006); Hoy et al. (2011)), construction (Hertin et al. (2003); Wedawatta et al. (2010)) and water (Arnell and Delaney (2006); Charlton and Arnell (2011)). Little research has examined corporate adaptation in other sectors of critical importance to society such as energy, transportation and health (Linnenluecke et al. (2013); Fankhauser (2017)).

The handful of studies on firm-level adaptation in the electricity sector report empirical insights into the capabilities needed by the electricity sector organisations

[26] In this study, climate risks refer to the physical climate risks associated with climate variability and change.

for climate adaptation (Busch, 2011), focus on risk identification, assessment and response in firms (Weinhofer and Busch, 2013), analyse how companies respond to specific climate risks, such as rising temperature, water availability, and extreme weather (Haigh and Griffiths, 2012) or drought (Gasbarro and Pinkse, 2016), and explore the role of learning in adaptation to climate change in companies (Orsato Renato et al., 2017). More recently Gerlak et al. (2018) reviewed the existing literature on climate risk management in the electric sector, focusing on: a) climate change impacts; b) measurement of risks; c) stakeholder engagement and cross-sectoral collaboration, and; d) adaptation actions. Although Audinet et al. (2014) review initiatives to assess climate risks and to manage future impacts in electricity companies in the developed world, they do not consider what drives electricity sector organisations to adapt to climate risks, of which little is still known (Linnenluecke et al. (2012); Averchenkova et al. (2016)).

It is noteworthy that none of the studies on climate change adaptation in the electricity sector explore the interplay between corporate adaptation and the institutional setting within which the companies operate. Therefore, this chapter examines the institutional setting in which electricity companies adapt to physical climate risks, and whether and to what extent their adaptation is driven by internal or external factors. In so doing, this chapter seeks to answer the following three questions:

1- How do electricity companies manage physical climate risks?
2- What drives and triggers adaptation measures in these companies?
3- Do adaptation-specific regulations make a difference to the way the companies adapt?

To answer these questions, documents were analysed and semi-structured interviews with representatives of electricity companies and stakeholders conducted in Great Britain and France. The case study countries were chosen because of the marked differences in the structures of their electricity sectors, dominant electricity generating technologies and governance. The findings are reported focusing on two key themes that emerged from the material: 1) climate risk assessment and management and; 2) drivers of corporate adaptation to physical climate risks. The interplay between the drivers of corporate adaptation and the institutional context in which electricity companies operate will also be reflected upon.

The remainder of this chapter is organised as follows. First, section 6.2 reviews the literature on corporate climate adaptation. Next, section 6.3 describes the case studies and the approaches used for material collection and analysis. Finally, sections 6.4 and 6.5 report the results and discuss the findings in relation to the existing literature.

6.2. CORPORATE CLIMATE ADAPTATION

Corporate decision-makers encounter challenges when their operating environment unexpectedly changes (Weick and Sutcliffe, 2015). Economic disruptions (strikes, changes in customer demand, competition, industrial and financial crises) trigger a call for managers to better understand and find ways to adapt (Kovoor-Misra et al., 2000) and anticipate future crises. But managing climate risks is different from responding to economic disruptions because few environmental changes exhibit as much uncertainty and potential for disastrous consequences as those associated with climate change and extreme weather events (Barnett, 2001).

Although many terms such as ecological discontinuities (Winn and Kirchgeorg, 2005), surprises (LaPorte, 2007), catastrophes (Changnon and Changnon, 1998) and disasters (Healey, 2006) have been used to describe extreme weather events, this thesis will follow Linnenluecke and Griffiths (2010) and consider that extreme weather events are events that challenge the coping range of an organisation, or exceed the range of normal climate variability with which an organisation can cope.

European electricity companies are already affected by extreme weather events and will be impacted by future climate change (Bonjean Stanton et al., 2016b). For example, severe winds can damage electricity grids and floods can impair substations, resulting in power cuts and loss of electricity supply. When such risks exist, organisations need to have strategies in place to manage the risks and avoid adverse consequences to business performance (Winn et al. (2011); Linnenluecke et al. (2012)).

Corporate adaptation refers to a gradual, continuous change process of an organisation as a response to or in anticipation of a stress or shock from the organisations' operating environment (Linnenluecke and Griffiths, 2010). Other definitions suggest that adaptation can involve both building adaptive capacity thereby increasing the ability of individuals, groups, or organisations to adapt to changes, and implementing adaptation decisions, i.e. transforming that capacity into action. Both dimensions of adaptation can be implemented in preparation for or in response to impacts generated by a changing climate (Adger et al., 2007). When applied to business organisations, the latter definition suggests that adaptation includes "adjustments and modifications that are being undertaken in expectation of and in response to environmental changes, which cover a wide range of attitudinal, cognitive and behavioural aspects at organisational and individual levels, and which also reflect and interact with the broader institutional or social context of the firm" (Linnenluecke et al. (2013); p.399). This study adopts this latter definition of corporate adaptation.

Emerging evidence indicates that organisations are incorporating risks related to extreme weather events and climate change into their corporate strategies, decision-making and practices (Winn et al. (2011); Weinhofer and Busch (2013)) and are adapting (Tompkins et al. (2010); Dubus (2012); Gasbarro and Pinkse (2016)). However, the evidence also suggests that corporate adaptation is more reactive than proactive, and often unintentional or a co-benefit of activities unrelated to climate change (e.g. planned infrastructure investment) (Tompkins et al., 2010).

Adaptation can be triggered by external drivers such as public policies, reputational risks or public pressure, or internal drivers such as the company's experience of climate impacts, corporate culture and attitude towards climate variability and change

(Averchenkova et al., 2016). Understanding the drivers and triggers of corporate adaptation is of paramount importance as it helps policy-makers to craft a policy environment conducive to corporate adaptation and enables non-profit organisations, international organisations and governments to engage with businesses on climate change adaptation (Hoffmann et al. (2009); National Round Table on the Environment and the Economy (NRTEE) (2012)).

But identifying the drivers and triggers of adaptation is challenging as they are often not documented or can be the means for justifying other measures such as cost-cutting (Tompkins et al., 2010). Some studies have identified drivers of corporate adaptation. However, the observations remain rather generic (Averchenkova et al. (2016); Tompkins et al. (2010)) or focus on one type of driver only (e.g. common internal features of organisations that adapt as in Wilby and Vaughan (2011) or explore organisational learning to anticipate climate risks (Orsato Renato et al., 2017). Although Gasbarro et al. (2017) investigate quantitatively the contextual drivers of multinational enterprises' responses to climate change, to date there has not been comprehensive examination of the drivers and triggers of corporate adaptation to climate risks in a specific sector in different geographical and political-economic settings. This chapter contributes to filling these research gaps by identifying the drivers and triggers of corporate adaptation to climate risks in the electricity sectors in Great Britain and France.

6.3. CASE STUDIES, MATERIALS AND METHODS

Climate risks do not impact all sectors equally: sectors responsible for critical infrastructure and public services are particularly vulnerable (Winn and Kirchgeorg, 2005). Climate risks already affect the European electricity sector (Bonjean Stanton et al., 2016b) and electricity generation, transmission and distribution companies have responded by adapting to the disruption caused by extreme weather events.

Great Britain and France were chosen as case studies because of the marked differences in the structure of their electricity sectors, generating technologies relied on, and the governance of their electricity sectors. Great Britain still produces most of its electricity from fossil fuels, mostly from natural gas and coal, whereas France relies primarily on nuclear energy. Great Britain liberalised its electricity sector in 1990s and has a market-based approach for governing the sector. In the recent past, government interventions have increased though to foster the decarbonisation of electricity supply. France has had a state-led governance strategy in the electricity sector although is now under pressure from the European Union (EU) to liberalise its energy market.

Semi-structured interviews and corporate and policy documents are the key materials gathered and analysed to answer the research questions. Interviews were carried out with electricity company employees, policy-makers and stakeholders. Corporate representatives were selected based on their role in assessing and managing climate risks. One participant was typically interviewed per electricity organisation unless the company had different sub-units for assessing and managing climate risks. If this was the case, two or more interviews were carried out with representatives of the same organisation. The participants came from eight British and five French electricity companies (covering electricity generation, transmission and distribution). The pool of organisations in each country is heterogeneous in terms of company size, region of operations and electricity generating technologies, covering both renewable and non-renewable energy technologies (Table 6-1 and Table 6-2). They are also differently exposed and vulnerable to climate risks (chapter 4). Interviews were also carried out with policy-makers and regulators involved in developing, implementing and evaluating policies and regulations on adaptation in the electricity sector, as well as researchers, consultants, and independent body organisations who are working on or knowledgeable about climate risk management in the electricity sector. For reasons of confidentiality, organisations or interviewees involved in the research were not explicitly named. In total, 26 interviews were conducted (13 in each country). At this point saturation was reached as final interviews did not yield new information. Each interview covered the following topics: 1) Information on the company and the interviewee; 2) climate risk exposure of the company and sector and management of these risks (including drivers and triggers to adapt and finance available for adaptation); 3) institutional and policy context of managing climate risks in the electricity sector. The typical interview duration was about one hour and interviews were conducted face-to-face or over the phone or Skype.

Publicly available corporate and policy documents relevant for climate risk management in the electricity sector were also gathered and analysed. These documents arise both from voluntary disclosure and compulsory reporting (e.g. the first and second round reports published under the UK Adaptation Reporting Power (UK ARP) provisions in Great Britain) by electricity companies in the two countries. In all, forty documents were analysed.

An inductive approach which seeks to identify categories as they appear in the evidence base was adopted. Interview transcripts, notes and documents were systematically analysed with MaxQDA, a qualitative analysis software. Statements were first allocated to three broad themes: 1) climate risk perceptions, assessment and management; 2) drivers and triggers of adaptation, and; 3) institutional and policy context of climate risk management. Sub-categories of these themes emerged through inductive category development (Mayring, 2000). Table 6-3 presents the sub-categories that emerged for the three themes

An important analytical step was to define what is an adaptation action and what is not for the purposes of this research. The definition has to encompass actions aiming to mediate both short-term climate variability and longer-term climate change. In this thesis, Tompkins et al. (2010)'s definition was modified so as to consider adaptation action as ''any adjustment by any actor or institution to any real or perceived climate change that enhances or reduces ability to cope with or adapt to climate change whether or not motivated by climate change'' (p. 630). This definition includes actions that are motivated by non-climate drivers such as financial savings.

Table 6-1: Characteristics of the British electricity companies included

		Organisation references							
		B1	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**
Size (n. employees)		>10000		> 750	>25000	>21000	>2500	>5000	> 700
Electricity generation	*Renewable*	X				X			X
	Non-Renewable	X				X			X
% national electricity production		>20[1]				<10[1]			<10[1]
Transmission					X	X			
Distribution						X	X	X	
Regulator				X					
Industry body			X						

[1] From: https://www.ofgem.gov.uk/data-portal/wholesale-electricity-generation-market-shares-company-2017-gb [Accessed 14/06/2018]

Table 6-2: Characteristics of the French electricity companies included

		Organisation references				
		F1	F2	F3	F4	F5
Size (n. employees)		> 65000	> 1350	> 9000	> 74000	> 35000
Electricity generation	*Renewable*	X	X			
	Non-Renewable	X				
% national electricity production		>90	<5		<5	
Transmission				X		
Distribution						X

Table 6-3: Coding categories and sub-categories that emerged from the data analysis

Coding category	**Sub-categories**
Climate risk perceptions, assessment and management	Climate risk perceptions
	Climate risk assessment (data and methods used, capacity to understand and carry out the assessments, barriers and overcoming these barriers)
	Climate risk management (types of actions implemented, barriers and overcoming these barriers, financing of these actions)
Management of climate variability and climate change	Action mediates climate variability (and not climate change)
	Action mediates climate variability and climate change
Drivers of adaptation actions	Adaptation action is a direct response of exposure to climate risk (e.g. building flood-defences in response of a flooding event)
	Adaptation action is not exclusively driven by exposure to climate risks
	Adaptation action is not driven by climate risks
Policy context of climate risk management	Policies or regulations that focus exclusively on climate risks
	Policies or regulations that include climate risk considerations
	Policies and regulations that do not consider climate risks but influence adaptation actions

6.4. Results

In what follows how the electricity companies perceive and assess climate risks is first reported and then, how companies manage climate risks and what motivates them to do so is presented.

6.4.1. Great Britain

Electricity companies in Great Britain are experiencing climate variability first hand. They are also aware of the impacts of extreme weather events such as floods, storms and droughts on their assets. Flooding was the most often mentioned climate risk for electricity generation, transmission and distribution. For network companies high winds, gales and storms were also of concern as trees falling on cables can lead not only to short-lived power cuts but also to longer-term damage to high voltage power lines. Generating companies with assets in coastal areas mentioned the risk associated with sea level rise but they did not consider it to require immediate attention.

Most companies used external expertise of the UK Met Office, the UK Climate Impacts Programme (UKCIP), researchers or consultants to understand the implications of climate projections. Some companies have in-house capacity to digest future climate projections and flood maps. After obtaining climate data and projections, companies translate them into potential risks for their assets and identify hotspots. Some companies have had collaborative research projects with for example the UK Met Office in the Impacts of Climate Change on the Energy Industry studies (UK Met Office, 2014) or with other energy companies as part of the Distribution Network Operators funded project aiming to quantify the impact of vegetation growth around overhead lines (Western Power Distribution, 2011).

But all interviewees did not view resilience to climate risks in the same way. For some, resilience meant accepting that physical assets do go down at times and that ability to restore the power back on quickly is key. For others it was doing as much as they could to ensure that the asset would not go down in the first place (e.g. flood proofing power stations).

The periods covered in the risk assessments tend to mirror the lifespans of the assets that companies are responsible for. For example, a generation company owning power stations that will be decommissioned in the 2030s carries out climate risk assessment up to that point for these assets. A transmission company with assets of lifespan extending to the end of the century considers the 2080s period in their risk assessment. Some companies use worst-case scenarios: these companies felt that if their assets are resilient against the worst scenario, then they should be fully adapted to less adverse climate change scenarios. But it is important to note that the assessment of worst-case scenarios does not necessarily lead to the climate proofing of assets to withstand them.

Companies manage short-, medium- and long-term climate risks using distinct approaches. For the short and medium terms, companies draw from their past experiences with extreme weather events and incorporate lessons from them into their risk registers. These risks are then managed using existing business practices, such as the iterative "Plan–Do–Check–Adjust" (PDCA) model at the operational level. But even the management of short to medium term climate risks is not trivial. As an interviewee pointed out "the main challenge is not knowing the impact ahead, not knowing how many people we need to bring on board to respond to the extreme event, or where it is going to hit exactly. Obviously when we get a prediction or warning it is a fairly broad brush … and … we don't know the full impact until it … actually hits us". Some interviewees also indicated that they have an internal adaptation strategy but it remained unclear if it was supplemented with an implementation plan or what timeframe the strategy covered.

Translating climate projections into actions to ensure long-term resilience of assets and continuity of services is more challenging. Some companies had tackled the issue head-on and had developed a long-term strategy up to the end of the century. However, interviewees had difficulty in explaining what such strategies actually implied. Other companies assumed that climate change impacts will unfold slowly and incrementally, believing that they will have time to adapt, and for now manage climate risks as per business as usual. One interviewee said: "I think the impacts of climate change on a lot of things in the UK will be fairly minimal and there is enough resilience in our network to accommodate lower levels of climate change impact. That doesn't say we wouldn't be looking at it in the future." Another interviewee said that his company has a "wait and see" approach: "climate change is a long-term process. … if those predictions were found to start to become true, then … we would then consider putting large plan in, or different plan in, something that would operate within that new environment. But as it stands at the moment, we will kind of continue as we are, and I don't think we are making any changes to what we are doing.". This lack of preparation for future climate risks now reflects that companies are still unsure about what they will need to adapt to.

Climate proofing actions were financed using two key solutions. First, as electricity generation is open to competition in the UK, generators could invest freely in climate proofing their assets, meaning it will be done when it saves money. In contrast, network companies are monopoly businesses, so Ofgem, the regulator, uses a performance-based framework, the RIIO framework (i.e. Revenue = Innovation + Incentives + Outputs), to set the price controls. The current RIIO-1 framework covers 8 years (2015-2023) and provides network companies with strong incentives to step up and meet the challenges of delivering a low carbon, sustainable energy sector at value for money for existing and future consumers. As such climate proofing investments fall under the RIIO framework and are overseen by the regulator Ofgem and investments in resilience can only be made within these regulatory constraints.

The results indicated that past experience with extreme weather events was one driver for adaptation in companies (such as flood proofing a substation after flooding). But the interviews further suggested that exposure to extreme weather events was rarely the main reason for adaptation. Adaptation was often the result of multiple drivers and the most important of them were the financial and business-related ones. Several interviewees mentioned that not only did they use economic evaluation methods such as cost-benefit analysis, but that they also considered viable asset lifetime and return on investments before financing adaptation actions. Companies would only adapt to climate risks if it made business sense. Financial policies based on penalties and rewards and price setting regulations also strongly influenced whether or not adaptation takes place. Some interviewees also suggested that their companies invest in adaptation because it gave them a competitive advantage over other electricity providers.

Environmental and climate policies were the second most often mentioned adaptation driver. Some voluntary policies were elaborated by electricity companies collaboratively. For example, electricity network companies developed the ETR 138 guidance for managing and building resilience against the risk of substation flooding. Other mandatory policies have been established by the government. For example, under the UK Climate Change Act 2008, the Adaptation Reporting Power (UK ARP) enables Government to require organisations such as electricity companies to report on how they adapt to climate change. The UK ARP is to encourage companies to assess the impacts of climate risks on their organisation and prepare adaptation plans.

Companies that own and manage nuclear power stations also have to manage climate risks because they need to ensure the safety of stakeholders and the public (Wilby et al., 2011). Following a major earthquake, a 15-metre tsunami disabled the power supply and cooling system of three Fukushima Daiichi reactors on 11th of March 2011, causing a major nuclear accident. This incident was a tipping point for nuclear power plant operators and triggered them to undertake significant nuclear safety reviews on their assets. Some companies went further and embarked on a collaborative program aiming to review the robustness of their fleet of reactors against unpredictable, extreme, 'beyond design basis' events, and to implement the necessary safety enhancements to help protect their assets.

Peer- and customer pressures were also considered drivers of adaptation. Avoiding power cuts is paramount to avoid bad publicity and to ensure customer satisfaction. Public expectations regarding electricity supply continuity and reliability have increased and thus power cuts due to extreme weather events could adversely affect the companies. The number of customers served by an asset is also an important factor in the prioritisation of adaptation investments. Some companies go further and consult stakeholders about their investment plans, including measures for managing climate risks.

6.4.2. France

The French electricity generators and network operators also consider that past experience from extreme weather events had made climate risks salient for them. Droughts and extreme high temperatures were mentioned most often among generators. During the 2003 heatwave, environmental policies protecting aquatic life prevented nuclear plant operators from discharging cooling water into watercourses which were already suffering from low flows and high water temperatures. Nuclear electricity generation was severely affected in a country relying heavily on nuclear power. Hydropower generators reported witnessing a shift in seasonality and reduced water availability for electricity production. Network operators considered flooding and severe storms as the most important climate risks to their assets.

In France, one company controls most of electricity generation, transmission and distribution. Although sub-divisions responsible for generation, transmission and distribution have functioned semi-independently since 2007, how the group as a whole assesses and prepares for climate risks is paramount for the country. The 1990 Intergovernmental Panel on Climate Change (IPCC) first assessment report and the 1992 Rio Summit both not only raised awareness of climate risks in the group but also contributed to the creation of a Research & Development (R&D) unit dedicated to understanding climate risks and their impacts on the group's assets and activities. This R&D department provides climate-related useable information that does not exist outside of the group. The group invested in in-house capacity not only to manage extreme weather events but also to assess the impacts of future climate change over the longer term for the assets owned by the group.

A few other generation companies also have internal capacity to assess climate risks to their assets but not as substantially as the dominant group of companies has. For example, one interviewee mentioned using impact models developed in partnership with research organisations to assess the vulnerabilities of their assets to flooding. All interviewees indicated involvement in collaborative climate change projects with national or international consultancies and research organisations.

French electricity companies have plans to not only assess and manage risks in the short term at the operational level but also strategies to manage longer-term climate risks. Almost all interviewees suggested that their companies had already developed and were implementing an adaptation strategy, independently of any regulatory requirements. The company culture influences the way the company decision makers perceive, interpret, devise and implement adaptation decisions.

Some companies already budget for climate-proofing their infrastructure. Others have an asset-resilience approach to managing climate risks. Some companies accept that an asset might go down during an extreme weather event but are prepared to recover quickly after the event. One interviewee suggested that most French electricity companies take a palliative approach to climate risks linked to the lifespan of their assets. Others were taking a preventive approach by looking at future climate data to identify future vulnerability hotspots.

But regardless of the company approach to managing climate risks, all interviewees agreed that adaptation decisions need to make economic sense. For existing assets, adaptation will only be undertaken if costs can be recovered during their remaining lifetime. For new assets, the question is not whether adaptation is funded but how it will take place. The decisions are taken in light of economic appraisal, for example using cost-benefit analysis. The decisions whether and how to adapt not only depend on the characteristics of particular assets but also on what other assets the company has in its portfolio: companies prioritise investments in assets serving the most people or offering the best return, for example.

Interviewees also considered that extreme weather events do not have much influence on the way French electricity companies manage their assets and ensure the continuity and reliability of electricity supply. Companies in the French electricity sector have good awareness of future climate change and some are re-thinking their business models. For example, one company is exploring win-win strategies to manage extreme weather events by developing adaptation actions that would ensure revenues despite climate risks. Indeed, by owning both nuclear and hydro-generation assets on the same river, this company could manage water flow with its hydropower plant to ensure that its nuclear plant downstream could operate during periods of droughts and low flows. However, this strategy is available only to companies with specific portfolios of electricity generation assets.

Although financing of adaptation is left to the discretion of generators, the investment plans of network companies are scrutinised by the regulator, the Commission de Regulation de l'Energie (CRE). The regulator sets the tariff for accessing public electricity systems (Tarif d'Utilisation des Réseaux Publics d'Electricité). This tariff is the remuneration paid by the consumers, through their supplier, to the transmission and distribution network operators. It makes up about 90% of network operators' income. As a result, the regulator also approves climate risk-related investments.

Exposure to climate risks is not the key trigger for adaptation in French companies just like in the companies in Great Britain. Adaptation has multiple triggers in France as well, of which financial and business-related ones are the most important. Adaptation actions have to make business sense and asset lifespan and rate of return drive adaptation decisions. Interviewees considered that their companies want to avoid any potential financial losses due to disruption of power supply and were vigilant to prevent them. The dominant group of companies took the threat of climate change on board very early on. Since the 1990s, its internal leadership and commitment to addressing climate risks has driven the response of the whole French electricity sector to climate change. Some interviewees considered that climate change is as much an opportunity as a risk as it can trigger new ways of dealing with the risks. Investing in internal climate change capacity as well as finding innovative ways to address climate risks can offer a competitive advantage over other companies and market entrants.

The interviewees also considered that regulation could impede investment to address climate risks. One interviewee said that although the generator s/he works for had established that revenue from hydropower generation could decrease slightly because of climate change and associated changes in flow regimes, it did not consider investing in adaptation; the permit to operate the dams in the river for regulating water flow is up for renewal so they cannot invest in an asset they might not have the right to exploit in a few years' time.

6.5. Discussion

This study took an organisation-focused view of adaptation, examining how electricity companies in Great Britain and France understand, assess and manage climate risks and exploring the drivers of corporate adaptation. Understanding drivers of adaptation in business organisations is of paramount importance as it "could offer significant guidance to policy-makers looking to mainstream climate change adaptation across government departments as well as in wider society." (Tompkins et al. (2010); p.633).

Although adaptation can be proactive or reactive and autonomous or planned (Smit et al., 2000), this study, like others (Kolk and Pinkse (2005); Amundsen et al. (2010); Haigh and Griffiths (2012); Gasbarro and Pinkse (2016)), finds that adaptation to climate risks in electricity companies is largely reactive, influenced by past experience of extreme weather events.

All interviewees said that their companies have operational measures in place to manage climate risks in the short and medium terms. The most common responses were the three management stages of identification, assessment, and response, which are part of their normal business continuity planning (Agrawala et al. (2011); Berrang-Ford et al. (2011); Crawford and Seidel (2013); Pauw (2015)). When dealing with climate risks most companies draw on tested alternative with only a few companies with R&D departments investing in new innovative measures. The companies also preferred “low-hanging fruit” and “no regret” measures because they involved smaller financial and other risks. They are also often low cost, easier to reverse if required and yield benefits whether or not predicted climate impacts materialise (Hallegatte (2009); Markandya et al. (2014)).

Extreme and changing weather has been a long-established concern for natural resource dependent companies (Adger et al. (2009); Preston, Dow, et al. (2013)). For most companies, responding to the potential impacts of weather and climate is business-as-usual and is integrated into other efforts to manage external changes and stressors. Most interviewees consider that climate risks were already included in their existing risk registers and managed using established practices. It is also likely that some companies practice continuous adaptation without acknowledging it (Gasbarro and Pinkse, 2016).

Yet most interviewees remained vague about how their electricity companies were thinking about and managing future climate change risks over the longer term. This finding echoes Dépoues (2017)’s observation that infrastructure companies tend to “focus on resilience to current weather and do not go so far as to question future climate.” (p.484). Indeed, examples of corporate adaptation to future climate change were not prominent in the evidence gathered here either, possibly for several reasons.

First, the decisions on when and how to adapt are conditioned on the process of receiving and interpreting climate change signals (Berkhout et al., 2006). All companies were aware of how climate risks could impact on their activities in the short and medium terms. However, they were less aware of the consequences of future climate change on the continuity of their operations over the longer term. Additionally, although awareness of future climate change risks is increasing, organisations are still lacking more detailed information necessary to support decision-making and long-term planning under deep uncertainties (Ebinger and Vergara (2011); Bonjean Stanton et al. (2016b)).

Second, decisions to implement adaptation actions also depend on their costs and benefits. Companies want to understand the impact of adaptation actions on their business performance and can use financial models to quantify risks (e.g. extreme value theory, stochastic differential equations, system dynamics simulation, fuzzy logic) and value avoided losses (Network for Business Sustainability, 2011). However, these financial decisions are made against remaining lifespans for existing assets or rely on economic appraisal methods to evaluate adaptation strategies for new assets. Thus economic appraisal and budgeting are important determinants of adaptation measures (Fankhauser et al. (1999); Lorenzoni et al. (2000a); Lorenzoni et al. (2000b); Preston, Mustelin, et al. (2013)).

Finally, adaptation investments need to be economically beneficial and not jeopardise near- and medium-term profitability. Adaptation measures were often perceived to be costly and immediate whereas their benefits were considered uncertain and distant and possibly hypothetical. Thus efficiency objectives could rule out proactive adaptation (Schneider, 2014). Risks of maladaptation and fear of lock-ins could also prevent electricity companies from anticipating future climate change impacts (Smith and Brown, 2014).

A mix of climatic and non-climatic triggers motivate electricity companies to adapt to climate risks. Electricity companies in Great Britain and France are aware of climate risks because they had experienced extreme weather events first hand. However, this direct exposure does not trigger responses on its own: companies do not perceive adaptation to extreme weather events as something standing apart from business routines and their normal business continuity planning (Crawford and Seidel (2013); Pauw (2015)). Additionally, Berkhout et al. (2006) outline that electricity companies regard adaptation as an artificial concept, as it relies on the separation of climate and non-climate factors. This corroborates the results of this study, that climate sensitivity was not perceived or treated differently from other drivers of technological, market or regulatory change. Non-climate drivers were actually found to be more important in triggering corporate adaptation.

The most common non-climatic drivers were financial and business-related ones, which affect what Berkhout et al. (2006) call the “organisation’s core business”. Almost all interviewees said that investing in adaptation needed to make economic sense. In other words, if extreme weather impacts are seen to have significant impacts on the core business, a company is more likely to adapt.

Public policies and regulations were considered a driving force for adaptation. They shape the sector and as Linnenluecke et al. (2013) suggest “firm and industry adaptation will always be strongly influenced by the context in which firms and industries are embedded; this in turn influences firm internal adaptation decisions and adaptation goals” (p.407). How governments shape the electricity sector’s institutional context to overcome market failures, correct policy distortions and incentivise private adaptation is of paramount importance (Fankhauser, 2017).

One prominent driver of adaptation in Great Britain was the companies’ desire to retain their competitive advantage. In the United Kingdom, the electricity sector is a complex mosaic of competing interests and imperatives. Over the past few years, new entrants to the UK electricity market have sought to break the dominance of the “big six” electricity suppliers. There are now about sixty independent suppliers as opposed to just eleven a decade ago (Pfeifer, 2018). Extreme weather events and future climate change can shake companies by disrupting their operations, reducing their production capacity, increasing the cost of materials and infrastructure maintenance, increasing insurance prices, and disrupting their supply chains (Agrawala et al. (2011); Crawford and Seidel (2013)). Self-interest therefore can be a powerful driver for organisations to proactively adopt measures that seek to reduce costs, minimise disruptions to their production and services, increase their profitability and improve their ability to do business.

The interviewees considered that the more proactively adapting companies had a common trait: they all have internal capacity to make sense of the future implications of climate change for their businesses. The main electricity company in France invested, since the 1990s, in internal R&D department dedicated to supplying climate data to support assessment of climate risks to their operations. Its internal leadership and corporate culture are drivers for adaptation to climate change. Although the company recognises the uncertainties associated with climate data, it believes that there is sufficient evidence to take precautionary measures protecting its assets. Interviewees considered that their company had a responsibility to ensure the continuity and reliability of electricity supply regardless of the risks that might challenge it. These observations corroborate results indicating the importance of organisational culture as a determinant of the way in which companies respond to new risks posed by climate change (Berkhout et al. (2006); Gledhill et al. (2013)).

Furthermore, this study found that, on one hand, adaptation specific policy instruments based on mandatory disclosure of climate risks have so far failed to prompt electricity companies to address climate risks. On the other hand, voluntary policy instruments inviting organisations to disclose their climate risks to shareholders and stakeholders might encourage companies to engage in adaptation; as early adapters these companies can retain their competitive advantage. Great Britain and France have both trialled reporting requirements as a policy instrument to trigger companies to consider not only short- and medium- but also longer-term climate risks. The UK Government adopted the UK ARP to mandate organisations responsible for critical infrastructure and public services to report on their climate risks (UK DEFRA, 2009). It was to ensure that everybody with public or statutory functions[27] (electricity companies among others) not only becomes more climate resilient, but also makes cost-effective and timely decisions about how and when to adapt, whilst aiming to make them more aware of how their plans affect the stakeholders they interact with. The UK ARP is the only legislative lever available in the UK Government to influence corporate behaviour regarding climate adaptation. It is based on the assumption that getting companies to engage with climate change through their corporate reporting

[27] The definition of statutory undertaker is taken from the Town and Country Planning Act (1990) the Town and Country Planning (Scotland) Act (1997) and the Planning (Northern Ireland) Order (1991).

will raise awareness and encourage action (Moffat and Newton, 2010) such as the adoption of adaptation measures (Füssel and Klein (2006); Hoffmann et al. (2009)).

Jude et al. (2017) recently analysed the first round of UK ARP reports and concluded that the UK ARP had achieved its aims and played a prominent role in helping to understand climate change risks and vulnerabilities, and develop adaptive capacity and adaptation in organisations. This study suggests however that although the UK ARP has positive aspects (helping companies to better understand their climate risks management practices to date and enabling them to engage about climate risks at a sector level), the act of reporting on climate risks itself does not drive corporate adaptation in the UK electricity sector. This resonates with earlier results suggesting that awareness of an issue does not necessarily lead to behavioural change (Bulkeley (2001); Demeritt and Langdon (2004); Amundsen et al. (2010); Agrawala et al. (2011); Berrang-Ford et al. (2011); Ford et al. (2011)).

Additionally, as a light form of regulation the UK ARP cannot incentivise companies to change their current practices. McDonald (2011) argues that law can support adaptation more meaningfully through other instruments such as using regulation to reduce exposure or sensitivity to climate hazards, establishing the legal architecture for new market mechanisms, and funding arrangements for adaptation costs and liability for climate impacts. Also, the UK ARP is based on a risk assessment approach and suggests the development of a company adaptation strategy. However, interviews with the company employees suggested that management of climate risks takes place mostly at the operational level rather than at the strategic level.

In France there are no provisions resembling the UK ARP. When queried about the usefulness of such an instrument, French interviewees unanimously rejected the idea: they saw a mandatory disclosure mechanism as a step back in how they manage climate risks as the French electricity sector is already highly regulated and the regulations often already encompass climate risk considerations. But French electricity companies are guided to disclose climate risks and adaptation actions in their annual report, the "Document de Reference" which describes the company, its organisation, activities, risks, financial situation, results and forecasts. It gives shareholders and other stakeholders information about the company and the viability of its business. Also, Article 173 of the 2015 Law on Energy Transition for Green Growth (i.e. LOI n° 2015-992) requires listed companies to disclose financial risks related to the effects of climate change and the measures adopted to reduce them. Banks and credit providers shall disclose the risks evidenced by the stress-tests that are regularly implemented in their mandatory risk reports and institutional investors must disclose information to beneficiaries on how their investment decision-making processes take social, environmental and governance criteria into consideration (including climate risks), and the means implemented to contribute to the financing of the ecological and energy transition (London School of Economics, 2015).

Although French electricity companies are not yet required to disclose their climate risks and adaptation strategies under an adaptation-specific policy instruments, most of them proactively do. This voluntary and transparent disclosure of climate risks can be explained by the fact that companies are eager to reassure investors about the market viability of the company. As such the act of reporting on climate risks itself, even if voluntarily, does not seem to be a driver for corporate adaptation per se but motivated more by a strong internal culture or stakeholder pressure.

6.6. Conclusions and policy implications

This study concludes that electricity companies in Great Britain and France are aware of climate risks, are already mainstreaming climate risks into their risk registers and are managing climate risks alongside other risks. But although the past experience of extreme weather events is an important factor, it rarely triggers companies to adapt. Non-climate drivers such as financial and business considerations, policy context, pressure to remain competitive as well as internal culture and leadership are among the key drivers of adaptation in the UK and French electricity sectors. Often multiple drivers need to combine for adaptation to occur.

This study further found that although the electricity companies manage climate variability in the short and medium terms, they rarely fully consider the implications of longer-term climate change on their operations and business models. This can be due to the lack of useable climate information to meaningfully support decision-making, cost of adaptation actions in the short term versus hypothetical future rewards in the longer term, fear of maladaptation and lock-ins.

The results also indicate that climate risk reporting requirements, voluntary or mandatory, are no driver of corporate adaptation to climate change. Reporting requirements do not provide sufficient incentives for companies to change their practices. Financial instruments (penalties or taxes) that would directly affect profit margins and core business would create more leverage for changing corporate practices in the area of adaptation.

7. DISCUSSION

7.1. INTRODUCTION

Electricity systems can be vulnerable to various threats that, when materialising, may cause unforeseeable disruptions to the continuity and reliability of electricity supply. Among such threats, climate variability and change (CV&C) can affect power systems either through acute, disruptive extreme weather events or have more gradual longer term implications (Sieber, 2013). Extreme weather events (e.g. earthquakes, tsunamis, hurricanes, floods…) are the biggest threats to power system secure operations (Gündüz et al., 2017), being globally responsible for 63% of blackouts[28] (Bompard et al., 2013).

This research explored how CV&C affect electricity systems in Europe and how electricity companies in Great Britain and France adapt to climate risks. Although the main objects of research are electricity companies themselves, this research took a multi-level and a multi-geographical approach; it did not only look at adaptation at the organisation-level but also considered the policy and climatic contexts in which electricity companies operate in two contrasting institutional environments (i.e. the UK and France). The material analysed in this study consisted of interview transcripts as well as peer-reviewed articles, and policy and company documents. The data were analysed qualitatively using the MaxQDA software. The United Kingdom and France were chosen as case studies because of the marked differences in the structure and the governance of their electricity sectors (chapter 3). The UK has a fully liberalised and privatised energy market. By contrast, the French electricity market, despite being

[28] The blackouts included in Bompard, et al. (2013) must conform to the following criteria: 1) the number of affected population > 1000 inhabitants; 2) the duration of interruption > 1 h and 3) the affected population times the duration must be larger than 1,000,000 inhabitant-hour.

more opened to competition following pressures from the European Union, still largely remains a monopoly.

This thesis explored corporate climate adaptation asking four specific research questions (RQs):

> RQ1: What do we know about the impacts of CV&C on electricity systems in Europe?
>
> RQ2: How are existing governance arrangements and policy instruments ensuring the lights stay on despite CV&C in the United Kingdom and France?
>
> RQ3: How do electricity companies manage physical climate risks?
>
> RQ4: What drives and triggers adaptation measures in these companies?

These research questions were addressed in three empirical chapters:

a) Chapter 4 identified the impacts of CV&C on electricity systems in Europe.
b) Chapter 5 explored what policy instruments governments in the UK and France use to ensure that the lights stay on in the shorter and longer terms amid physical climate risks.
c) Chapter 6 investigated how electricity companies in Great Britain and France manage physical climate risks, what drives and triggers them to adapt and whether adaptation-specific regulations make a difference to the way they adapt.

In what follows, the insights gained for each individual research question are first outlined and then further expanded upon. This chapter then finishes by reflecting on some of the study limitations and suggests some avenues for future research.

7.2. REVISITING THE RESEARCH QUESTIONS

RQ1: What do we know about the impacts of CV&C on electricity systems in Europe?

Chapter 4 answered this research question. A systematic literature review (SLR) was carried out to collate consistent patterns of impacts of CV&C on electricity systems (generation, transmission and distribution) in Europe. It answered the questions: i) what patterns of impacts of CV&C on electricity systems can be identified by collating the results of peer-reviewed articles? ii) are any of these patterns robust? The review considered two time-periods to collate the results from the peer-reviewed papers included in the analysis; near term to mid-21st century (NT-MC) covers the period from the present until 2070, while the end of the 21st century (EC) covers the period from 2061 until 2100.

The SLR established that thermal electricity generation from the current capacity is projected to decrease throughout the 21st century due to diminishing cooling capacity. In contrast renewable electricity generation will increase for hydroelectricity in Northern Europe (NT-MC and EC), for solar electricity in Germany (NT-MC) and the United Kingdom and Spain (NT-MC and EC) and for wind electricity in the Iberian Peninsula (NT-MC) and over the Baltic and Aegean Sea (NT-MC and EC).

Overall conclusion from RQ1:

CV&C impacts negatively more traditional electricity generation technologies such as thermal power plants for the near-term to mid-21st century (NT-MC) and the end of the 21st century (EC). In contrast, electricity generation is projected to increase from current capacity as a consequence of climate change for some renewable technologies in some parts of Europe.

RQ2: How are existing governance arrangements and policy instruments ensuring the lights stay on despite CV&C in the United Kingdom and France?

Chapter 5 explored how the UK and France govern electricity supply to ensure that the lights stay on amid climate risks in the short and longer terms. The analysis first indicates that in both countries, climate risks are mostly mainstreamed through policies aiming to ensure future generation capacity. In these policies, climate risks are predominantly considered along other risks and are not the object of specific stand-alone policies. The only exception is the UK Adaptation reporting Power (UK ARP), an innovative binding policy instrument developed under the UK Climate Change Act 2008, requiring key sector organisations, such as energy or water companies, to report every four years on what they are doing to adapt to climate risks.

Additionally, although some policy instruments encourage adaptation to climate risks in the short and medium terms, they do not ensure climate resilience in the electricity sectors in the longer term. Indeed, the UK has no clear strategy in place for maintaining generating capacity in the electricity sector amid climate risks in the longer term. France does have longer-term objectives and pathways for its electricity sector, but their achievability is not evident as policies set unrealistic targets that are unlikely to be met in the planned timeframes.

Overall conclusions from RQ2:

In both countries, climate risks are mostly mainstreamed through policies aiming to ensure generation capacity. In both countries, although some policy instruments encourage adaptation to climate risks in the short and medium terms, they do not ensure climate resilience in the electricity sectors in the long term.

RQ3- How do electricity companies manage physical climate risks?

RQ4- What drives and triggers adaptation measures in these companies?

Chapter 6 examined how electricity companies in Great Britain and France understand, assess and manage climate risks as well as what triggers corporate adaptation in these organisations. The analysis reveals that adaptation to climate risks in electricity companies is largely reactive. It also showed that electricity companies manage short-, medium- and long-term climate risks using distinct approaches. For the short and medium terms, companies draw from the past experience with extreme weather events and incorporate climate risks into their risk registers. These risks are then managed using existing business practices, such as the iterative "Plan–Do–Check–Adjust" (PDCA) model at the operational level. Translating climate projections into actions to ensure long-term resilience of assets and continuity of services is however more challenging. Some companies tackle the issue head-on and already developed a long-term strategy up to the end of the century. Other companies assume that climate change impacts will unfold slowly and incrementally and, thinking they will have time to adapt, manage climate risks as per business as usual for now. Others adopt a "wait and see" approach as companies are still unsure about what they will need to adapt to.

In both countries past experience with extreme weather events is one trigger for corporate adaptation (such as flood proofing a sub-station after flooding, for example). But exposure to extreme weather events is rarely the main reason for adaptation. Indeed, adaptation in electricity companies in both countries is often the result of multiple triggers, some "endogenous" and some "exogenous" to the company. The most important drivers of corporate climate adaptation in the electricity sectors in both countries were found to be regulations and more particularly economic regulations. Indeed, financial policies based on penalties and rewards and price-setting regulations strongly influence whether or not adaptation takes place. Furthermore, in the liberalised UK electricity sector, investing in adaptation allow companies to retain their competitive advantage over other companies. In France, by contrast, where the electricity sector is still largely dominated by a single company for electricity generation, transmission and distribution, a strong climate change internal culture was found to be an important driver of adaptation.

Additionally, both countries have climate adaptation specific policy-instruments based on climate risk disclosure, aiming to prompt adaptation in companies. However, the influence of these instruments on corporate climate adaptation in the electricity sectors contrasts in both countries. In the UK, the mandatory Adaptation Reporting Power (UK ARP) helped electricity companies to better understand their climate risks management practices to date and enabled them to engage about climate risks at a sector level. However, the act of reporting on climate risks itself, did not drive corporate adaptation in the electricity sector. This resonates with earlier results suggesting that awareness of an issue does not necessarily lead to behavioural change (Bulkeley (2001); Demeritt and Langdon (2004); Amundsen et al. (2010); Agrawala et al. (2011); Berrang-Ford et al. (2011); Ford et al. (2011)). This finding suggests that non-specific climate regulations are more prominent in prompting adaptation in UK electricity organisations that the adaptation-specific one. On the other hand, in France climate reporting is not mandatory but French electricity companies are guided to disclose climate risks and adaptation actions in their annual report, the "Document de Reference" which describes the company, its organisation, activities, risks, financial situation, results and forecasts, giving shareholders and other stakeholders information about the company and the viability of its business. Although the French electricity companies are not yet required to disclose their climate risks and their adaptation strategies under this policy instrument, most of them proactively do. This voluntary and transparent disclosure of climate risks can be explained by the fact that companies are eager to reassure investors about the market viability of the company. As such the act of reporting on climate risks itself in France, even if voluntarily, does not seem to be a driver for corporate adaptation per se but motivated more by a strong internal culture or stakeholder pressures.

Overall conclusions from RQ3 and RQ4:

Adaptation to climate risks in electricity companies is largely reactive. For the short and medium terms, companies draw from past experiences with extreme weather events and incorporate climate risks into their risk registers. Past experience with extreme weather events is one trigger for adaptation in electricity companies but corporate climate adaptation is often the result of multiple triggers. Economic and financial regulations bound the activities of electricity companies in both countries and often condition adaptation in these organisations.

In the British market-based electricity sector, companies also tend to implement adaptation measures if in doing so, they retain a competitive advantage. In France however, where the electricity sector still remains largely a monopoly, electricity companies' internal corporate culture is an important driver of corporate climate adaptation.

7.3. CONTRIBUTIONS TO KNOWLEDGE

7.3.1. Corporate climate adaptation

The first area of contribution this thesis makes is to the under-researched field of corporate climate adaptation. Like Tompkins et al. (2010) and Berkhout (2012), this study also found that corporate adaptation is the result of multiple drivers; some "endogenous" and some "exogenous" to the organisations and that climate risks are rarely the sole or primary driver.

In both countries, the most prominent drivers for corporate adaptation are financial and business-related ones. Adaptation actions have to make business sense and asset lifespan and rate of return drive adaptation decisions. Also, companies want to avoid any potential financial losses due to disruption of power supply and are vigilant to prevent them. Binding and non-binding environmental policies were the second most often mentioned adaptation trigger in both countries. For example, during the 2003 heatwave in France, environmental policies protecting aquatic life prevented nuclear plant operators from discharging cooling water into watercourses which were already suffering from low flows and high water temperatures. Nuclear electricity generation was severely affected in a country relying heavily on nuclear power. In the UK, electricity network companies developed collaboratively the ETR 138 guidance for managing and building resilience against the risk of substation flooding, a standard that the companies now abide by. In the liberalised UK electricity market, another driver often mentioned is peer- pressure and the need to retain a competitive advantage over other companies. In France, EDF's strong internal culture around climate change drives some of the adaptation behaviours observed in the company, such as the establishment of in-house capacity not only to manage extreme weather events but also to assess the impacts of future climate change on the groups' physical assets.

Extreme and changing weather has been a long-established concern for natural resource dependent companies (Adger et al. (2009); Preston, Dow, et al. (2013)) and most of the electricity companies included in this study, already respond to the potential impacts of weather and climate. Indeed, extreme weather events are managed as business-as-usual and are integrated into the efforts to manage other external changes and stressors. Most interviewees considered that climate risks were already included in their existing risk registers and managed using established practices, such as the iterative "Plan–Do–Check–Adjust" (PDCA) model at the operational level. It might also be that some companies practice continuous adaptation without acknowledging it (Gasbarro and Pinkse, 2016). Although most companies have only started their adaptation journeys and still need to engage further with future climate change, this study suggests that electricity companies in the UK and France are early adapters as they are already stepping up and adapting to extreme weather events as part of their existing corporate risk management. This corroborates the results found in other studies (e.g. Audinet et al. (2014); Limbrick (2015)).

Adaptation-specific policy regulations, when in place, also present little incentive for companies to adapt to extreme weather events. In the UK, the ARP is a government attempt to coordinate adaptation nationally and oversee the preparedness of critical economic sectors, such as the electricity sector, to climate variability and change by nudging companies into reporting on their climate risks. Nudge theory emerged from behavioural science, political theory and economics. It argues that positive reinforcement and indirect suggestions are ways to alter the attitudes, and decision-making of groups or individuals and provides a more efficient means of achieving non-forced compliance than direct instruction, legislation, or enforcement (Thaler and Sunstein, 2008). However, the findings of this study contest this argument, instead revealing that nudging electricity companies to disclose their climate risks has so far failed to prompt them to adapt to physical climate risks. Whilst electricity companies did comply and reported their climate risks, nudging them to do so did not consistently get them to take responsibility for their actions or indeed take much action at all beyond business as usual. Additionally, electricity companies already manage the risks of weather extreme events along other risks they might face. In France, at the moment, there is no need for adaptation-specific policy instruments such as the UK ARP as the dominant electricity provider EDF is directly responsible for ensuring electricity supply amid climate risks. Indeed, the public service contract between the main French electricity company, EDF, and the State (Contrat de Service Public entre L'Etat et EDF, 2005) outlines clearly EDF's responsibility to not only understand and study weather forecasts and climate change projections and their consequences for electricity generation and consumption, but also to secure electricity supply amid climate risks. The French State and EDF have a close relationship; indeed the French State has had and still has a strong hold on the main electricity producer EDF as its largest owner (i.e. as of 31 December 2017, the French State held 83.50% of EDF's share capital and 83.60% of EDF's voting rights, (Électricité de France (EDF), 2017)). This close State-main electricity provider relationship removes the need for binding adaptation policy instruments such as the UK ARP to ensure the continuity and reliability of electricity supply despite climate risks.

So far companies have been able to absorb the costs associated with restoring power post-extreme weather events or climate proofing some of their infrastructure. However, as extreme weather events are to become more intense and frequent with climate change (Intergovernmental Panel on Climate Change (IPCC), 2012), companies might not be able to cope with these new critical thresholds or tipping points and might then be unable to ensure that the lights stay on not only in the short and medium terms but that the electricity sector becomes resilient in the longer term as well. As such, business organisations face complex challenges now to which they need to find economically, technologically and socially suitable solutions not only for the short and medium terms but also for the longer term and without fostering maladaptation. Resilience to future climate change needs to be further emphasised as different from existing climate risk management practices (Linkov et al., 2014).

However, how companies consider future climate change is still not well-understood (Slawinski and Bansal, 2012). This study revealed that although, some electricity companies might already have some internal adaptation strategies in place that cover longer-term climate change, most interviewees remained vague about how their companies were thinking about and managing future climate change risks for the longer term. The study further found that nudging adaptation-specific policy instrument, like the UK ARP, are not enough of an incentive to make companies think about the risks of longer-term climate change. Several factors could explain this “short-termism[29]” in companies. First, Loewenstein and Thaler (1989) advance the theory that humans have a bias for immediate gratification and temporal discounting; they generally prefer to consume less now than wait for more later. This bias is exacerbated by urgency and uncertainty because people want more rewards now and future rewards are obscured. Graham et al. (2005)’s work corroborates this theory; in a landmark study of 400 executives, primarily chief financial officers, the authors found that nearly four out of every five executives willingly sacrificed long-term value creation in order to smooth earnings or meet short-term earnings targets. Furthermore, Dasgupta and Maskin (2005)’s research on hyperbolic discounting also showed that managers are discounting the future more today than they ever did, so that many investments that could create long-term value tend to be overlooked.

[29] Laverty (1996) define short-termism as “decisions and outcomes that pursue a course of action that is best for the short term but suboptimal over the long run. [Laverty, K. J. (1996). Economic “Short-Termism”: The Debate, the Unresolved Issues, and the Implications for Management Practice and Research. Academy of Management Review 21(3): 825-860.]

Second, companies are inherently unsuited to deal with issues that span over the medium to long terms. Organisations are constrained by regulatory and policy instruments only concerned with the short and medium terms and rarely giving clear directions for the longer term (chapter 5). Third, organisation themselves tend to be unable to internalise this long timescale of change as their business models tend to be impeded by internal organisation changes such as declining financial performance, leadership changes, etc.. Thus, due to their long-term nature, climate change challenges are readily discounted by businesses in favour of more immediate problems and opportunities (Wright and Nyberg, 2017). An organisation's perspective on "time" can also affect its response to climate change Indeed, Slawinski and Bansal (2012) uncovered two categories of oil and gas firms: on one hand, the "linear time perspective" organisations that focus on the present, seeking immediate technology-based solutions, and aiming to remove the uncertainty inherent in the long-term future (i.e. the clock time perspective) and the "cyclical time perspective" organisations that tend to make a greater number of connections between the past, present, and future (i.e. the events time perspective). Consequently, the first category of firms tend to execute a narrow set of solutions, and as such can respond with agility or speed whereas the other type of firms are unable to respond quickly due to the sheer complexity of their response. Fourth, the power industry might assume particular (economic) lifetimes for generation technologies. Asset lifetime is a determinant factor for infrastructure asset management. Bankers for example often work with a ten-year financing period whereas the physical lifetime of energy infrastructure could be much longer, e.g. fifty years for coal/nuclear, or even up to 100 years for hydro (Lise and van der Laan, 2015). Fifth, organisations can be complicit in causing the very problems they are asked to solve. This conflict is particularly evident with climate change as organisations' reliance on economic growth and fossil fuel-based energy is a central contributor of escalating greenhouse gas emissions, which in turn causes climate change. As such mitigating climate change would require the radical decarbonisation of the electricity sector on an unprecedented scale that is incompatible with their existing business models and more widely with economic growth (Anderson and Bows, 2011).

This lack of planning for the longer term can be further explained by the uncertainties surrounding strategic decision-making activities. Indeed, interviews with electricity sector professionals, policy-makers, and stakeholders carried out during the course of this study unanimously highlighted the lack of usable climate information as a barrier to adaptation decision-making in the short and medium terms as well as the longer term. As Sikich (2003) pointed out: "Information, no matter how well managed, is not knowledge unless it can be used." (p.58). Whilst the terms "usable" and "useful" are often used interchangeably when talking about climate information, useful information becomes usable once adopted by users (Lemos et al., 2012). During the infrastructure development process for example, weather-related hazards are often expressed as pre-packaged datasets and charts presenting statistics on various climate elements (e.g. temperature, precipitation, wind speed etc.). However, these historical distributions may be becoming less useful in planning infrastructure performance for risks under changing and unpredictable climate conditions (Milly et al., 2008).

Usable climate projections needed for effective adaptation planning display a number of uncertainties (Füssel (2007); Stainforth et al. (2007); Foley (2010)) that have tentatively been classified in many studies (e.g. Dessai and Hulme (2004); Curry and Webster (2011)). Wilby and Dessai (2010) introduce the concept of "cascade of uncertainty" and define it as the process through which uncertainty accumulates throughout the elaboration of climate change predictions and impacts assessment, i.e. from future society, greenhouse gas emissions, climate model, regional scenario, impact model, local impacts to adaptation responses.

Chapters 5 and 6 further highlighted that, apart from climate data related uncertainties, organisations are experiencing uncertainties that are very much policy-driven or policy-created. Uncertainties over policies covering the longer term actually are a bigger theme for electricity companies than the further upstream sources of uncertainties associated with climate data.

Brunekreeft and McDaniel (2005) conceptually define policy uncertainty as the lack of credible commitments by governments and/or regulators. Romano and Fumagalli

(2018) on the other hand, use a more empirical definition and define policy uncertainty as uncertainty over either the introduction (or the removal) of a policy, or the change in the design details of an existing one, including the related implementation timing. This work will adopt this latter definition.

The uncertainty associated with climate policies have decisive influence on energy sector strategies (Fuss et al., 2009). The energy sector is characterised by long-lived investments in infrastructure that will be used throughout their lifetime and most probably even beyond. In the UK and France existing generation capacity is ageing and much of it will need to be replaced in the coming decades (International Energy Agency (2012); International Energy Agency (2017)). Government's foresight and a comprehensive and favourable climate policy framework are important drivers of investments and future adoption of innovative generation technologies (Romano and Fumagalli, 2018). Indeed, if a climate policy is implemented during the lifetime of a power plant, it would greatly affect the cost-effectiveness of that plant, which in turn impacts the value of the investment (Morris et al., 2017). Similarly, regulatory changes also bring uncertainties that affect the entire market (Pérez Odeh et al., 2018). For example, environmental policies can bring positive environmental effects, but could also introduce new uncertainty by creating new emission markets or by requiring new investments in adaptation or mitigation technologies (Isik (2004); Barradale (2010)).
Additionally, since capital investments in the electricity sector are largely irreversible and will be decisive for the future energy mix, it is important for policy-makers to devise policies for the short and medium terms but also develop a vision for the electricity sector in the longer term.

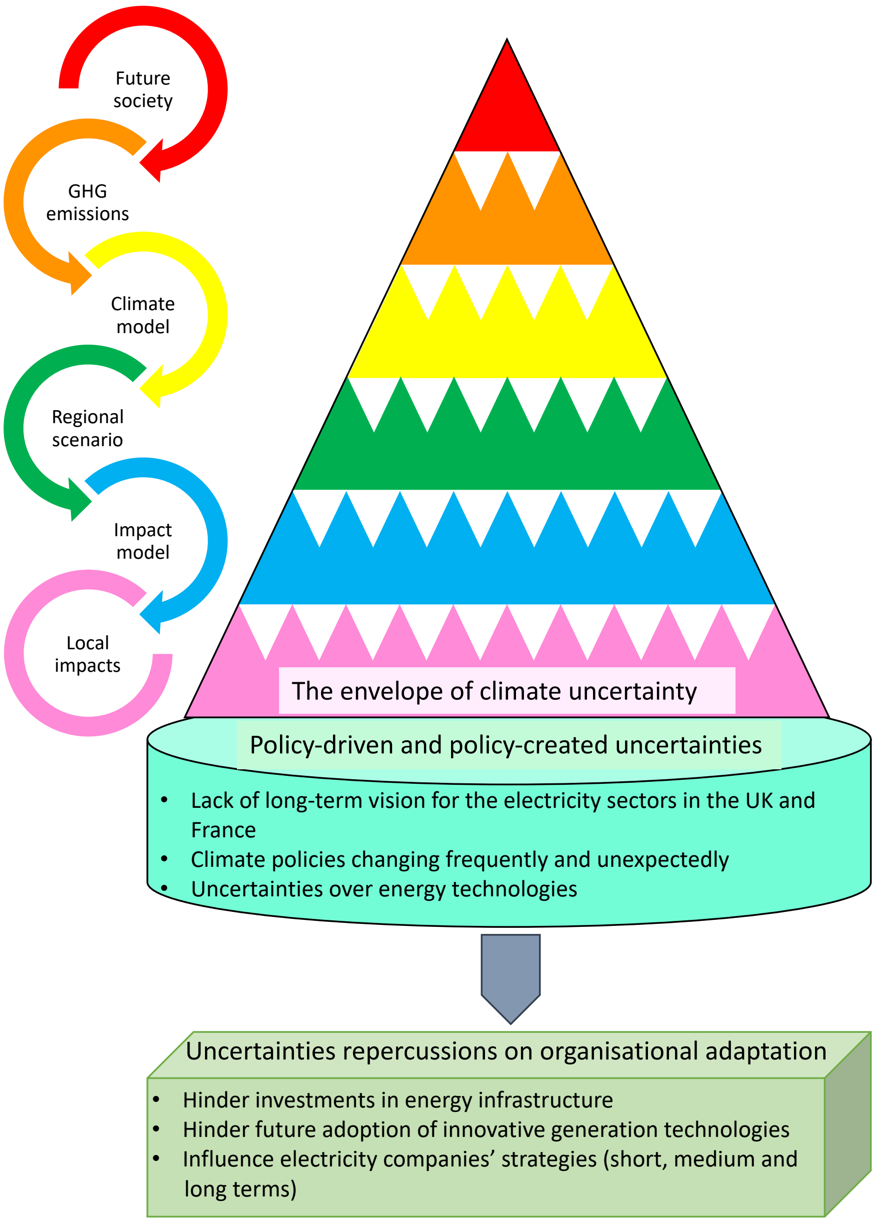
On the one hand, climate policies may also frequently and unexpectedly change due to, for example, change of governments and arrival of new information on climate sensitivity and energy technologies. These frequent changes indicate that policy frameworks often lack predictability but also credibility. Without a longer-term vision for the sector, electricity producers and investors might refrain from undertaking the investments necessary to keep the lights on in the longer-term future (Ford et al., 2013). On the other hand, some steadfast regulatory instruments might hinder adaptation in the electricity sector. For example, infrastructure design standards remain difficult to change even when political, social, economic, and environmental systems change around them (Chester and Allenby, 2018).

But designing longer-term climate policies conducive to corporate climate change adaptation is hampered by the significant uncertainties that surround energy technologies (Anadon et al., 2016). Technology uncertainties cover different aspects: technology costs and availability (Messner et al. (1996); Krey et al. (2007); Usher and Strachan (2012); Webster et al. (2013); Leibowicz (2014)), technological learning rates (Gritsevskyi and Nakićenovi (2000); Chen and Ma (2014); Shittu (2014)), renewable resource availability and demand (Stoyan and Dessouky, 2012), climate policy (Loulou and Kanudia (1999); Yang and Blyth (2008); Fan et al. (2010)), climate sensitivity (Syri et al. (2008); Ekholm (2013)) or combinations of these (Keppo and van der Zwaan (2012); Labriet et al. (2012); Bistline and Weyant (2013)). Expectations for technological changes are also very important in making investment decisions because they directly affect expected costs (Gross, 2010). For example, Binz et al. (2014) highlight that large solar PV plants showed the biggest decline in relative cost among all other technologies in the United States, passing from the third most expensive technology in 2012 to the seventh low cost technology in 2014, out of twenty-two technologies presented in that ranking. This is expected to fundamentally affect energy supply balance for 2020s (Pérez Odeh et al., 2018).

If most technological changes to limit atmospheric greenhouse gases concentration by reducing emissions (i.e. the renewable sector) have received most of the research attention in the past decade (Pérez Odeh et al., 2018), policy-makers are still faced with the lack of evidence available on technologies that can be employed for climate change adaptation (Klein and Tol, 1997). Indeed, technologies for adaptation to climate change are not well-covered in existing research (Biagini et al., 2014). This lack of clarity on the longer-term institutional setting for the energy sectors is likely to be detrimental to corporate adaptation as it does not foster the development or implementation of technology for climate adaptation.

The findings of this study therefore extends Wilby and Dessai (2010)'s cascade of uncertainties of climate projections and impacts, with policy and technological uncertainties (Figure 7-1). Policy and technological uncertainties were indeed found to be fundamental challenges for corporate climate adaptation decision-making in the electricity sector (chapter 6).

Figure 7-1: Extending the cascade of uncertainties (adapted from Wilby and Dessai (2010))



7.3.2. Climate adaptation governance

The second area of contribution this thesis makes is to the governance of climate adaptation. The policy instruments to ensure electricity supply continuity and reliability amid CV&C mainly reflect the electricity sector governance structures of the UK and France. In the UK, the electricity sector is traditionally market-led with little state intervention and the policy instruments used are mainly financial, following the principles of market governance (Table 2-1). However, since the year 2000, decisions about the electricity market are increasingly made centrally and the UK Government has relied less on financial instruments; the UK Government is for example setting prices for generation technologies such as offshore and onshore winds or nuclear power. As a result, the UK is moving from a competitive market to a “state micro-managed market” for electricity. This observation is further supported by a recent UK Labour Party announcement unveiling the Party’s plans to take the National Grid into public ownership and create a National Energy Agency to own and maintain transmission infrastructure (The UK Labour Party, 2019). In France, by contrast, the energy market is highly concentrated. Electricity generation is still largely dominated by Électricité de France (EDF), the vertically integrated French incumbent utility that is still controlled by the French State. The French transmission system operator, RTE, and the distribution network operator, Enedis, are 100% owned by EDF. As such the policy instruments used in France for electricity supply continuity and reliability are mainly regulatory and as such compatible with the state-centric management of the electricity sector; the sector traditionally follows the hierarchical style of governance (Table 2-1). However, in the year 2000 and under the pressure from the EU, France was forced to liberalise its electricity sector and to open its electricity market for competition. France is now moving towards a more market-led approach. It is also adopting new financial policy instruments such as the “capacity mechanisms” which seek to ensure that all actors will contribute to electricity supply continuity and reliability in the new market setting.

Although the UK and France still contrast by the modes of governance the national electricity sectors abide by, a common observation for both countries is the increasing number of public as well as private actors involved. The energy sector has traditionally been managed as a public monopoly by the central government for both production and provision of electricity. However, under the influence of the liberalisation of electricity markets (either in the 1990s for the UK or under the influence of the EU in the year 2000 for France), ownership, operation and maintenance of many critical infrastructures have been divided amongst an increasing number of actors. This study has also uncovered that climate risks are mainly mainstreamed into policies that aim to ensure electricity supply continuity and reliability in both the UK and France. However, mainstreaming adaptation across various established institutions (Wilson, 2006) and sectors also increases the number of actors involved and the need for co-operation between them (Mees, 2014).

The climate adaptation governance observed in the electricity sectors in the UK and France has also started to exhibit some of the characteristics of polycentricity foreseen by Elinor Ostrom, that is, more diverse, multi-levelled, and with a much greater emphasis on bottom-up initiatives (Ostrom, 2010b). This observation echoes (Biesbroek and Lesnikowski, 2018) findings that, in several high-income countries across the globe, early signs of the emergence of a polycentric adaptation landscape become visible. Indeed, in many instances, adaptation is local, self-organising and increasingly connected, and efforts are made to create overarching sets of rules to govern adaptation (e.g. reporting of climate risks or devising adaptation plans). States are making efforts to seek the optimal mix between monocentric steering and polycentricity in order to reconcile some of the limitations of both modes of governance (Biesbroek and Lesnikowski, 2018).

Since Ostrom's publication of the eight design principles to govern the Commons in 1990 (Ostrom, 1990), a literature has emerged outlining the advantages of polycentric governance for sustaining natural resources and adapting to climate change (e.g. Newig and Fritsch (2009); Pahl-Wostl and Knieper (2014); Marshall (2015)). Blomquist (2009) observes that the literature advocating for polycentric governance includes themes such as: "1) the recognition of scale diversity; 2) the desire to reduce error-proneness and promote learning; 3) the recognition of limitations on human information processing capabilities; 4) the presence of multiple goals for resource management; and 5) the recognition of the diversity of human interests and values associated with most complex natural resource systems" (p. 115). Marshall (2009) further notes that polycentricity has been associated with advantages such as better access to local knowledge, closer matching of policy to context, reduction of the risk that a resource will fail for an entire region on account of multiple avenues for policy experimentation, improved information transmission due to overlap, and enhanced capacity for adaptive management. These advantages generally illustrate three broad claims concerning polycentric governance i) polycentric governance systems have a greater capacity to adapt to social and environmental change; ii) polycentric governance systems provide good "institutional fit" for complex natural resource systems; and iii) redundancy inherent in polycentric governance systems mitigates risk (Marshall, 2009). More recently, Sovacool (2011) highlights how polycentricism enhance climate and energy governance. Indeed, polycentrism "i) can combine the strengths of local and global action without adulterating policy and action without some of their weaknesses" (…), ii) recognizes that climate and energy problems differ substantially by region (capturing the "flexibility" of local action) but also ensure that a common standard motivates all communities to act (capturing the "uniformity" and "equity" issues associated with local actions", (…) and iii) posits that when multiple actors at a variety of scales must compete in overlapping areas, they can often promote innovation as well as cooperation and citizen involvement" (Sovacool (2011); p. 3843). This study affirmed that engendering the right sort of political environment is key to manage short and long-term climate risks in the electricity sector. As coordinating collective actions is a challenge further exacerbated by climate change, polycentric forms of governance represent promising avenues for the governance of climate adaptation in energy systems.

7.3.3. Climate adaptation in the electricity sector

The third area of contribution this research makes is an observation about the dominant short-termism of CV&C risks management in electricity sectors. Laverty (1996) defined short-termism as "decisions and outcomes that pursue a course of action that is best for the short term but suboptimal over the long run" (p. 826). Indeed, this study uncovered that electricity companies are already well-adapted to climate risks in the short and medium terms but that they are less prepared for future climate change. This observation corroborates Mark Carney's comment that climate change is "the tragedy of the horizon" (Mark Carney, Chairman of the Financial Stability Board from 2011-to 2018, in a speech he gave to Lloyd's of London in September 2015). Indeed, Carney (2015) highlights the mismatch between the short-term nature of the financial decision-making and the long-term impacts of climate change. The "tragedy" is that by the time climate change "becomes a defining issue for financial stability, it may already be too late" (Carney, 2015). Goldstein et al. (2019) identify five key private sector adaptation blind spots that shape this tragedy. First, companies seem to underestimate the magnitude and costs of physical climate change risks. Second, companies overlook climate change risks and adaptation strategies that are "beyond the fence line", having a narrow view of climate risks, often leading to narrowly focussed adaptation strategies. Third, companies underrate the potential of ecosystem-based adaptation to manage climate risks. Fourth, companies report upfront investments in climate adaptation but rarely the estimated cost of inaction; the near-absence of these cost comparisons limits investors' ability to understand or assess the strategy against available alternatives, including 'no adaptation'. Fifth, companies' disclosures on climate risk reveal their preference for incremental or reactive adaptation strategies (e.g. business continuity planning), assuming the quasilinear relationship between the accumulation of GHG in the atmosphere and global temperature rise. Yet, Steffen et al. (2018) point out that nonlinearities in the climate system and biophysical feedback processes (e.g. permafrost thawing, loss of polar ice sheets, and Amazon forest dieback), could lead to more abrupt changes and severe risks to society. In this context, radical climate change calls for radical climate adaptation that transcends "business-as-usual" risk management practices.

However, electricity companies can't go it alone. Indeed, as shown above, uncertainties over longer-term policies for the energy sector are major obstacles for electricity companies to think about future climate change. National governments often have broad legislative powers and have therefore a key role to play in promoting the policies needed for long-term adaptation planning, an observation echoed in recent literature by Huitema et al. (2016). Indeed, electricity companies need policies and policy instruments that focus on the longer-term climate change and transcend political cycles. In the UK for example the RIIO-T1 and RIIO-ED1 frameworks (i.e. the price control frameworks for electricity transmission and distribution networks respectively) are reviewed on an 8-year basis. This time-span, although covering several UK political cycles, does not actually allow for longer-term planning according to the electricity companies interviewed.

Additionally, as chapter 5 demonstrated, the only climate adaptation-specific policy instruments to ensure electricity continuity and reliability despite CV&C, the Adaptation Reporting Power (UK ARP), does not actually encourage climate resilience in the electricity sector in the longer term. Indeed, although the UK ARP was a step towards prompting climate adaptation in the sector, the improved awareness electricity companies gained from reporting their climate risks, under the current form of the UK ARP, was insufficient to make a compelling business case to implement longer-term adaptation measures (Tang, 2016). However, several modifications to the UK ARP (and to the Climate Change Act, which outlines the UK ARP) could be brought forward to encourage companies to consider longer-term climate change and avoid the “tragedy of the horizon” (Carney, 2015). First, this refined version of the UK ARP should be specific to the electricity sector. As demonstrated here, electricity companies are early adaptors, whereas existing evidence point towards other sectors of critical importance lagging behind (UK Committee on Climate Change (CCC), 2019). Second, help packages should support companies to better understand climate forecasts and future long-term projections so that companies can better appreciate their long-term climate risks. Third, this refined UK ARP should orientate companies towards using tools and techniques for planning under deep uncertainties such as scenario planning, robust decision-making, etc. and to develop long-term internal adaptation plans. Fourth, this refined version of the UK ARP would have to remain mandatory and not alternate between mandatory and voluntary rounds of reporting as in the current setting. Indeed, Hess (2008) argues that mandatory reporting requirements and standardised performance indicators do encourage firms to disclose important contextual information, information that can then be used to developing better-fitted long-term policies that in turn can support companies' long-term planning. Fifth, this new ARP should support the design of a long-term vision for the national electricity sector, one where future climate change is mainstreamed. This long-term vision should be co-created by both government and electricity companies and the responsibilities for keeping the lights on despite CV&C should be clearly outlined. Under this long-term vision, electricity companies should also be made accountable for managing extreme weather events in the short and medium terms but also in the longer term. Companies' internal adaptation plans for example could be scrutinised by external stakeholders (e.g. investors, governments), and possible sanctions and fines could be applied in case of no compliance. Developing a long-term vision, one that shift focus from crisis management to resilience building, involves developing policies under condition of deep uncertainties.

In this context, some innovative approaches to policy-making might help. In Adaptive Policy Making for example, rather than developing an optimal management strategy designed to perform well for a single deterministic or probabilistic forecast of future conditions, planners use a robust and adaptive strategy—robust in that it performs well over a wide range of possible futures, and adaptive in that it can adjust over time in response to evolving conditions (Groves et al. (2013); Walker et al. (2013)). Experimentalism in climate governance might also encourage the emergence of modes of responses that would be well-suited to the challenges of mitigating climate change and adapting to climate risks and support action in an area that is fraught with uncertainty, complexity, diffuse authority and agency (Turnheim et al., 2018a). New national policies to ensure electricity supply amid future climate risks will also have to be sensitive to contexts, heterogeneity, and spatial variations. The results of the systematic literature review (chapter 4) presented here could prove to be valuable in this respect. Indeed, it could inform the development of longer term policies especially when devising long-term sectoral visions for future energy mixes. The review indeed established the likely opposite outcomes for thermal generation (i.e. decrease) and renewable electricity (i.e. increase) in Europe for the long-term changing climate, providing further evidence towards the necessity to support the development of low-carbon electricity generation technologies in the future if future electricity continuity and reliability is to be ensured.

Finally, clarifications are needed about what a climate-resilient electricity sector actually is. Indeed, throughout this research, interviews with electricity company employees, policy-makers and stakeholders revealed that they do not all share the same understanding of climate resilience. For example, within the UK and France electricity sectors, interviewees did not view resilience to climate risks in the same way. For some, resilient infrastructure systems meant that they were doing as much as they could to ensure that the asset would not go down in the first place (e.g. flood proofing power stations). This view reflects current infrastructure development practices, referred to as "fail-safe"[30] because they focus on making failure a rare and preventable event as long as plans and designs are followed and maintained (Kim et al., 2019). For others, resilience meant accepting that physical assets do go down at times and the ability to restore the power back on quickly is key. Recent work on managing infrastructure in a non-stationary climate supports this approach. Indeed, Kim et al. (2019) elaborate on the "safe-to-fail" paradigm, one in which built systems are "designed to lose function in controlled ways, thus different types of failure consequence are experienced as incurred by prioritized decisions, even when safety thresholds are exceeded by unpredicted risks" (page not allocated yet).

This is not entirely surprising as these observations echo the on-going debate on what resilience to CV&C actually means in academic literature (e.g. Klein et al. (2003); Béné and Doyen (2018); Helfgott (2018)). Indeed, many definitions of resilience exist and are pertinent to the analysis of the potential impacts of CV&C on energy critical infrastructure (Varianou Mikellidou et al., 2018). But a consensus on the definition of resilience for critical infrastructure could lead to new ways of managing climate risks

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30 "Fail-safe" means that infrastructures are not intended to fail, and when failure happens the consequences are severe.

for infrastructure that detract from traditional risk management and support resilience management instead.

7.4. Limitations of the study

When I set out on this research, an early literature review highlighted the lack of information on corporate climate adaptation in developed countries and particularly in Europe. As such, this work was very exploratory in nature and offered little direction on what research approach would be best-suited to look at climate adaptation in business organisations. At first, I thought to look at corporate climate adaptation not only from the outside of the organisation, carrying interviews with electricity company respondents, but also to undertake a longitudinal data collection from within a handful of UK organisations. Indeed, as Berkhout (2012) observed, there is a call for more research to be undertaken on corporate adaptation from the "inside-out, rather than outside-in".

However, as gaining inside access to electricity companies became more and more unlikely as time went by and possibly not feasible within the timeframe allocated for this thesis, I then approached the research from a different perspective and chose to explore corporate climate adaptation in two different geographical and institutional settings, using the UK and France as case study countries. Including two settings in the study allowed for some explanations of similarities or differences to emerge.

Additionally, not being able to go inside the organisation turned out to be quite a blessing in disguise as the research revealed that the policy setting is paramount for corporate adaptation and dissociating the study of corporate adaptation from its institutional settings would have been a mistake.

Regarding access to interviewees, it proved easier than expected to carry out interviews with policy-makers (at all levels from national to more local level of government), more or less as expected with stakeholders, and more difficult than expected with electricity companies in both countries.

The difficulty in gaining access to electricity companies could be explained by 1) the potential sensitivity surrounding disclosure of climate risks in organisations, 2) the possible lack of existing management procedure for climate risks or 3) the potential absence of direct benefits that electricity company interviewees could draw from the research.

To mediate some of these hurdles, the research was clearly outlined in a research brief sent to potential interviewees and was presented in a neutral and non-threatening way whilst being truthful and clear about what it hoped to achieve. I also presented myself as an independent researcher affiliated with the University of Leeds and the Centre for Climate Change Economics and Policy in the UK and provided interviewees with consent forms guaranteeing their anonymity.

One of the consequences of this limited access to electricity companies was that in most cases, only one interview per electricity company was secured. As such, the perspective presented in the interview might have been more indicative of the interviewee's beliefs than the company's beliefs on climate change adaptation.
On the other hand, it might not have been possible to locate additional respondents in the companies interviewed. As mentioned earlier, climate adaptation is a concept that most companies are just starting to grapple with and not all electricity companies have the capacity to engage with climate adaptation at this point or to appoint more than one person responsible for climate adaptation issues within the company. Indeed, most of the interviewees included in this study were not solely responsible for climate adaptation but were responsible for climate adaptation amongst other responsibilities.

Additionally, numerous attempts were made to include Small and Medium Enterprises (SMEs) in the data collection but all my efforts proved unsuccessful. It is shame as it would have been interesting to learn whether company size matters in corporate climate adaptation. This could also be the object of future research as studies focussing on climate adaptation in SMEs are still relatively scarce (Kuruppu et al., 2013).

7.5. Avenues for future research

As was noted in the previous sections this dissertation has provided some valuable insights on corporate climate adaptation. However, as a PhD dissertation is bound in time, not all aspects of corporate climate adaptation in the electricity sector could be covered and choices had to be made to frame the study. These boundaries can however provide some avenues for future research at the company, sector and national and international levels.

First, this study did not consider whether the descriptive characteristics of an electricity company had an influence on its adaptation behaviour. Indeed, it would be interesting to explore the influence of ownership (e.g. national or foreign) or control (e.g. headquarter or subsidiary of a holding company) on the companies' adaptation decision-making and behaviours. A study could also look at adaptation behaviours in companies belonging to the same multinational corporation (following the work from Kostova and Roth (2002) for example).

As highlighted above, it was not possible to carry out any research within electricity organisation themselves. Insights on internal process of corporate climate adaptation could be very valuable as to date little information still exists on how decision-makers within companies are responding to climate change and the role they have in influencing company-level action for example. How adaptation decisions evolve over time (longitudinal study) could also be a new avenue for research within electricity organisations.

Furthermore, research is also needed to support decision-making in the face of uncertainties in electricity companies. Robust decision making (RDM) strategies are better suited to take these uncertainties on board, than standard methods like cost-benefit, or multi-criteria analyses. But RDM approaches work well in different circumstances (Dittrich et al., 2016) and the variety of tools available to practitioners, makes it a confusing landscape to navigate. However, whilst this literature starts to emerge (Soroudi and Amraee (2013); Kalra et al. (2014)), it does not really cover the challenges of operationally ensuring resilience in the electricity sector nor does it support climate adaptation in electricity companies. In the absence of useable, targeted toolkits on robust decision making, organisations are likely to stay within the boundaries of the “knowns” and revert back to standard decision-making approaches. More work is therefore needed to develop targeted toolkits highlighting the applicability of these methods to electricity decision-makers.

Furthermore, the “social dimension” of corporate climate adaptation seems to be overlooked in existing literature and policies. Indeed, several electricity company interviewees in the UK and France revealed that social acceptability of power cuts and customer satisfaction are key and central to how their organisations respond to and plan for climate risks. As electricity companies cannot resist every climate risks, what society is willing to accept will condition the level of climate-proofing infrastructure the company will take on and as such how much it will cost. This raises the question of “how prepared is prepared enough” and the answer to such question will be conditioned by what is considered socially acceptable. Such observation could be an area for future research and one that could draw upon the principles of legitimacy theory; this theory is based is based on the notion that in order to continue to operate successfully, companies must act within the bounds of what society deems to be socially acceptable behaviour (Suchman, 1995).

Then, the study only considered the supply side of electricity provision and did not extend to the demand side. A system view of how climate risks affect both electricity supply and demand could have made sense for this research.
However, on one hand, such study would have been over-complicated as electricity suppliers, who are intermediaries between electricity supply and demand, could have not been over-looked given the increasing difficulty they face in balancing supply and demand as the weather becomes more variable (e.g. shifting of peak demand of electricity from winter heating to summer cooling).

On the other hand, starting with how climate risks affect electricity demand which in turn affects electricity generation is another study all together. Indeed, managing (and reducing) electricity demand means that electricity generators can be more flexible in how and when electricity is generated and as such could become less vulnerable to climate variability.

Also, this study was concerned only with the electricity sector. However, variations in different sector characteristics have been shown to affect responses to social and environmental matters (Ihlen, 2009) and are recognised as potential influences on climate decision-making (Berkhout et al., 2006). As such, this study could be extended to other sectors of critical importance such as water for example. Also, given the importance of the institutional setting for corporate climate adaptation in the electricity sector, new insights could be gained from extending the study to other national contexts.

Finally, it would be interesting to explore how European Union (EU) policies influence corporate climate adaptation in EU member countries. Indeed, on the 30th of November 2016, the European Commission adopted a proposal for a regulation on risk-preparedness in the electricity sector. This proposal addresses shortcomings in the existing legislation, notably a lack of regional coordination, and differing national rules and procedures. The proposed regulation would establish common rules on crisis prevention and crisis management in the electricity sector and would enhance transparency by requiring an ex-post evaluation of crisis situations. This proposal is still a work in progress but when ready is to be transposed in the national legislation of EU member states.

On the other hand, as the UK is now set to leave the European Union at 23:00 GMT on 31st of October 2019, more work remains to be done to better understand how Brexit would affect the UK’s continuity and reliability of electricity provision, climate change or not.

8. CONCLUSIONS

This thesis set out to understand better how private sector organisations manage the risks associated with climate variability and change (CV&C), as literature in this area is still relatively scant.

To help address this gap in the literature, this research examined corporate climate adaptation in the electricity sector in the UK and France, following a multi-level approach, exploring corporate adaptation in electricity companies explicitly considering the policy and climatic contexts within which these organisations operate.

The thesis first identified the impacts of CV&C on electricity systems in Europe and established that more traditional forms of electricity generation such as thermoelectricity will be negatively impacted by CV&C in the short and longer terms, whereas that some renewable electricity generation technologies might benefit from a changing climate in different parts of Europe.

The thesis then explored what policy instruments governments in the United Kingdom and France use to ensure that the lights stay on in the shorter and longer terms amid physical climate risks. This research found that in the UK and France, climate risks were mostly mainstreamed through policies aiming to ensure future generation capacity. In both countries, although some policy instruments encouraged adaptation to climate risks in the short and medium terms, they did not ensure climate resilience in the electricity sectors in the longer term. Furthermore, adaptation specific policy instruments based on mandatory disclosure of climate risks have so far failed to prompt electricity companies to adapt to physical climate risks. On the other hand, voluntary policy instruments inviting organisations to disclose their climate risks to shareholders and stakeholders might encourage companies to engage in adaptation; as early adapters these companies could retain their competitive advantage.

Finally, the study investigated how electricity companies in the UK and France manage physical climate risks, what drives and triggers them to adapt and whether adaptation-specific regulations make a difference to the way they adapt. Adaptation to climate risks in electricity companies was found to be largely reactive. In the short and medium terms, companies draw from past experience with extreme weather events and incorporate lessons from them into their risk registers. Planning for the longer-term future and translating climate projections into actions to ensure long-term resilience of assets and continuity of services is more challenging. Past experience with extreme weather events was one trigger for adaptation in electricity companies but corporate climate adaptation is mostly driven by multiple triggers. In the British market-based electricity sector, companies implement adaptation measures only if regulations mandated them to do so, or if so doing they gain a competitive advantage. In the state-led electricity sector in France, electricity companies' internal corporate culture was an important driver of corporate climate adaptation.

These findings have implications for the future continuity and reliability of electricity supply as well as for the future governance of the electricity sectors in the UK and France. Electricity companies integrate physical climate risks into their risk registers and are well-prepared in the short and medium terms, but they make limited effort to ensure the resilience of the electricity sector in the longer term. This can be explained by short-policy cycles, a lack of long-term strategic and realistic direction for the sector and a lack of adequate adaptation policy instruments. Furthermore, as governance of the electricity sectors is changing in the United Kingdom and France, a window of opportunities opens for companies to adopt decision-making approaches that embrace uncertainties as well as for governments to explore more innovative policy processes (as outlined for example in Turnheim et al. (2018b)). Indeed, on one hand, companies could benefit from robust decision making techniques (e.g. exploratory modelling scenario discovery, etc.) to better understand the implications of long-term climate change on their activities and plan for them. On the other hand, policy experimentation and learning have been found to improve policy, especially in areas of high uncertainty and complexity such as climate change (Pahl-Wostl (2009); Ostrom (2010b)). This flexibility within a governance arrangement is vital for responding to rapid or unexpected changes in the natural environment (Pahl-Wostl, 2009). Polycentric approaches have two chief advantages over monocentric ones; on one hand, they provide more opportunities for experimentation and learning to improve policies over time, and on the other hand they increase communications and interactions (formal and informal, bilateral and multilateral) among parties (Cole, 2015). These two key attributes of polycentricity support a more polycentric governance approach as a promising avenue to build climate resilience in the electricity sectors in the UK and France.

"Limits of survival are set by climate, those long drifts of change which a generation may fail to notice. And it is the extremes of climate which set the pattern. Lonely finite humans may observe climatic provinces, fluctuations of annual weather and occasionally may observe such things as 'this is a colder year than I've ever known'. Such things are sensible. But humans are seldom alerted to the shifting average through a great span of years. And it is precisely in this alerting that humans learn how to survive… They must learn climate."

Herbert and Herbert (2008), p.350

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10.APPENDICES

Appendix A: Interviewees' anonymous profiles, interview invitation and research leaflet (English version)

Appendix B: Interview protocol (English version)

Appendix C: Supplementary material for Chapter 4: A systematic review of the impacts of climate variability and change on electricity systems in Europe

Appendix D: Supplementary material for Chapter 5: Keeping the lights on amid changing physical climate risks: policy instruments for climate resilient electricity sectors in the United Kingdom and France

10.1. Appendix A: Interviewees' anonymous profiles, interview invitation, and research leaflet (English version)

Table 10-1 presents the anonymous profiles of the participants who were interviewed in this study

Table 10-1: Interviewees' anonymous profiles

	Activity of the organisation the interviewee works for	Company size (n. of employees)	Position of the interviewee
UNITED KINGDOM			
Interviewee 1	Electricity transmission	> 25 000	Energy and climate strategy manager
Interviewee 2	Electricity generation	>13 000	Head of energy policy
Interviewee 3	Trade association for the GB energy industry		Environmental expert
Interviewee 4	Government regulator for gas and electricity markets in Great Britain	>760	Senior manager
Interviewee 5	Electricity transmission	> 25 000	Energy forecasting manager
Interviewees 6	Electricity generation and distribution	>21 000	Person 1: Group Sustainability Accountant Person 2: Health, Safety & Environmental Manager
Interviewee 7	Electricity distribution	> 2500	Asset manager and responsible for the ARP reporting
Interviewee 8	Electricity distribution	> 6000	Civil standards and asset manager and responsible for the ARP reporting
Interviewee 9	Government support service to help businesses, public sector and other organisations in adapting to a changing climate.	Shut in March 2016	ARP coordinator

	Activity of the organisation the interviewee works for	Company size (n. of employees)	Position of the interviewee
Interviewee 10	Research network on UK infrastructure policy and practice		Infrastructural Network Analyst
Interviewee 11	Research group on climate adaptation in the UK		Director
Interviewee 12	Independent, statutory body provide advice to the UK government on climate change		Member of the committee (up to December 2015)
Interviewee 13	Independent, statutory body provide advice to the UK government on climate change		Head of adaptation (up to October 2017)
Interviewee 14	Research institute on climate change and the environment		Head of adaptation research; Involved in the UK Climate Change Risk Assessment 2017: Business and Industry
Interviewee 15	Consultancy offering advice on resilience to weather and climate change.		Director
Interviewee 16	UK national weather service		Head of Climate Impacts;
Interviewee 17	UK national weather service		Senior Business Development Manager - Energy
Interviewee 18	Electricity generation	> 13 300	Climate Change Adaptation lead for Nuclear Generation
Interviewee 19	British consultancy	> 18 000	Senior International Climate Change Adaptation Consultant

	Activity of the organisation the interviewee works for	Company size (n. of employees)	Position of the interviewee
FRANCE			
Interviewee 1	Electricity generation	> 65 000	Expert researcher in energy meteorology.
Interviewee 2	Electricity generation	> 65 000	Researcher
Interviewee 3	Electricity generation	> 65 000	Deputy Vice President Sustainable Development
Interviewee 4	Government body in charge of the effects of global warming		Project lead
Interviewee 5	Autonomous organisation working to ensure reliable, affordable and clean energy for its 30 member countries and beyond		Researcher - Environment & Climate Change Unit
Interviewee 6	Autonomous organisation working to ensure reliable, affordable and clean energy for its 30 member countries and beyond.		Energy policy analyst
Interviewees 7	Electricity generation	> 1300	Person 1: Head of risk management Person 2: hydrologist / modeller / researcher
Interviewee 8	Association of large companies from all sectors of the economy, who want to make environmental considerations more a part of both their long-term planning and their day-to-day management.		Environment and sustainable development manager

	Activity of the organisation the interviewee works for	Company size (n. of employees)	Position of the interviewee
Interviewee 9	Ministry for the environment and climate change		Project lead – sustainable development
Interviewee 10	Ministry for the environment and climate change		Project lead - Assessment of the National Adaptation Plan
Interviewee 11	Ministry for the environment and climate change		Project lead
Interviewee 12	Ministry for the environment and climate change		Director – energy and climate change division
Interviewee 13	Electricity transmission	> 9000	Head of sustainable development
Interviewee 14	Electricity generation and distribution	> 25 000	Senior risk manager
Interviewee 15	Think tank working on sustainability in economic sectors		Director
Interviewee 16	Intergovernmental economic organisation / Nuclear energy agency		Deputy Head Nuclear Development - Specialist on climate change vulnerability and adaptation
Interviewee 17	Electricity distribution	> 38 500	Head of environment

Examples of email inviting participants to be interviewed for the research and information leaflet about the research

<u>Example of email invitation:</u>

Title: RESEARCH: Managing climate risks in the electricity sector in Britain and France

Dear Mr/Ms A.,

I am currently pursuing my PhD at the Centre for Climate Change Economics and Policy (CCCEP) at the University of Leeds under the supervision of Professor Jouni Paavola and Professor Suraje Dessai.

My research explores climate adaptation practices in electricity companies in Britain and France, i.e. how electricity companies assess and manage risks linked to extreme weather events and future climate change (or climate-related risks).

I attach an information leaflet for your consideration.

I already talked to Dr B. at the Organisation C. but I would also like to include you in the research and as such I was wondering if you would be interested in sharing some of the experience you have built over the past few years, working on quantifying the impacts that weather and climate have on electricity assets and infrastructure.

Depending on your preferences, I could call you by phone or Skype at a date and a time that suit you. My time over the next few weeks and until the end of March is fairly flexible. If you would be willing to talk to me, would there be a time that could also work for you then? All information collected will be anonymised and kept strictly confidential.

The results of this study will be published in scientific journals and presented at conferences. A summary of the results will be available at the end of the PhD to interested participants.

If you have any questions, please do not hesitate to contact me.

I thank you very much for taking the time to read this message,

Sincerely,

Muriel BONJEAN STANTON

Example of supporting information leaflet:

Managing and adapting to climate change risks in business organisations

An analysis of the electricity sector in Britain and France

Extreme climate events challenge the business continuity of the electricity sector and threaten the reliability of a public service.

How are companies and policy-makers stepping forward to build resilience in the electricity sector?

Overview of the study

Climate variability and change (CV&C) risks are new, emerging and collective risks that need to be managed. At the **national level, governments** are implementing adaptation policies that aim to promote a coordinated and coherent risk management approach across the country. But how do these adaptation policies resonate in private sector companies and how they support adaptation efforts in the electricity sector are still questions of interests to policy-makers.

The **electricity sector** has made huge efforts to reduce greenhouse gas emissions, and achieve new energy efficiencies, yet the sector as a whole still remains vulnerable to changes in the frequency and intensity of extreme weather events, both in the short and long terms. How to manage these new and emerging risks, satisfy regulatory demands and responsibilities, as well as keep customers and shareholders happy, can present those working in the electricity sector with a number of competing, and sometimes, irreconcilable challenges.

This research explores how electricity companies evaluate risks associated with CV&C, what adaptation measures they develop to manage these risks and what challenges they face when doing so. It also investigates what role adaptation policies play in shaping the electricity companies' responses to current and future climate risks, in two different countries: **France and Britain.**

Participating in the research

I would like to meet with professionals, who are involved in developing, implementing, evaluating or informing adaptation policies. This includes policy-makers at national and local levels, advisors to national governments, researchers, consultancies, etc. The interview will last no longer than 40 minutes and can be carried out by phone, Skype or face to face at your convenience.

Confidentiality

All information collected will be fully anonymised and kept strictly confidential.

Results

Once the study is completed, I plan to publish the results in peer-reviewed journals, give talks at conferences and share the findings with others working in this area. If you are interested, I can send you a summary of the results at the end of the study.

HOW COULD YOU BENEFIT?

You could:

- GAIN SOME INSIGHTS about adaptation practices in the electricity sector and the adequacy of adaptation policies;
- CONTRIBUTE to bridge differences in perspectives between electricity companies and policy-makers about adaptation to CV&C;
- GAIN ACCESS to academic information;
- ENGAGE in climate research;
- BE KEPT INFORMED of the results of this research.

Mrs Muriel BONJEAN STANTON

- Postgraduate research student at the Centre for Climate Change Economics and Policy (CCCEP), University of Leeds, UK under the supervision of Professor Jouni Paavola and Professor Suraje Dessai.
- 10 years previous experience in environmental policies & management and adaptation to climate change (research and consultancy in the Global Climate Adaptation Partnership, the University of Oxford, the UK Centre for Ecology and Hydrology, the Massachusetts Institute of Technology and the US Environmental Protection Agency)
- Research sponsored by the EU-funded project BASE (http://base-adaptation.eu/).
- Contact: *M.C.BonjeanStanton13@leeds.ac.uk*

10.2. Appendix B: Interview protocol (English version)

1- General information about the interviewee & the company

2- Assessment and management of present and future climate risks in the company (both weather extremes in the short term and future climate change in the longer term)

Has the company already had to face extreme weather events? If yes, what consequences did these have for the company and the way the company is looking at managing these risks?

How are the risks associated with short term and long term climate change assessed in the company (in house expertise; use expertise of external organisations, what type of information is used, etc)?

Does the company have a strategy in place to manage climate related risks in the short term and in the long term? Is this a stand-alone strategy or fully integrated with other types of risks?

What is the planning horizon in the climate risk assessment and management plan? How often are these reviewed?

How are adaptation actions financed within the company?

How are the decisions made about which adaptation actions to implement or prioritise in the company?

Adapting existing assets to climate variability within their lifetime and integrating climate change aspects when new assets are developed. How is this done?

What challenges does the company face in trying to adapt to short term and long term climate variability?

What are the potential opportunities?

What motivates the company to adapt to extreme weather events and future climate change?

3- Current institutional and regulatory background and its influence on the company' adaptation

In the UK there is a policy instrument called the Adaptation Reporting Power (ARP). What influence if any did reporting under the ARP have about the way the company thought about climate risks and climate risk management?

What standards and regulations have the most bearing on encouraging the company to adapt to extreme weather events and future climate change?

4- Adequacy of the current regulatory and policy framework to allow electricity companies to adapt to weather extremes and prepare for climate change

The UK has strong industry regulations and standards that apply to electricity generating companies. Do these standards and regulations include climate change considerations? Are they adequate to support electricity companies in adapting to extreme weather events and future climate change? Should they be changed?

Is the current policy and regulatory setting in the UK supporting or hindering adaptation efforts in the company? Should anything be changed? If yes what?

10.3. Appendix C: Supplementary material for chapter 4: A systematic review of the impacts of climate variability and change on electricity systems in Europe

Appendix C1- Detailed method followed in the systematic review

Appendix C2- Data: Peer-reviewed articles included in the systematic review and their characteristics

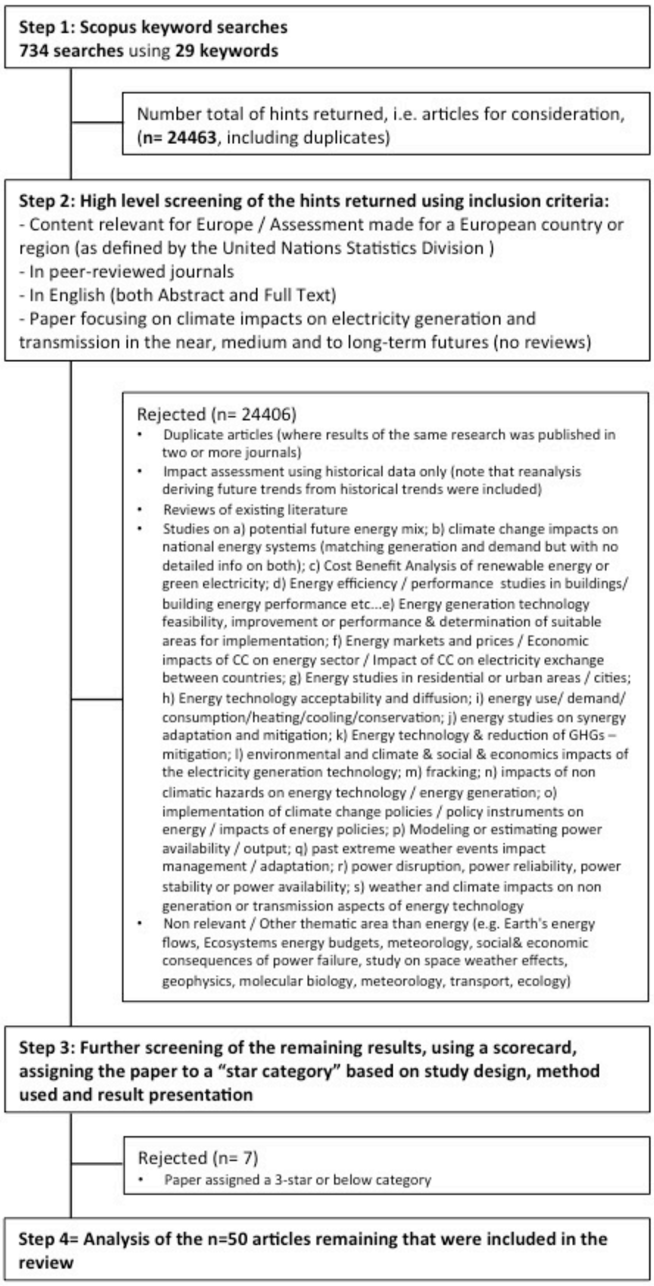
Appendix C3 - Peer-reviewed articles included in the systematic review but excluded from the analysis

Appendix C4- Impacts of climate variability and change (CV&C) on hydro-, wind, thermal and solar electricity generation at sub-national scale

10.3.1. Appendix C1- Detailed method followed in the systematic review

The systematic review was carried out in four steps as illustrated in Figure 10-1.

Figure 10-1: The four-step process followed to carry out the systematic literature review



Step 1: Scopus keyword combination searches

The keywords used

Table 10-2: Keywords that were combined for the searches.

Level 1	Level 2	Level 3
climat*	impact*	energy
climat* change	?ffect*	power
climat* project*	sensitivity	electric*
climat* model*	suscept-ibility	hydropower
climat* condition*	availability	hydro*
weather	potential*	*energy
stochastic simulation	performance	*lectric*
change	vulnerab*	
project*	assessment	
model*	consequence*	
condition*	*plication	

The search process

Each search was carried out using the following combination of keywords: “One keyword word from Level 1 AND One keyword from Level 2 AND One keyword from Level 3”.

Several combinations of keywords were tested. Results with search terms x and y returned few relevant articles. The relevant articles returned were already covered by other search terms combination

This led to 734 search combinations returning 24463 resources (including duplicates).

Step 2: High level screening of the articles returned for each of the keyword combination search

The articles returned for each keyword combination search were screened and only retained if they met all of the following inclusion criteria:

- Content relevant for Europe / Assessment made for a European country or region (as defined by the United Nations Statistics Division[31])
- In peer-reviewed journals
- In English (both Abstract and Full Text)
- Articles focusing on the impacts of CV&C on electricity generation and networks in the near-, medium- and long-term (no reviews).

Note: studies on energy resource endorsement were excluded (e.g. impacts of CV&C on coal mining when coal is used as a fuel for thermal electricity generation)

Step 3: Screening using a star-rating scorecard

The remaining articles were then further assessed using the star-rating scorecard outlined in Table 10-3.

A 5* paper is a paper that includes all the individual attributes outlined in the scorecard.

A 4* paper includes the following: D1 (and maybe D2), M1 and at least 4 attributes amongst M2-M9, R1, R2 and at least 2 of the attributes amongst R3-R6.

A 3* paper includes the following: D1 (and maybe D2), M1 and less than 4 attributes amongst M2-M9, R1, R2 and less than 2 of the attributes amongst R3-R6.

Papers scoring below 3* were not retained in the study.

Step 4: Analysis of the retained papers

Only fifty articles in total were retained in this study as a result of the systematic review. Their full references can be found in Table 4-1 (in the main body of the thesis).

[31] http://unstats.un.org/unsd/methods/m49/m49regin.htm#europe [Accessed 09/10/2015])

Table 10-3: The screening scorecard

Study design	
D1	The study design is appropriate for the assessment. E.g. appropriate for the scale of the assessment, technology etc.
D2	There is a good balance in the paper between the methods and the results section (some paper have a lot of info on assessment method but the result section is rather underdeveloped even if the key messages are there OR the paper described the model used in details in another paper and concentrates on the results)
Methods	
M1	The method used for the assessment, etc is outlined
M2	The method used for the assessment, etc is clearly outlined. The information given about the assessment method are enough to allow the study to be reproduced for a different location
M3	The method clearly explains why one climate model, impact model, region of assessment was chosen over another)
M4	The method uses several climate models to create an envelope of climate data / uses ensembles of climate data References: - "Ensemble means have proven to be more accurate than individual models in reproducing the instrumental observational period" (From: Gleckler, P.J., Taylor, K.E., Doutriaux, C., 2008. Performance metrics for climate models. Journal of Geophysical Research: Atmospheres 113, n/a-n/a.) - "In most cases the multi-model mean agrees more favourably with observations than any individual model." (From: Intergovernmental Panel on Climate Change (IPCC), 2014. Climate Change 2013 - The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, , Cambridge, United Kingdom and New York, NY, USA; p. 767)
M5	The method uses several climate scenarios to forecast different future conditions
M6	The method assesses the impact in the near term to mid-21st century and the end of the 21st century

M7	The information on the calibration and validation of the climate and impact model used is explicit The climate models were rigorously tested before they are applied Reference: Refsgaard, J.C., Madsen, H., Andréassian, V., Arnbjerg-Nielsen, K., Davidson, T.A., Drews, M., Hamilton, D.P., Jeppesen, E., Kjellström, E., Olesen, J.E., Sonnenborg, T.O., Trolle, D., Willems, P., Christensen, J.H., 2014. A framework for testing the ability of models to project climate change and its impacts. Climatic Change 122, 271-282
M8	The method assesses annual changes as well as seasonality (intra seasonal variations)
M9	The impact model used has been widely applied and tested in various contexts
Results	
R1	The results are explicit
R2	The results are consistent and answer the question raised
R3	The paper mentioned further information about the results. This can be for example limitations associated with the method that influence the results, uncertainties associated with the results, confidence intervals of the results, taking the results with caution etc.
R4	The paper mentions what the results could be used for and by whom and / or some adaptation to palliate to the impacts identified by the results of the study
R5	"The results are triangulated with one or several studies. None of the author from the assessment study is an author or co-author of a study used for triangulation of the results"

10.3.2. Appendix C2- Data: Peer-reviewed articles included in the systematic review and their characteristics

Table 10-4 outlines the peer-reviewed articles included in the study and their detailed characteristics.

Table 10-4: Detailed characteristics of the peer-reviewed articles and individual results included in this study

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
1	IPCC SRES A2 and B2	Monte Carlo simulations (first-order Markov chain and an autoregressive moving average (ARMA) model)	2013–2037		1971–2000	Hydro	Rainfall–runoff model: IHACRES	Alcantara River Basin, Sicily (Italy)	2	European Commis-sion (FP5 project)
2	Response to a doubling of effective CO2 concentration	Hadley Centre Coupled Model HadCM2	2008-2050		1971-2002	Hydro	Reservoir operation model developed in the study. It simulates a water budget model	Ilarion reservoir, Greece	1	Not mentioned
3	IPCC SRES A1B	Ensemble of four CGCMs: GFDL V2.0 (T42); ECHAM5 (T42); HADCM3 (T42); CCSM3 (T85)	2020-2049			Wind	Downscaling of data from four CGCMs to estimate the future wind power production potential at the 100 m level	Northern Europe	4	Norwegian Research Council
4	UKCP02 model for scenarios at Low, Medium-Low, Medium-High and High emissions	The UKCIP02 data have been developed on the basis of HadCM3, which drove the regional model (HadRM3) (Modelling not performed in the study; i.e. the study uses the UKCP02 projections)		2080s		Bioene rgy	Map of the geographical suitability cover for the crops. The baseline suitability cover was compared to the actual agricultural land use in the year 2005	UK	Not included in analysis	UK DEFRA

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
5	IPCC SRES A2	Hadley Centre's PRECIS Regional Climate Modelling System		2071-2100	1961-1990	Wind	The PRECIS regional model over the East Mediterranean is used to dynamically downscaled the results of the Had3CM GCM. Wind field changes are determined by comparing the current climate simulation with the IPCC A2 emissions scenario simulation. The consistency of the current climate simulation of wind speeds is assessed by comparing its results to the ERA40 re-analysis data.	Eastern Mediter-ranean (EM)	4	Not mentioned
6	UKCP09 low, medium high scenarios	The UKCP09 data have been developed using the Hadley Centre Coupled Model, version 3 (HadCM3) (the study only uses the projection data and does not perform the modelling)	2040-2069 (2050s)	2070-2099 (2080s)	1961-1990	Solar	The projected average percentage change of horizontal surface solar irradiance can be calculated for the 2050s and 2080s by projecting the UKCP09 climate change values onto the baseline solar irradiance model	UK	42	UK Engineering and Physical Sciences Research Council and UK Energy Research Centre studentship
7	UKCP09 medium and high emission scenarios	UKCP09 data	2010-2029 (2020s) and 2040-2059 (2050s)		1961-1990	Hydro	Rainfall–runoff model: IHACRES	Wales, UK	3	Not mentioned

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
8	IPCC SRES A2 and B2 (HadAm3H) and IPCC SRES B2 (ECHAM4)	Two AOGCM: the Max Planck Institute general circulation model ECHAM4 and the Hadley Centre general circulation model HadAM3H developed from the component of the AOGCM HadCM3		2071–2100	1961–1990	Hydro	HBV (Hydrologiska Byråns Vattenbalansavdelning) hydrological model and the nMAG hydropower simulation model	Small scale hydropower plant in Norway (the Aurland hydropower system)	3	Norwegian Research Council
9	None directly: Used results from studies that took the IPCC SRES A2 or using double CO2 level	None directly (the study uses future crop yields from existing studies using the IPCC SRES A2 scenario or using double CO2 level)	2020 and 2030		Average value 2003-2007	Bioenergy	Future yields were assessed according to two factors: technological development and climate change. the former was based on prospect of DG-Agriculture for conventional crops and expert judgments for bioenergy crops, while the latter based on relevant research papers and literature reviews which used site-specific crop growth models	European Union	Not included in analysis	European Commis-sion (FP7)
10	IPCC SRES A2 (HadCM3) and IPCC SRES A2, A1B, B1 (ECHAM5)	ECHAM5 from the Max Planck Institute for Meteorology and the Hadley Centre's HadCM3		2081-2100	1961-1990	Wind	The authors derive GCM geostrophic wind and use it as a proxy indicator	UK	4	UK Engineering and Physical Sciences Research Council (EPSRC)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
11	IPCC SRES A1B	HadGEM1 and HadCM3 from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset	2010 to 2080	2010 to 2080	1980–1999	Solar	General equations are used for PV and CSP technologies to calculate the power output as a function of irradiance and ambient temperature	California, Nevada, Spain, Algeria (north), Germany (south), Saudi Arabia, China (south), Australia (south)	16	Not mentioned

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
12	NoC—No climate run has been applied to the energy system, as in traditional energy system modelling. This is the reference case to which the KNMI, METO, DMI and MPI climate runs are compared. KNMI: A representative average or central climate run based on an A1B baseline energy system scenario. METO: Show significant deviations from the average climate run, usually warmer and drier than the average, based on an A1B baseline energy system scenario. DMI: Show significant deviations from the average climate run, usually colder and wetter than the average, based on an A1B baseline energy system scenario. MPI: A representative average or central climate run based on an E1B emissions reduction energy system scenario	Data taken from the ENSEMBLE project. The ENSEMBLES project developed probabilistic estimates of uncertainty in future climate based on state-of-the-art, high resolution, global and regional Earth System models.	2050		There is a no-climate-change-impact run for both the A1B and the E1 scenarios (called no C-A1B and no C-E1, respectively)	Thermal, hydro, wind, solar	A modified POLES model was used (Prospective Outlook for the Long-term Energy System)	EU27	0	Not mentioned

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
13	IPCC SRES A1B	Used data from 7 RCMs ensemble available from the EU FP6 Integrated Project ENSEMBLES:	2037 to 2064	2071-2098	1992 to 2019	Hydro	A rainfall-runoff model: the modified topographic kinematic approximation and integration model (TOPKAPI)	Vispa valley, Switzerland (Mattmarks eereservoir)	2	European Commis-sion (FP6 and FP7)
14	IPCC A2 scenario	IPSL-CM4 model from the Institute Pierre Simon Laplace, France (IPCM.4) and MIROC3.2 model From the Center for Climate System Research, University of Tokyo, Japan (MIMR)	2040-2069 (2050s)		1961-1990	Therm al	The Water Use model of WaterGAP3 covering the covering the whole of Europe	Europe	2	European Commis-sion (FP6)
15	IPCC SRES B2 and three different combinations of aerosols emissions scenarios: (1) in the 2030GHG experiment, aerosols emissions are kept at the 2000 level; (2) in the 2030 CLEMFR experiment, MFR (Maximum Feasible Reduction) is assumed in continental Europe and CLE (Current LEgislation) elsewhere; (3) in the 2030MFR experiment, MFR is assumed worldwide.	ECHAM5-HAM aerosol-climate model	year 2030		year 2000	Solar	The photovoltaic performance model used in this study integrates climate variables in a model for inclined-plane irradiation and photovoltaic system output.	Europe	2	European Commis-sion Joint Research Centre

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
16	A merging of dynamic and stochastic downscaling (Upper Rgne and Val d'Aosta case studies) A point scale meteorological forcing computed from RCM simulations with a quantile based error correction approach (Toce case studies) The resulting daily scenarios were further refined to 3-hourly time series, using sub-daily data from the RCMs	Two regional climate models (RCMs), the REMO and the RegCM3	2031–2050		Past periods are 1991–2010 for Switzerland and 2001–2010 for Italy.	Hydro	Combination of hydrologic and economic models Hydrological models Future hydrological data was obtained with different models. For the Upper Rhone and the Val d'Aosta case studies, data was generated with the TOPKAPI. For the Toce case study, data was obtained with the FEST-WB distributed water balance model. Electricity prices models Switzerland (Upper Rhone Valley): GARCH model of spot prices & Italy: Energy Value Index (EVI) Management models Hydrological and electricity prices models outputs feed the management models: Swiss case study: a binary local search algorithm, so-called Threshold Accepting & for Val d'Aosta: SOLARIS & for Toce: BPMPD Solver	Three neighbour-ing catchments in the Alps were selected in Switzerland and Italy, i.e. Valais (Mattmark Dam), Val d'Aosta (17 inter-connected hydropower plants and in depth studies for Valpelline and Hone II) and Toce (18 plants: 6 run of river plants and 12 storage plants)	10	EC (FP7); Research Fund for the Italian Electrical System under the Contract Agreement between RSE and the Ministry of Economic Development General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
17	IPCC SRES A1B	Hadley Center Coupled Model (HadCM3) and the Max Planck Institute model ECHAM5		2070-2099 (2080s)	1961–1990	Hydro, Thermal	Multi-market equilibrium model LIBEMOD	Western European (Austria, Belgium/Luxemburg, Denmark, Finland, France, Germany, Greece, Ireland/Eire, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom.)	37	Research Council of Norway

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
18	IPCC SRES A2 and B2	HIRHAM model driven by the United Kingdom's Hadley Center HadAM3H GCM.		2071-2100	1961-1990	Solar	Simulated data are used to determine potential change in climate and land-use according to two different development scenarios. Incident solar radiation flux from re-analyses, spatial interpolation, and the application of the Delta change method are used to assess the current and future solar resource potential within this catchment. Potential sites suitable for PV power plants are selected following a Fuzzy logic approach, and thus the total potential solar energy through PV power generation can be determined.	Black Sea catchment	1	European Commis-sion (FP7)
19	IPCC A1B	12 GCMs CGHR CGCM3.1 (T63), ECHOG, FGOALS FGOALS-g1.0, LASG, GFCM20 GFDL-CM2.0, GFCM21 GFDL-CM2.1, GIEH GISS-EH, NASA, HADCM3 UKMO-HadCM3, HADGEM UKMO-HadGEM1, MIHR MIROC3.2, MPEH5 MPEH5:, MRCGCM MRI-CGCM2.3.2, NCCCSM CCSM3	Computed future for 2050		Baseline for 2005	Hydro	Relating the runoff changes to hydropower generation potential through geographical information system (GIS), based on 2005 hydropower generation. Then changes in water resource availability were converted in to changes in hydropower generation.	Global (all world)	4	Norwegian Research Council

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
20	UKCIP02 low, medium high scenarios	UKCP02 data		2071-2100 (2080s)	1961–1990	Wind	The mean monthly value was used to generate a Rayleigh distribution that was then combined with the turbine production characteristics to estimate production. The turbine chosen for this study was the 3 MW Vestas V90. The V90 possesses a 90 m diameter rotor at 80 m hub height. With the UKCIP wind data available only at 10 m height, a correction was applied to translate it into higher speeds experienced at the 80 m hub height of the wind turbine.	UK but also assessment at five locations around the UK were selected to cover a range of different regions: two in England and one each in Scotland, Wales, and Northern Ireland	14	UK Engineering and Physical Sciences Research Council and Scottish Funding Council for the Joint Research Institute with Heriot-Watt University
21	Simulations by altering the mean annual wind speed by up to +/-20% in 10% intervals	Changes in marine climate were simulated by altering the mean annual wind speed by up to+/-20% in 10% intervals. (did not use GCM but probability distribution)	No specific period			Wave	Use of a Wave Energy Converter (WEC) developed by Edinburgh-based Ocean Power Delivery Ltd. The Pelamis is a 120 m long floating device that resembles a sea-snake with four articulated sections that flex (and produce up to 750 kW) as waves run down the length of the device.	Scottish West Coast (UK)	Not included in analysis	Not mentioned

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
22	IPCC SRES A1B, A2, and B1	regional climate model REMO (UBA run)	2011-2040; 2041-2070		1961-1990	Thermal	Modelling thermal power plant units and their respective cooling systems through dynamic simulation taking into account legal thresholds for heat discharges to river water together with climate data projections (SRES scenarios A1B, A2, and B1).	Germany (26 German power plants are analyzed, both coal and nuclear and only units that were operating at the end of 2010 are considered.)	12	Not mentioned
23	IPCC SRES A1B	Two different RCMs are considered in this study:1) COSMO CLM and 2)REMO driven by ECHAM5/MPI-OM1 simulations		2061-2100	1961–2000	Wind	The quantity Eout is computed from the wind velocities in 80 m. Wind turbine characteristics are assumed as following a 2.5-MW wind turbine from the GeneralElectricCo., Inc.	Europe	11	German Federal Ministry of Education and Research (BMBF)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
24	Created using the statistical regional climate model STAR	STARS (STatistical Analogue Resampling Scheme (STARS) is based on the assumption that already observed weather situations will very likely recur in the same or similar way in the near future.)	2008-2052		1951-2009	Thermal	An approach is applied here for analysing links between water availability and water temperature, air temperature and electricity generation by power plants. A highly disaggregated level is used combining a power plant model and hydrological models. It is applied to analyse effects of climate change on 17 nuclear power plants in Germany. Because cooling systems, hydro-climatic conditions and the related legal restrictions differ for the different power plants, a separate consideration of each power plant is necessary.	Germany (17 nuclear power plants in Germany)	1	German Federal Environment Agency (Umweltbundesamt)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
25	RCP2.6, RCP 8.6	Applying the statistical regional climate model STARS (STatistical Analog Resampling Scheme) Gerstengarbe et al. (2015) produce 100 realizations (ensemble runs) for each scenario	2031-2060		1981–2010	Hydro, Thermal, Wind	Thermal: River discharge is simulated using the ecohydrological model SWIM. Thermal conditions in the surface waters next to the power plants were simulated using a water temperature model developed for the river Elbe by Koch and Grünewald (2010). Water temperature models were then developed. Hydro: River discharge is simulated using the ecohydrological model SWIM Wind: Long-term wind speed at 80m over ground as calculated by the DWD (2008).	Germany	7	Not mentioned

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
26	Set of scenario assumptions for changes in human water use, which are largely are largely consistent with the no-climate-policy IPCC-IS92a and the intermediate Baseline-A scenario as developed by the Dutch National Institute of Public Health and Environment (RIVM). This global emission pathway is also within the range of marker scenarios of the updated IPCC-SRES scenarios, and slightly above their intermediate 'A1B' scenario	HadCM3 model and the ECHAM4/OPYC3 model	2050s	2080s	1961–1990	Hydro	Integrated global water model WaterGAP (Water—Global Assessment and Prognosis). WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model.	Europe Within this study, the geographic extent of Europe is defined to include the European part of Russia (limited by the Ural Mountains) to the east and Turkey to the south.	146	German Federal Ministry of Education, Science, Research and Technology (BMBF)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
27	IPCC SRES A1B	The 4 selected climate models are listed in the following with their acronyms, which refer to the corresponding driving GCM first three characters) and nested RCM (last three characters), respectively: i) 'HCH–RCA' = HadCM3–High Sensitivity (UK) driving RCA (Sweden); ii) 'ECH-RMO' = ECHAM5/MPI (Germany) driving RACMO2 (Netherlands); iii) 'ECH–REM' = ECHAM5/MPI (Germany) driving REMO (Germany); and vi) 'ECH–RCA'=ECHAM5/MPI (Germany) driving RCA (Sweden)	2040–2070		1970–2000	Hydro	The semi-distributed modeling system GEOTRANSF.	Italy Noce catchment, which is located in the Southeastern Alps, Italy (5 hydropower plants considered in the present study)	5	European Commis-sion and Italian Ministry of Public Instruction, University and Research

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
28	IPCC SRES A1B	ECHAM General Circulation Model. These global projections were downscaled through two different Regional Climate Models, REMO and RegCM	‘‘Middle’’ refers to the near future (from 2011 to 2030) and ‘‘Future’’ refers to the far future (from 2031 to 2050).		2002 and 2010	Hydro	The hydrological simulations were provided by ETHZ using TOPKAPI model (Ciarapica and Todini, 2002), a rainfall–runoff model that handles the topography and a representation of below ground in three layers. The management of hydropower systems was simulated with a simple optimization tool, called SOLARIS (Maran et al., 2006) developed by RSE, that allows the user to identify the optimal management of a network of hydroelectric reservoirs.	Italy hydropower system in Valle d’Aosta Region in Italy.	4	European Commis-sion and Research Fund for the Italian Electrical System under the Contract Agreement between RSE (formerly known as ERSE) and the Ministry of Economic Develop-ment – General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
29	IPCC SRES A1B	Eleven HadRM3 model variants (Met Office Hadley Centre)	2020-2080	2020-2080	1st March 1990 to 31st April 2009	Electricity network	By formalising the current relationship between weather-related faults and weather, the authors use climate projections from a regional climate model (RCM) to quantitatively assess how the frequency of these faults may change in the future.	UK	Not included in analysis	UK Energy Networks Association

30	Two equilibrium scenarios (UK Meteorological Office High Resolution model, UKHI and Canadian Climate Centre model, CCC) referring to years 2020, 2050 and 2100 and one transient scenario (UK High Resolution Transient output, UKTR) referring to years 2032 and 2080 were applied to represent both "green- house" warming and induced changes in precipitation and potential evapotranspiration. The two equilibrium experiments using high resolution atmospheric GCM (UKHI and CCC) and assuming the standard 1992 IPCC emissions scenario, a "central" climate sensitivity of 2.5°C and ignoring the effects of sulphate aerosols, produced climate change scenarios for the years, 2020, 2050 and 2100. The transient experiment UKTR, using the high resolution coupled ocean-atmosphere GCM of the Hadley Centre, gave climate change scenarios with a climate sensitivity of 2.5°C and	The climate modelling followed the methodology developed by the Climatic Research Unit (CRU) of the University of East Anglia, UK. The methodology adopted used the CRU 1961-1990 baseline, climatologies for Europe, the results from three GCM (General Circulation Models) climate change experiments (UKHI, CCC and UKTR) and a range of projections of global warming calculated by MAGICC (Model for the Assessment of Greenhouse gas Induced Climate Change), a simple upwelling-diffusion energy balance climate model	1 and 2: 1990-2100; 3- 1990-2080	1 and 2: 1990-2100; 3- 1990-2080	1961-1990	Hydro	The operation of the Polyfyto reservoir is described by a model, which consists of the water budget under various constraints concerning storage volume, outflow from the reservoir and energy production. The reservoir water budget equation is applied on a monthly basis.	Greece (Polyfyto reservoir in northern Greece)	2	EC, DG XII, Environ-ment Programme

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
	assuming no sulphate aerosol effect corresponding to the years 2032 and 2080 respectively									
31	IPCC SRES A2 emission scenario were used to derive three climate change scenarios: dry, mean and wet, which correspond roughly to the 5th, 50th and 95th percentiles of flow projections	Six Global Climate models	2011-2040		1961-1990	Thermal	The assessment investigates whether the number of days during which Hands-Off Flow conditions are reached and the power station in the catchment is forced to cease or reduce abstraction for electricity generation.	UK (Ferrybridge power station in Yorkshire)	1	Not mentioned
32	IPCC SRES A1B, A2, B1, B2	Max Plank Institute's GCM, European Center Hamburg Model, is used to drive the Rossby Center's RCM (RCA3).	2021-2060		1961-2000	Wind	RCA3 Model (No impact model per se)	Ireland	2	Environ-mental Protection Agency and the Higher Education Authority

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
33	IPCC SRES A1B	Five regional climate models of the ENSEMBLES (http://ensemblesrt3.dmi.dk/) database: 1- C4IRCA3 from SMHI, Sweden (Driven by HadCM3Q16) 2- ETHZ-CLM from ETHZ, Switzerland (driven by HadCM3Q0) 3- MPI-M-REMO, from MPI, Germany (driven by) ECHAM5-r3 4- SMHIRCA, from SMHI, Sweden (driven by BCM) 5- CNRM-RM5.1, from CNRM, France (driven by APREGE RM5.1)	2011–2050	2061–2100	1950–2000 (for temperature) and 1985–2005 (for irradiance)	Solar	The potential percentage change in PV output is calculated through the fractional change $\Delta P\text{PV}/P\text{PV}$ (from J. A. Crook, L. A. Jones, P. M. Forster, and R. Crook, "Climate change impacts on future photovoltaic and concentrated solar power energy output," Energy and Environmental Science, vol. 4, no. 9, pp. 3101–3109, 2011.)	Greece	8	European Commis-sion (FP7)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
34	IPCC SRES A2	The climate data used for this assessment were taken from the global climate model ECHAM5-MPIOM and dynamically downscaled by the regional climate model RegCM at Croatian Meteorological and Hydrological Service (DHMZ)	2011-2040; 2041-2070		1961-1990	Solar Wind Hydro	Solar: Climate modelling studies for Croatia made at DHMZ Wind: Electricity production from wind power plants is in the cubic relationship with wind speed, and it is proportional with air density Hydro.: The current practice in Croatia is that the Croatian Power Utility (HEP) forecasts the annual electricity production based on DHMZ data of aggregated water inflows into reservoirs. A linear relationship is assumed between the water inflow and the electricity production from hydro power plants.	Croatia	3	European Commis-sion (FP7)
35	IPCC SRES A1B	Three different regional climate models (RCM) from the ENSEMBLES Project: These are: RACMO2, CLM, and REMO	2036-2065		1961-1990	Hydro	A stochastic dynamic programming approach (see below) was used to formulate operating rules for hydropower generation in the Iberian system	Iberian Peinsula	1	Not mentioned

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
36	IPCC SRES A2, B2	Rossby Centre coupled Regional Climate Model (RCM) (RCAO) with boundary conditions derived from ECHAM4/ OPYC3 AOGCM and the HadAM3H atmosphere- only GCM		2071-2100	1961–1990	Wind	To further explore the impact of potential changes in the speed distribution on the wind energy sector the authors computed the frequency of wind speeds in four classes that pertain to the operation of wind turbines in the 2–4 MW class (e.g. turbines such as the Vestas V-90 or GE 3.6s)	northern Europe	3	Nordic Energy Research (Nordisk Energiforskning) and the energy sector in the Nordic countries as well as the partici-pating institutions

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
37	IPCC SRES A2	5 GCMS: 1- GFDL CM2.0 (GFDL) From Geophysical Fluid Dynamics Laboratory (NOAA, USA) 2- GISS ModelE-R (GISS) From Goddard Institute for Space Sceince USA 3- IPSL CM4 V1 (IPSL) From Institut Pierre Simon Laplace, France 4- MIROC3.2 medium resolution (MIROC) From Center for Climate System Research, University of Tokyo Frontier Research Center for Global Change 5- MRI_CGCM2.3.2a (MRI) From Meteorological Rsearch Institute of Japan	2046-2065	2081-2100	1961-1990	Wind	None: Empirical downscaling tools are used to output from 5 state-of-the-art AOGCMs to investigate projected changes in wind speeds and energy density in northern Europe.	northern Europe, and specifically the Baltic region	1	Nordic Energy Research; grants to Indiana University from IBM (Shared University Research) and the National Science Foundation
38	IPCC SRES scenarios A1B and B1	This study uses the Global Climate Model (GCM) and Regional Climate Model (RCM) wind output provided by the Max Planck Institute for Meteorology		2061-2100	1961-2000	Wave	Use of a wave energy converter (WEC): The Wave Hub	Wave Hub, Cornwall, UK	Not included in analysis	

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
39	IPCC SRES A1B, B1, A2	Statistical–dynamical downscaling (SDD) with the regional climate model COSMO-CLM		2061-2100		Wind	Use of wind turbine characteristics of an idealized 2.5MW wind turbine from General Electric (2010):	Special focus on Germany but results for other countries in Europe too	11	German Federal Ministry of Education and Research
40	IPCC SRES A1B, SRES B1	regional climate models REMO and CLM	2021-2050	2071-2100	1961-1990	Wind	Use of a specific the 2.3 kW wind turbine ENERCON E-82	South West Germany (Freiburg im Breisgau)	2	Not mentioned
41	IPCC SRES A1B	COSMO-CLM simulations driven by ECHAM5	2041-2070			Wind	Use of the characteristics of a 2 MW E-82 E2 turbine from ENERCON GmbH	Iberia (northern Galicia (1); Burgos (2); Ebro valley (3); northern Portugal (4); Southern Cataluna (5); Oeste (6); Albacete (7); Southern Andalucía (8))	13	Portuguese Foundation for Science and Technology and FEDER (Fundo Europeu de Desenvolvimento Regional)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
42	Results of the global mean warming - regional climate - scaling scaling methodology	The future local scale meteorological time series - namely daily mean precipitation and temperature - are generated by perturbing the observed series for a control period according to the method of Shabalova et al (2003). In this method, the perturbation of local scale precipitation and temperature is based on the corresponding regional scale outputs of a Regional Climate Model (RCM) for the same control and future period.		2070-2099	1961-1990	Hydro	The simulation tool includes 4 types of models: - a water management model - a hydrological model - a glacier surface evolution model - a model for the generation of local scale meteorological time-series under a given climate change scenario Climate change impacts on the management system are evaluated in terms of relative changes. Two types of indicators are used: - some quantitative: one set evaluates the total annual electricity production and the other its seasonal distribution - some qualitative, e.g. the Reliability-Resilience-Vulnerability (RRV) criteria	A Hydropower plant in the southern Swiss Alps (The dam of Mauvoisin)	1	EU Energy, Environment and Sustainable Development Programme and Swiss Federal Office for Education and Science

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
43	IS92a (ECHAM4), IPCC SRES B2 (ECHAM4 and HadAM3H), IPCC SRES A2(HadAM3H), IPCC SRES A1B (BCM v2), CIMP2 (BCM v1), 1.63*CO2 (CAMSOslo)	Five different global models: the global climate model (GCM) data were provided from the Max Planck Institute, Germany (MPI), the Hadley Centre, U.K. (HC), the Bjerknes Centre, Norway (BCCR), and University of Oslo, Norway (UiO). The global models are geographically downscaled using the HIRHAM atmospheric regional climate model (RCM). Ten climate experiments, based on five different global models and six emission scenarios, and are selected to cover the range of possible future climate scenarios.	2031–2060		The first nine climate experimt: 70 years (1961–1990) The tenth experimt: 50 years (1981–2010)	Hydro, Wind	MARKAL (MARKet ALocation) Norway model. MARKAL is a modelling tool developed by the Energy Technology System Analysis Programme (ETSAP), an implementing agreement of the International Energy Agency (IEA).	Norway	1	Research Council of Norway and the Norwegian Water Resources and Energy Directorate
44	IPCC SRES A1B (which lies between the IPCC AR5 RCP4.5 and RCP8.5 scenarios)	Ensemble of 15 regional climate projections achieved from 10 Regional Climate Models downscaling six Global Climate Models	2031-2060	2071-2100	1951–2000	Wind	Wind speed at the turbine height is converted into EWP using a standard modern turbine power curve. The power curve shape is derived from interpolated manufacturer data (for the VESTAS V90-3 MW) normalized by the turbine nominal (i.e. maximum) power. The power curve is then scaled by the nominal power of the turbines under consideration in the analysis.	Europe	20	EC (FP7 and FP6)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
45	IPCC SRES B1 and A2 scenarios	?	80 years fixed rotation length		1971–2000	Bioenergy	Use of a forest ecosystem model	Norway spruce forest area in central Finland	Not included in analysis	Graduate School in Forest Sciences (GSForest), University of Eastern Finland (UEF) and the School of Forest Sciences
46	IPCC SRES emission scenarios, A1FI, A2, B1 and B2	Four global climate models, HadCM3, CSIRO2, PCM and CGCM2	2020 and 2050	2080s	1961–1990	Bioenergy	Use of simple rules for suitable climatic conditions and elevation.	Europe	Not included in analysis	
47	IPCC SRES A2 (medium–high) and B1 (low) emission scenarios	Biased-corrected general circulation model (GCM) output (Hagemann et al 2011). In the study by Hageman et al, they use 3 GCMs but difficult to say whether the author of this publication also used 3 GCMs as not explicit	2031–2060		1971–2000	Hydro, Thermal	Thermal: Thermal electric power production model (Koch and Vogele 2009, Rubbelke and Vogele 2011) Hydro: gross hydropower potential is directly calculated from gridded datasets of water availability and elevation differences, without requiring additional data of exact location and installed capacities of hydropower plants Lehner et al (2005).	Europe	81	EC

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
48	IPCC SRES A2 and B1	Ensemble of biased-corrected general circulation model (GCM) output for 3 GCMs	2031-2060 (2040s)	2071-2100 (2080s)	1971 2000	Therm al	Use of a hydrological-water temperature modelling framework The methodology used to assess the impact of climate change induced daily water temperature and 195 river flow changes on the usable capacity of thermal electric power plants was based on: Koch, H., Vögele, S., Kaltofen, M. & Grünewald, U. Trends in water demand and water availability for power plants scenario analyses for the German capital Berlin. Climatic Change 110, 879-899 (2012).	Europe and USA	0	EC (FP6 and FP7)

#	Emission scenario(s) used	Climate model(s)/projection(s) used	Period of assessment (Near term to mid-21st century)	Period of assessment (End of the 21st century)	Baseline / Control	Energy type	Impact model used	Geo-graphical coverage	Number of individual result considered in the analysis	Source of funding
49	IPCC SRES A1B	Two regional climate models available for Germany. One of these models is REMO, developed at the Max-Planck-Institut fuer Meteorologie (MPI). The second climate model is the CLM model developed by the consortium of BTU Cottbus, Forschungszentrum GKSS, and Potsdam-Institut fuer Klimafolgenforschung. Both models are operated at the MPI and capture dynamic processes in the atmosphere at several spatial scales and with different regional coverages	2036-2065	2071-2100	1981-2010	Solar, Wind	Solar: The authors develop a model of PV power generation based on a) the change in global radiation and b) the averaging due to the distribution of orientations and the tilt angles of PV modules within a region. Wind: Use of an Enercon E40 wind turbine with a rated power of 500 kW, a cut-in wind speed of 2,5 m/s and a rated wind speed of 13,0 m/s.	Germany's Northwest Metropolitan Region	14	German Ministry for Education and Research
50	The climate model estimates an average warming of 1.4°C, and an increased and more variable precipitation total	The climate-change scenario was a regional model 'nested' within the Global Circulation Model (GCM) developed by the Hadley Centre, Bracknell, Berkshire. (HadCM2)	2031-2060		1961-1990	Hydro	A simple water-balance model was used which describes the water level in Lac des Dix as the product of inflows and outflows of water in a particular month, as well as water stored from the previous month.	Grande Dixence Hydro-Electricity Scheme,Valais, Switzerland	1	Not mentioned

10.3.3. Appendix C3- Peer-reviewed articles included in the systematic review but excluded from the analysis

Results from the articles focusing on bioenergy, wave energy and electricity networks were not included in the analysis because of the limited and conflicting evidence base they provided. Only four articles examine the impacts of CV&C on electricity generation from bioenergy (# 4, 9, 45, 46). They model the yields of different bioenergy crops in future climate conditions. No consistent patterns of impacts of CV&C could be extrapolated from the results of these four articles.

Two articles focus on electricity generation from wave energy. The first article (#21) quantifies how changes in the mean wind speed (a proxy for climate change) influence electricity generation by a Wave Energy Converter (WEC) in Western Scotland (UK). Harrison and Wallace (2005) demonstrate that under fixed conditions, WEC generation changes by up to 800 MWh/year (42%) for a 20% wind change. The second article (Reeve et al. (2011); #38) assesses the impacts of CV&C on generation by the Wave Hub WEC in Cornwall (UK). Although generation is projected to decrease by 2-3% under the A1B and B1 emissions scenarios for 2061-2100, this could be mainly due to the low efficiency of generation from steeper waves by the examined WEC (Reeve et al., 2011).

A single article examines the impacts of CV&C on electricity networks (#29). McColl et al. (2012) first formalise the current relationships between five types of weather-related faults and weather, and then use climate projections from a Regional Climate Model (RCM) to quantitatively assess how fault frequency could change in the 2020s-2080s. Their results suggest that lightning and solar heat faults are likely to increase but snow, sleet and blizzard (SSB) faults are likely to decrease McColl et al. (2012). There are uncertainties regarding future wind, gale and flooding related faults.

The two articles on wave energy and the one on energy networks do not provide sufficient evidence to enable the identification of consistent patterns of impacts of

CV&C. They also have limited spatial foci and thus limited value from a European perspective. For these reasons they were excluded from further analysis.

References

Harrison, G. P. and A. R. Wallace (2005). Climate Sensitivity of Marine Energy. Renewable Energy 30(12): 1801-1817. http://dx.doi.org/10.1016/j.renene.2004.12.006

McColl, L., E. J. Palin, H. E. Thornton, D. M. H. Sexton, R. Betts and K. Mylne (2012). Assessing the Potential Impact of Climate Change on the UK's Electricity Network. Climatic Change 115(3-4): 821-835. http://dx.doi.org/10.1007/s10584-012-0469-6

Reeve, D. E., Y. Chen, S. Pan, V. Magar, D. J. Simmonds and A. Zacharioudaki (2011). An Investigation of the Impacts of Climate Change on Wave Energy Generation: The Wave Hub, Cornwall, UK. Renewable Energy 36(9): 2404-2413. http://dx.doi.org/10.1016/j.renene.2011.02.020

10.3.4. Appendix C4- Impacts of climate variability and change on hydro-, wind, thermal and solar electricity generation at sub-national scale

Hydroelectricity generation

The reviewed articles contained sub-national scale projections in the United Kingdom (#7), Switzerland (#13, #16, #50), Italy (#1, #27, #28) and Greece (#2, #30) for the near term to mid-21st century, and in Norway (#8), Switzerland (#13, #42) and Greece (#30) for the end of the 21st century.

A catchment-scale assessment for the South East of Switzerland (#13 (1 individual result)) projects a decrease in annual hydroelectricity generation for the near term to mid-21st century and the same study (#13 (1)), together with an assessment for the South West of Switzerland (#42 (1)), both consistently project a decrease in annual hydroelectricity generation for the end of the 21st century.

Two sub-national assessments (#2 (1), #30 (1)) project a decrease in annual hydroelectricity generation for Greece for the near term to mid-21st century and a single assessment (#30 (1)) projects an annual decrease in hydroelectricity generation also for the end of the 21st century.

The Aurland hydroelectric power plant in Norway (#8 (1)) is the only sub-national scale case where the projections consistently suggest an annual increase in hydroelectricity generation for the end of the 21st century.

Only four articles provide individual results on seasonal impacts of CV&C on hydroelectricity generation for the near term to mid-21st century (#7, #16, #27, #28). For the Plynlimon catchment (UK), hydroelectricity generation is projected to increase in winter and decrease in summer. However, these seasonal impacts cancel each other out, to leave no discernible projected annual impact for the near term to mid-21st century (#7 (1)).

For the Swiss and Italian Alps, for the near term to mid-21st century, most individual results project a decrease in hydroelectricity generation for summers (#16 (3), (#27 (1)) the only exception being the Valle d'Aosta catchment in Italy for which no robust pattern could be found (#28 (1)). An increase of hydroelectricity generation is consistently projected for autumns for the Val d'Aosta (#16 (1)) and Toce (#16 (1)) catchments in Switzerland and for the Noce catchment in Italy (#27 (1)).

The only catchment scale seasonal assessment for the end of the 21st century projects a decrease in hydroelectricity generation for the Aurland hydroelectric power plant in western Norway in winter (#8 (1)) and an increase in hydroelectricity generation in spring, summer and autumn (#8 (1,1,1 respectively))

Wind electricity generation

Sub-national assessments of impacts of CV&C on wind electricity generation are available for Germany (#25, #40), Croatia (#34), Portugal (#41) and Spain (#41) for the near term to mid-21st century and for Germany (#40) and the United Kingdom (#20) for the end of the 21st century. Northern and South Western Germany are projected to experience an increase in annual wind electricity generation for the near term to mid-21st century (#25 (1), #40 (1)) and so are the North of Scotland (#20 (1)), the North (#20 (1)), Middle (including Wales, #20 (1)) and South (#20 (1)) of England, and the Eastern Mediterranean (#5 (1)) region over land for the end of the 21st century. But an annual decrease in wind electricity generation is predicted for South Germany (#25 (1)) for the near term to mid-21st century and South West Germany (i.e. Freiburg, #40 (1)), Northern Ireland (#20 (1)) and the Eastern Mediterranean region over the sea (#5 (1)) for the end of the 21st century.

Wind electricity generation is projected to increase in autumn and winter in North West Germany (i.e. Bremen Oldenburg) (#49 (1, 1)) and in summer on the coast of Croatia (#34 (1)), the Ebro Valley (Spain, #41 (1)) and Albacete (Spain, #41 (1)) for the near term to mid-21st century. It is also projected to increase in summer, autumn and winter for Southern Andalucia (Spain #41 (1,1,1)) for the near term to mid-21st century.

Wind electricity generation is projected to decrease in North West Germany in August and November (#49 (1,1)) and in Northern Portugal in spring and autumn (#41 (1,1)) for the near term to mid-21st century. It is also projected to decrease in the Oeste Region (Portugal, #41 (#41 (1)), Northern Galicia (Spain, #41 (1)), Burgos (Spain, #41 (1)), and Albacete (Spain, #41 (1)) in spring and in Southern Cataluna in autumn and winter for the near term to mid-21st century (Spain, #41 (1, 1)).

For the end of the 21st century, wind electricity generation is projected to increase in summer on the West coast of Norway (#23 (1)) and in Northern France (#23 (1)) and the Western part of Iberia (#44 (1)). It is also projected to increase from December to March in the North of England (#20 (1)), Mid-England and Wales (#20 (1)) and England (#20 (1)), and in winter on the North Coast of Wales (North Hoyle wind farm, #10 (1)), the South East coast of England (Kentish Flats wind farm, #10 (1)), and in Northern Ireland (#20 (1)) and Western Germany (#23 (1)). Finally, wind electricity generation is projected to increase in autumn and winter in North West Germany (Bremen Oldenburg, #49 (1, 1)) and in April and August in the Eastern Mediterranean region (#5 (1)).

Wind electricity generation is projected to decrease in the summers of the end of the 21st century in Northern England (#20 (1)), Mid-England and Wales (#20 (1)), England (#20 (1)), Northern Ireland (#20 (1)), on the North Coast of Wales (North Hoyle wind farm, #10 (1)), on the South East coast of England (Kentish Flats wind farm, #10 (1)), the Bay of Biscay (#23 (1)), the Thyrean Sea (Italy, #23 (1)) and in winters in Scotland (#20 (1)), the Po Valley (Italy, #23 (1)), Southern Mediterranean (#23 (1)), and Eastern Spain (#23 (1)). It is also projected to decrease in December, January and May in the Eastern Mediterranean region (#5 (1,1,1)).

Thermal electricity generation

Thermal electricity generation at the Ferrybridge Power Plant in the United Kingdom is projected to decrease annually (#31 (1)) in the near term to mid-21st century, and similar projections exist for the plants on the River Weser (Central North West Germany, #25 (1)) and the River Rhine (central Southwest Germany, #25 (1)).

Solar electricity generation

Annual solar electricity generation is projected to increase for the near term to mid-21st century and the end of the 21st century in Mid- and South Scotland, Northern Ireland, Northern, Mid- and Southern England and Wales (for the UKCP09 50% probability level, #6 (1, 1, 1, 1, 1, 1)) and Western Greece (#33 (1)). It is projected to increase for the end of the 21st century only in Northern Greece (#33 (1)), Western Greece and Thrace (#33 (1)) and in Crete and the Aegean Islands (#33 (1)).

A decrease in annual solar electricity generation is projected for the Attica and Thessaly regions (Greece) for the near term to mid-21st century (#33 (1, 1)) and the end of the 21st century (#33 (1, 1)) and for the Northern of Scotland for the end of the 21st century (for the UKCP09 50% probability level, #6 (1)).

Seasonal impacts of CV&C on solar electricty generation were assessed in only one article, which projects an increase in solar eletricity generation in summers in North West Germany (Bremen Oldenburg, #49 (1)) and a decrease in winters (#49 (1)) for both the near term to mid-21st century and the end of the 21st century.

10.4. Appendix D: Supplementary material for Chapter 5: Keeping the lights on amid changing physical climate risks: Policy instruments for climate resilient electricity sectors in the United Kingdom and France

Appendix D1: List of documents included in the analysis

Appendix D2: Details of the UK and French policy instruments that ensure electricity supply continuity and reliability

10.4.1. Appendix D1: List of documents included in the analysis

D1-1 The United Kingdom

Table 10-5: List of the documents included in the analysis for the United Kingdom

Number	Nature of the document	Name	Year	Source
UK-DI1	Distribution and Connection Use of System Agreement	Distribution and Connection Use of System Agreement (DCUSA) - version 9.4	2017	https://www.dcusa.co.uk/DCUSA%20Document%20Public%20Version/DCUSA%20v9.4%20Public.pdf
UK-DI2	Ofgem document	Electricity Generation Licence: Standard conditions 2017	2017	https://epr.ofgem.gov.uk//Content/Documents/Electricity%20Generation%20Standard%20Licence%20Conditions%20Consolidated%20-%20Current%20Version.pdf
UK-DI3	DBEIS document	Capacity Market (Amendment) Rules 2017	2017	https://www.gov.uk/government/publications/capacity-market-rules#history
UK-DI4	Cabinet office Guidance	National Risk Register of Civil Emergencies – 2017 Edition	2017	https://www.gov.uk/government/publications/national-risk-register-of-civil-emergencies-2017-edition
UK-DI5	House of Commons Business, Energy and Industrial Strategy (BEIS) Committee document	Future challenges for UK energy and climate policy response published 2017	2017	https://publications.parliament.uk/pa/cm201617/cmselect/cmbeis/945/945.pdf
UK-DI6	UK House of Commons - Briefing paper	Energy Policy Overview 2016	2016	http://researchbriefings.files.parliament.uk/documents/CBP-7582/CBP-7582.pdf
UK-DI7	DBEIS document	Statutory security of supply report: 2016	2016	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/563436/57327_HC_717_Print.pdf
UK-DI8	Infrastructure and Projects Authority policy paper	National Infrastructure Delivery Plan 2016 to 2021	2016	https://www.gov.uk/government/publications/national-infrastructure-delivery-plan-2016-to-2021
UK-DI9	House of Commons Energy and Climate Change Committee document	The Energy revolution and future challenges for UK energy and Climate Change policy 2016	2016	https://publications.parliament.uk/pa/cm201617/cmselect/cmenergy/705/705.pdf
UK-DI10	UK HOUSE OF LORDS - Science and Technology Select Committee Report	The Resilience of the Electricity System 2015	2015	https://publications.parliament.uk/pa/ld201415/ldselect/ldsctech/121/121.pdf
UK-DI11	UK Parliament - Energy and Climate Change Committee inquiry	Investor confidence in the UK energy sector inquiry	2015	https://www.parliament.uk/business/committees/committees-a-z/commons-select/energy-and-climate-change-committee/inquiries/parliament-2015/investor-confidence/
UK-DI12	DECC document	Electricity Supply Emergency Code (revised January 2015)	2015	https://www.gov.uk/government/publications/electricity-supply-emergency-code-revised-january-2005
UK-DI13	Ofgem document	The Electricity (Standards of Performance) Regulations 2015	2015	https://www.ofgem.gov.uk/publications-and-updates/electricity-standards-performance-regulations-2015-and-electricity-connection-standards-performance-regulations-2015

Number	Nature of the document	Name	Year	Source
UK-DI14	Ofgem document	Electricity (Connection Standards of Performance) Regulations 2015	2015	https://www.ofgem.gov.uk/sites/default/files/docs/2014/12/electricity_connection_standards_of_performance_regulations_2015_-_stat_con_0.pdf
UK-DI15	DECC document	Delivering UK Energy Investment: Low Carbon Energy March 2015	2015	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/419024/DECC_LowCarbonEnergyReport.pdf
UK-DI16	DECC document	Delivering UK Energy Investment: Networks January 2015	2015	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/394509/DECC_Energy_Investment_Report_WEB.pdf
UK-DI17	UK Act	Infrastructure Act 2015 / PART 6 ENERGY	2015	http://www.legislation.gov.uk/ukpga/2015/7/contents/enacted
UK-DI18	UK Act	Deregulation Act 2015	2015	http://www.legislation.gov.uk/ukpga/2015/20/contents/enacted
UK-DI19	UK HM Government - DECC Report	Delivering UK Energy Investment July 2014	2014	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/331071/DECC_Energy_Investment_Report.pdf
UK-DI20	DECC document	National Emergency Plan: Downstream Gas and Electricity	2014	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/385885/UK_DGE_NEP_-_November_2014.pdf
UK-DI21	DECC report	Energy Emergencies Executive Committee Annual Report 2014	2014	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/386626/E3C_Annual_Report_2014.pdf
UK-DI22	UK Act	Water Act 2014	2014	http://www.legislation.gov.uk/ukpga/2014/21/contents/=england+wales+scotland?text=flood#match-1
UK-DI23	UK Act	Energy Act 2013	2013	http://www.legislation.gov.uk/ukpga/2013/32/contents/=england+wales+scotland?text=risk#match-1
UK-DI24	UK Act	Growth and Infrastructure Act 2013	2013	http://www.legislation.gov.uk/ukpga/2013/27/contents/=england+wales+scotland?text=energy#match-1
UK-DI25	UK Act	Enterprise and Regulatory Reform Act 2013	2013	http://www.legislation.gov.uk/ukpga/2013/24/contents/=england+wales+scotland?text=energy#match-1
UK-DI26	DECC document	Electricity Market Reform: policy overview 2012	2012	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65634/7090-electricity-market-reform-policy-overview-.pdf
UK-DI27	DECC Policy paper	Planning our electric future: a white paper for secure, affordable and low-carbon energy 2011	2011	https://www.gov.uk/government/publications/planning-our-electric-future-a-white-paper-for-secure-affordable-and-low-carbon-energy
UK-DI28	UK Act	Energy Act 2011	2011	http://www.legislation.gov.uk/ukpga/2011/16/contents/=england+wales+scotland?text=weather#match-1
UK-DI29	Ofgem factsheet	RIIO - a new way to regulate energy networks (factsheet 93) 2010	2010	https://www.ofgem.gov.uk/ofgem-publications/64031/re-wiringbritainfs.pdf
UK-DI30	DECC document	National Renewable Energy Action Plan for the UK 2010	2010	https://www.gov.uk/government/publications/national-renewable-energy-action-plan
UK-DI31	UK Act	Flood and Water Management Act 2010	2010	http://www.legislation.gov.uk/ukpga/2010/29/contents?text=flood#match-1
UK-DI32	UK Act	Flood Risk Management (Scotland) Act 2009	2009	http://www.gov.scot/Topics/Environment/Water/Flooding/FRMAct

Number	Nature of the document	Name	Year	Source
UK-DI33	UK Act	Climate Change Act 2008	2008	http://www.legislation.gov.uk/ukpga/2008/27/data.pdf
UK-DI34	UK Act	Planning Act 2008	2008	http://www.legislation.gov.uk/ukpga/2008/29/contents
UK-DI35	UK Act	Energy Act 2008	2008	http://www.legislation.gov.uk/ukpga/2008/32/contents/=england+wales+scotland?text=risk#match-1
UK-DI36	Code	Fuel Security Code	2007	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/79194/FuelSecurityCode.pdf
UK-DI37	UK House of Commons - Environmental Audit Committee Report	Keeping the lights on: Nuclear, Renewables and Climate Change - Sixth Report of Session 2005–06; Volume I - Report, and oral evidence together with formal minutes. 2006	2006	https://publications.parliament.uk/pa/cm200506/cmselect/cmenvaud/584/584i.pdf
UK-DI38	UK Department of Trade and Industry Guidance	Guidance on the electricity safety, quality and continuity (amendment) regulations 2006	2006	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82785/Guidance2006.pdf
UK-DI39	Department of Trade and Industry document	The energy challenge: energy review - a report 2006	2006	https://www.gov.uk/government/publications/the-energy-challenge-energy-review-a-report
UK-DI40	UK Act	Climate Change and Sustainable Energy Act 2006	2006	http://www.legislation.gov.uk/ukpga/2006/19/contents/=england+wales+scotland?text=weather#match-1
UK-DI41	UK Act	Energy Act 2004	2004	http://www.legislation.gov.uk/ukpga/2004/20/contents/=england+wales+scotland?text=risk#match-1
UK-DI42	UK Act	Sustainable Energy Act 2003	2003	http://www.legislation.gov.uk/ukpga/2003/30/contents/=england+wales+scotland?text=energy#match-1
UK-DI43	POST - Parliamentary Office of Science and Technology document	Security of electricity supplies, September 2003. POSTnote 03/203.	2003	http://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-203#fullreport
UK-DI44	UK Act	Water Act 2003	2003	http://www.legislation.gov.uk/ukpga/2003/37/contents/=england+wales+scotland?text=risk#match-1
UK-DI45	UK Act	Enterprise Act 2002	2002	http://www.legislation.gov.uk/ukpga/2002/40/contents/=england+wales+scotland?text=electricity#match-1
UK-DI46	UK Act	Utilities Act 2000	2000	http://www.legislation.gov.uk/ukpga/2000/27/contents/=england+wales+scotland?text=energy#match-1
UK-DI47	UK Act	Pollution Prevention and Control Act 1999	1999	http://www.legislation.gov.uk/ukpga/1999/24/contents/=england+wales+scotland?text=risk#match-1
UK-DI48	UK Act	Planning (Consequential Provisions) (Scotland) Act 1997	1997	http://www.legislation.gov.uk/ukpga/1997/11/contents/=england+wales+scotland?text=flood#match-1
UK-DI49	UK Act	Environment Act 1995	1995	http://www.legislation.gov.uk/ukpga/1995/25/contents/=england+wales+scotland?text=flood#match-1
UK-DI50	UK Act	Competition and Service (Utilities) Act 1992	1992	http://www.legislation.gov.uk/ukpga/1992/43/data.pdf
UK-DI51	UK Act	Water Resources Act 1991	1991	http://www.legislation.gov.uk/ukpga/1991/57/contents/=england+wales+scotland?text=drought#match-1

Number	Nature of the document	Name	Year	Source
UK-DI52	UK Act	Environmental Protection Act 1990	1990	http://www.legislation.gov.uk/ukpga/1990/43/contents/=england+wales+scotland?text=energy#match-1
UK-DI53	UK Act	Electricity Act 1989	1989	http://www.legislation.gov.uk/ukpga/1989/29/contents?text=flood#match-1
UK-DI54	UK Act	Water Act 1989	1989	http://www.legislation.gov.uk/ukpga/1989/15/contents?text=flood#match-1
UK-DI55	UK Act	Environment and Safety Information Act 1988	1988	http://www.legislation.gov.uk/ukpga/1988/30/contents/=england+wales+scotland?text=energy#match-1
UK-DI56	UK Act	Energy Act 1983	1983	http://www.legislation.gov.uk/ukpga/1983/25/contents/=england+wales+scotland?text=energy#match-1
UK-DI57	UK Act	Water (Scotland) Act 1980	1980	http://www.legislation.gov.uk/ukpga/1980/45/contents?text=flood#match-1
UK-DI58	UK Act	Energy Act 1976	1976	http://www.legislation.gov.uk/ukpga/1976/76/contents/=england+wales+scotland?text=energy#match-1
UK-DI59	UK Act	Water Act 1973	1973	http://www.legislation.gov.uk/ukpga/1973/37/contents/=england+wales+scotland?text=flood#match-1
UK-DI60	UK Act	Atomic Energy Authority Act 1971	191	http://www.legislation.gov.uk/ukpga/1971/11/contents/=england+wales+scotland?text=energy#match-1

D1-2: FRANCE

Table 10-6: List of the documents included in the analysis for France

Number	**Nature of the document**	**Name**	**Year**	**Source**
FR-DI1	Law	Code de l'Environnement	Version consolidée au 1 Novembre 2017	https://www.legifrance.gouv.fr/affichCode.do?cidTexte=LEGITEXT000006074220
FR-DI2	Website from the Ministère de la Transition écologique et solidaire	Programmations pluriannuelles de l'énergie (PPE)	Publi-shed 5 December 2016 [Accessed November 2017]	https://www.ecologique-solidaire.gouv.fr/programmation-pluriannuelle-energie
FR-DI3	Law	Code de l'Energie	Dernière modi-fication: 1 Juillet 2017	https://www.legifrance.gouv.fr/affichCode.do?cidTexte=LEGITEXT000023983208&dateTexte=20120406
FR-DI4	Government document	Panorama énergies air climat 2017	2017	https://www.ecologique-solidaire.gouv.fr/sites/default/files/17068-1_panorama-energie-air-climat_BAT.pdf
FR-DI5	Document from the Ministère de l'Ecologie, du Développement et de l'Aménagement durables (ex Ministère de la Transition écologique et solidaire) / Observatoire National sur les effets du rechauffement climatique	Adaptation au changement climatique - Évaluation de la démarche nationale et recommandations	2016	https://www.ecologique-solidaire.gouv.fr/sites/default/files/ONERC_Rapport_2016_EvaluationPnacc_WEB_0.pdf

Number	**Nature of the document**	**Name**	**Year**	**Source**
FR-DI6	Legal order	Arrêté du 29 novembre 2016 définissant les règles du mécanisme de capacité et pris en application de l'article R. 335-2 du code de l'énergie	2016	https://www.legifrance.gouv.fr/eli/arrete/2016/11/29/DEVR1632005A/jo
FR-DI7	Information report to the government	RAPPORT D'INFORMATION DÉPOSÉ en application de l'article 146 du Règlement PAR LA COMMISSION DES FINANCES, DE L'ÉCONOMIE GÉNÉRALE ET DU CONTRÔLE BUDGÉTAIRE sur la situation du groupe Électricité de France et de la filière nucléaire (2016)	2016	http://www.assemblee-nationale.fr/14/pdf/rap-info/i3952.pdf
FR-DI8	Legal decree	"Décret no 2016-1442 du 27 octobre 2016 relatif à la programmation pluriannuelle de l'énergie	2016	https://www.legifrance.gouv.fr/eli/decret/2016/10/27/DEVR1619015D/jo/texte.
FR-DI9	Legal decree	Décret n° 2016-687 du 27 mai 2016 relatif à l'autorisation d'exploiter les installations de production d'électricité	2016	https://www.legifrance.gouv.fr/eli/decret/2016/5/27/2016-687/jo/texte
FR-DI10	Law	LOI n° 2016-786 du 15 juin 2016 autorisant la ratification de l'accord de Paris adopté le 12 décembre 2015	2016	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000032711388&categorieLien=id

Number	**Nature of the document**	**Name**	**Year**	**Source**
FR-DI11	Government document	Rapport sur les moyens consacres a la politique energetique	2015	https://www.performance-publique.budget.gouv.fr/sites/performance_publique/files/farandole/ressources/2015/pap/pdf/jaunes/jaune2015_politique_energetique.pdf
FR-DI12	Government document	Evaluation du plan national d'adaptation au changement climatique	2015	http://cgedd.documentation.developpement-durable.gouv.fr/documents/cgedd/010178-01_rapport.pdf
FR-DI13	Conference proceedings organised by the Conseil Général de l'Environnement et du Développement Durable et le Conseil Economique du Développement Durable	Régulation économique et infrastructures de réseaux - Rencontre avec Jean Tirole, prix Nobel d'économie 2014	2015	http://www.cgedd.developpement-durable.gouv.fr/IMG/pdf/Actes_combines_CR_cle2b1483.pdf
FR-DI14	Law	LOI n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte (Law no. 2015-992 on Energy Transition for Green Growth (Energy Transition Law))	2015	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000031044385&categorieLien=id
FR-DI15	Law	LOI n° 2015-1567 du 2 décembre 2015 portant diverses dispositions d'adaptation au droit de l'Union européenne dans le domaine de la prévention des risques	2015	https://www.legifrance.gouv.fr/eli/loi/2015/12/2/DEVP1507712L/jo
FR-DI16	Law	LOI n° 2014-1 du 2 janvier 2014 habilitant le Gouvernement à simplifier et sécuriser la vie des entreprises	2014	https://www.legifrance.gouv.fr/eli/loi/2014/1/2/EFIX1320236L/jo/texte

Number	**Nature of the document**	**Name**	**Year**	**Source**
FR-DI17	Document from the Ministère de l'Ecologie, du Développement et de l'Aménagement durables (ex Ministère de la Transition écologique et solidaire) / Comité de la Prévention et de la Précaution	Adaptation aux changements climatiques Acceptabilité et gouvernance des risques	2013	http://www.societechimiquedefrance.fr/IMG/pdf/aviscpp-a4_v6.pdf
FR-DI18	Law	LOI n° 2013-619 du 16 juillet 2013 portant diverses dispositions d'adaptation au droit de l'Union européenne dans le domaine du développement durable	2013	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000027713399&categorieLien=id
FR-DI19	Government document	PNACC 2011-2015	2011	https://www.ecologique-solidaire.gouv.fr/sites/default/files/ONERC_PNACC_1_complet.pdf
FR-DI20	Law	LOI n° 2010-788 du 12 juillet 2010 portant engagement national pour l'environnement	2010	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022470434
FR-DI21	Law	LOI n° 2010-1488 du 7 décembre 2010 portant nouvelle organisation du marché de l'électricité	2010	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000023174854&categorieLien=id
FR-DI22	Document from the Ministère de l'Ecologie, du Développement et de l'Aménagement durables (ex Ministère de la Transition écologique et solidaire)	La programmation pluriannuelle des investissements de production d'électricité : période 2009 - 2020	2009	http://www.ladocumentationfrancaise.fr/rapports-publics/094000317/index.shtml

Number	Nature of the document	Name	Year	Source
FR-DI23	Law	LOI n° 2009-179 du 17 février 2009 pour l'accélération des programmes de construction et d'investissement publics et privés	2009	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000020276457&categorieLien=id
FR-DI24	Law	LOI n° 2009-967 du 3 août 2009 de programmation relative à la mise en œuvre du Grenelle de l'environnement (1)	2009	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000020949548&categorieLien=id
FR-DI25	Document from the Ministère de l'Ecologie, du Développement et de l'Aménagement durables (ex Ministère de la Transition écologique et solidaire)	Catastrophes environnementales – preparer l'evaluation de leurs effets et le retour d'experience	2008	https://www.ecologique-solidaire.gouv.fr/sites/default/files/CPP%20avis%20200802.pdf
FR-DI26	Law	LOI n° 2008-66 du 21 janvier 2008 relative aux tarifs réglementés d'électricité et de gaz naturel	2008	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000017942023
FR-DI27	Law	LOI n° 2008-757 du 1er août 2008 relative à la responsabilité environnementale et à diverses dispositions d'adaptation au droit communautaire dans le domaine de l'environnement	2008	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000019277729
FR-DI28	Legal decree	Décret n°2006-1731 du 23 décembre 2006 approuvant le cahier des charges type de concession du réseau public de transport d'électricité.	2006	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000820236

Number	**Nature of the document**	**Name**	**Year**	**Source**
FR-DI29	Law	Loi n° 2006-686 du 13 juin 2006 relative à la transparence et à la sécurité en matière nucléaire	2006	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000819043
FR-DI30	Law	Loi n° 2006-1772 du 30 décembre 2006 sur l'eau et les milieux aquatiques	2006	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000649171
FR-DI31	Law	Loi n° 2005-781 du 13 juillet 2005 de programme fixant les orientations de la politique énergétique (Energy Policy Framework (POPE, No. 2005-781))	2005	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000019277729&fastPos=17&fastReqId=215843938&categorieLien=cid&oldAction=rechTexte
FR-DI32	Law	Loi n° 2004-803 du 9 août 2004 relative au service public de l'électricité et du gaz et aux entreprises électriques et gazières	2004	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000819043&fastPos=198&fastReqId=636792571&categorieLien=cid&oldAction=rechTexte
FR-DI33	Law	LOI n° 2003-699 du 30 juillet 2003 relative à la prévention des risques technologiques et naturels et à la réparation des dommages	2003	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000649171&fastPos=190&fastReqId=636792571&categorieLien=cid&oldAction=rechTexte

Number	Nature of the document	Name	Year	Source
FR-DI34	Law	Loi 2003-591 (aussi abroge la loi no 2001-153 du 19 février 2001 tendant à conférer à la lutte contre l'effet de serre et à la prévention des risques liés au réchauffement climatique la qualité de priorité nationale et portant création d'un Observatoire national sur les effets du réchauffement climatique en France métropolitaine et dans les départements et territoires d'outre-mer)	2003	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000813253&fastPos=218&fastReqId=636792571&categorieLien=cid&oldAction=rechTexte
FR-DI35	Law	LOI n° 2003-8 du 3 janvier 2003 relative aux marchés du gaz et de l'électricité et au service public de l'énergie	2003	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000776748
FR-DI36	Law	Loi n° 2001-420 du 15 mai 2001 relative aux nouvelles régulations économiques	2001	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000223114
FR-DI37	Law	Loi n° 2000-108 du 10 février 2000 relative à la modernisation et au développement du service public de l'électricité	2000	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000787077&fastPos=81&fastReqId=1192115829&categorieLien=cid&oldAction=rechTexte

Number	Nature of the document	Name	Year	Source
FR-DI38	Law	Loi n° 99-533 du 25 juin 1999 d'orientation pour l'aménagement et le développement durable du territoire et portant modification de la loi n° 95-115 du 4 février 1995 d'orientation pour l'aménagement et le développement du territoire	1999	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000604335&fastPos=12&fastReqId=1794178457&categorieLien=cid&oldAction=rechTexte
FR-DI39	Law	Loi n° 95-101 du 2 février 1995 relative au renforcement de la protection de l'environnement	1995	https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000422094&dateTexte=&categorieLien=id
FR-DI40	Document from the Ministère de l'Ecologie, du Développement et de l'Aménagement durables (ex Ministère de la Transition écologique et solidaire)	Volet relatif à la sécurité d'approvisionnement et au développement des infrastructures et de la flexibilité du système énergétique		https://www.ecologique-solidaire.gouv.fr/sites/default/files/Volets%20S%C3%A9curit%C3%A9%20d'approvisionnement%20-%20infrastructures.pdf
FR-DI41	Document from the Ministère de l'Ecologie, du Développement et de l'Aménagement durables (ex Ministère de la Transition écologique et solidaire) / Conseil économique pour le développement durable	La gestion des infrastructures de réseaux		https://www.ecologique-solidaire.gouv.fr/sites/default/files/CEDD%20-%20La%20gestion%20des%20infrastructures%20de%20r%C3%A9seaux.pdf
FR-DI42	Ministry document	National action plan for the promotion of renewable energies 2009-2020		https://ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans

10.4.2. Appendix D2: Details of the UK and French policy instruments that ensure electricity supply continuity and reliability

Appendix D2-1: The UK policy instruments to ensure the continuity and reliability of electricity supply and government planning time horizons (non-exhaustive)

Table 10-7: UK policy instruments to ensure the continuity and reliability of electricity supply and government planning time horizons (list non-exhaustive)

Government planning timeline / *Type*	**Unknown/ Not clear**	**Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline**	**Review within the next 4 years**	**Review within the next 4-8years**	**Review after 9 years or more**
Regulative		Compulsory Oil Stocking Obligations	Balancing and Settlement Code (Industry Electricity Code)	Reporting under the Climate Change Act 2008/ UK Adaptation Reporting Power (First round compulsory, second round voluntary)	
Regulative		Electricity Generation Licence: Standard conditions (last version in 2017)	Annual reporting by the Gas and Electricity Markets Authority on security of electricity supply under the Energy Act 2011 (since 2012)	Network Output Measures (NOMs)	
Regulative		Grid Code (Industry Electricity Code) (brought in in the early 1990s)			
Regulative		Connection and Use of System Code (Industry Electricity Code)			
Regulative		Distribution Code (Industry Electricity Code)			

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Regulative		System Operator – Transmission Owner Code (Industry Electricity Code)			
Regulative		Distribution and Connection Use of System Agreement (DCUSA) - version 9.4 2017			
Regulative		Electricity (Connection Standards of Performance) Regulations 2015			
Regulative		Electricity Distribution Licence (last version in 2017)			
Regulative		Electricity Safety, Quality and Continuity Regulations 2002 and the Electricity Safety, Quality and Continuity (Amendment) Regulations 2006 and Electricity Safety, Quality and Continuity (Amendment) Regulations 2009 (ESQCR)			

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Regulative		Electricity Supply Emergency Code (ESEC) (2015)			
Regulative		Electricity Transmission Standard Licence Conditions (last version in 2017)			
Regulative		Fuel Security Code 2007 (FSC)			
Regulative		National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) (last version in 2017)			
Regulative		Supply licences			
Regulative		Connection and Use of System Code (CUSC) (brought into effect in 2001)			
Regulative		System Operator - Transmission Operator Code (STC) (Implemented in 2005)			

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Regulative		The Electricity (Standards of Performance) Regulations 2015			
Financial	Fees for services provided for energy resilience purposes (Energy Act 2013 Article 148)	Financial penalties when failure to comply with conditions of a licence	Electricity Market Reform (EMR) / Capacity Market (Amendment) Rules 2017)	Electricity Market Reform (EMR) / Contracts for Difference (CFD): The first round; October 2014 to March 2015 for project to 2026; The second round opened in April 2017 for project in 2021/22)	Electricity Market Reform (EMR) / Contracts for Difference (CFD): The first round: October 2014 to March 2015 for project to 2026; The second round opened in April 2017 for project in 2021/22)
Financial	Funding under the UK Green Investment Bank (created in 2012)	Quality of Service Guaranteed Standards	Feed in Tariffs (FITs) (The Renewables Obligation (RO) is one of the main support mechanisms for large-scale renewable electricity projects in the UK. Smaller scale generation is mainly supported through the Feed-In Tariffs (FIT scheme) / open until 2019))	Network Innovation Allowance (NIA) (Started 2015)	
Financial			Network Innovation Competition	The Innovation Roll-out Mechanism (IRM)	

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Financial			Renewables Obligation (RO) (support mechanisms for large-scale renewable electricity projects in the UK / The RO will close to all new generating capacity of any technology on 31 March 2017)	RIIO (Revenue = Incentives+Innovation+Outputs) / RIIO-T1	
Financial				RIIO (Revenue=Incentives+Innovation+Outputs) / RIIO-ED1	
Procedural	DECC Energy Security Strategy (2012)	National Policy Statements for energy infrastructure (2011)	National Emergency Plan: Downstream Gas and Electricity 2016	National Adaptation Programme (NAP) (2013) / Climate Change Risk Assessment (2012 / 2017)	National Renewable Energy Action Plan for the UK (2010-2020)
Procedural			BEIS/Ofgem's joint annual 'Statutory Security of Supply Report 2016		2011 White Paper: Planning our Electric Future: a White Paper for secure, affordable and low-carbon electricity (looking to 2030) and the December 2011 technical update to it

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Procedural			National Grid's Winter Outlook Report		
Procedural			Energy Emergencies Executive Committee (E3C) / Electricity Task Group (ETG)		
Procedural			Electricity Ten Year Statement (first published in 2012; latest version 2016)		
Cooperative	ENA ETR 138 (Energy Network Association (ENA)'s Engineering Technical Report (ETR) 138): Electricity Substation Resilience to Flooding (Issue 1 October 2009)	Electricity companies consultation before guidance on different matters is issued from the Secretary of State (for Energy & CC) or the Gas and Electricity Markets Authority – (GEMA)	National Risk Assessment (NRA) / National Risk Register of Civil Emergencies		

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Cooperative	ENA ETR132 'Improving Network Performance under Abnormal Weather Conditions by Use of a Risk-Based Approach to Vegetation Management Near Electric Overhead Lines' [dated March 2006]	Electricity Networks and Futures Group (ENFG)	Electricity Networks Strategy Group (ENSG)		
Cooperative	ENA TS 43-8 'Overhead Line Clearances' [Issue 3, 2004] in relation to clearances from lines to trees and other vegetation for all lines	Emergency Planning Managers Forum (EPMF)	Risk Documents published by Emergency Planning Managers' Forum (EPMF) for briefing Local Resilience Forums (LRFs).		
Cooperative	Energy Systems Catapult (since 2015)	Exercise Hopkinson (one-day emergency response workshop organised by DECC)			
Cooperative		Infrastructure operators adaptation forum (IOAF) (first dialogue in 2014)			
Cooperative		Infrastructure Security and Resilience Industry Forum (ISRIF)			

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Cooperative		Local Resilience Forums (LRFs)			
Cooperative		NEWSAC Mutual Aid Agreement			
Cooperative		Overhead Line Resilience (ETR132 Working Group)			
Cooperative		Electricity Networks and Futures Group (ENFG)			
Cooperative		Substation Flooding Resilience (ETR 138 Working Group)			
Persuasive			Voluntary disclosing of climate risks e.g. the Carbon Disclosure Project		
Persuasive			ISO 14000, ISO 26000, ISO/TC 207/SC 7, ISO 31000		

Appendix D2-2: French policy instruments to ensure the continuity and reliability of electricity supply and government planning time horizons (non-exhaustive)

Table 10-8: French policy instruments to ensure the continuity and reliability of electricity supply and government planning time horizons (list non-exhaustive)

Government planning timeline / *Type*	**Unknown/ Not clear**	**Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline**	**Review within the next 4 years**	**Review within the next 4-8years**	**Review after 9 years or more**
Regulative		Autorisation d'exploiter des installations de production d'électricité / Licences to produce electricity	Analyse équilibre offre/demande d'électricité (adequacy analysis for the following winter or the following summer)	Programmation Pluriannuelle de l'Énergie (PPE) (multi-year energy plan) (2016-2018) (2019-2023) and then 2 successive 5 year periods (2024-2034)	Concession du réseau public de transport d'électricité (Concession type specifications for the public transmission system)
Regulative		Certification par la Commission de Régulation de l'Énergie (CRE) et la Commission Européenne (Certification according to a process associating the CRE and the European Commission)	Audits/ controles economiques et financiers par l'Etat / (Audits and financial and economics controls by the State)	Mécanisme de capacité / garanties de capacité (aussi appele certificats de capacité) (Capacity guarantees)	ENEDIS (ex ERDF since 31 May 2016) Plan Aléas Climatiques (PAC) (2006-2016) (ENEDIS climate plan)
Regulative		Contrat de service public entre l'État et EDF (Contract of public service between EDF and the French State)	Bilan electrique national (National Annual Electric Balance)		Energy Transition for Green Growth Act (Loi relative à la transition énergétique pour la croissance verte, LTECV)

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Regulative		Litiges (litigation actions in case of no compliance to various regulations)	Fonds de péréquation de l'électricité (Electricity Equalisation Fund)		Programmation Pluriannuelle des Investissements d'électricité (PPI, pluriannual programming of investments) (2009-2020) (Arrêté du 7 juillet 2006 relatif à la programmation pluriannuelle des investissements de production d'électricité)
Regulative		Mesures temporaires de sauvegarde prises par le ministre chargé de l'énergie (e.g. octroi ou suspension des autorisations d'exploiter des installations de production d'électricité) (Specific regulatory measures decided by the government or energy minister in case of energy shortage (re-allocation of energy, suspension of energy use etc.))	Plan stratégique d'EDF (i.e. Cap2030) (Strategic Plan produced by any electricity producer responsible for at least a third of the national electricity production		Schéma décennal de développement de réseau (10 year network development plan) (the new forthcoming version is under consultation in December 2016)

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Regulative		Sanctions penales en cas de manquements au Code de l'energie (Penal penalties for breaches of the Energy Code)	Renouvellement des concessions hydrauliques (Renewal of concessions for hydropower facilities)		Bilan prévisionnel de l'équilibre offre-demande d'électricité de RTE (forecast supply balance or adequacy outlook)
Regulative			Bilan prévisionnel de l'équilibre offre-demande d'électricité de RTE (forecast supply balance or adequacy outlook)		RTE annual 10 year electricity transmission system development plan (RTE prepares a yearly plan for the following 10 years at a national level, which is reviewed by CRE (and its annual investments are approved by CRE).)

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Regulative			RTE annual 10 year electricity transmission system development plan (Schéma décennal de développement du réseau à 10 ans; RTE prepares a yearly plan for the following 10 years at a national level, which is reviewed by CRE (and its annual investments are approved by CRE).)		Programmation Pluriannuelle de l'Énergie (PPE) (multi-year energy plan) (2016-2018) (2019-2023) and then 2 successive 5 year periods (2024-2034)
Regulative			Programmation Pluriannuelle de l'Énergie (PPE) (multi-year energy plan) (2016-2018) (2019-2023) and then 2 successive 5 year periods (2024-2034)		Mécanisme de capacité / garanties de capacité (aussi appele certificats de capacité) (Capacity guarantees)
Regulative			Mécanisme de capacité / garanties de capacité (aussi appele certificats de capacité) (Capacity guarantees)		

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Financial		Appels d’offres (Tendering procedure which may be initiated by the Minister for Energy when production capacities do not meet the targets of the multi-year energy plan)	Complément de rémunération (feed-in premium for renewables)		Programme d’Investissements d’Avenir (PIA) – (Investments for the Future Programme)
Financial		Effacement de consommation électrique (electricity load shedding)	Contribution au service public de l'électricité (CSPE) (contribution to electricity public services		
Financial		Obligation d’achat de l’électricité produite à partir des énergies renouvelables (Obligation to purchase green electricity) (will be replaced by another mechanism called complément de remuneration or additional remuneration regime)	La Taxe intérieure sur la consommation finale d’électricité (TICFE)		

Government planning timeline *Type*	Unknown/ Not clear	Ad hoc, when needed / on-going until revoked / under constant review but with no clear timeline	Review within the next 4 years	Review within the next 4-8years	Review after 9 years or more
Financial		Sanctions financieres en cas de manquements au Code de l'energie (Financial penalties for breaches of the Energy Code)	Tarif d'Utilisation des Réseaux Publics de transport et de distribution d'Électricité (TURPE) (Tariffs for Using the Public Electricity		
Financial			Transmission and Distribution Networks)		
Procedural		Plan de Prévention des Risques Naturels (PPRN) (natural risk prevention plan)		Plan national d'adaptation de la France aux effets du changement climatique 2011 – 2015 (National Adaptation Plan)	National action plan for the promotion of renewable energies 2009-2020
Cooperative		Entreprise pour l'Environnement (EpE)			
Persuasive			ISO 14000, ISO 26000, ISO/TC 207/SC 7, ISO 31000		
Persuasive			Voluntary disclosing of climate risks e.g. the Carbon Disclosure Project		