ACROSS SCALES IN ENERGY DECISION-MAKING (ASCEND)

LITERATURE REVIEW

Decarbonisation strategies based on whole energy system analysis are critical in the transition to a low carbon economy. Energy systems integration is attracting increasing interest across the organisational landscape of decision-making as scenarios show how electricity, heat and transport systems are likely to become even more interlinked in the future. This results from changes in technologies, governance arrangements and societal values, practices and requirements.

The ASCEND scoping study, funded by EPSRC and the Energy Systems Catapult (EP/R002231/1), sets out to analyse how whole energy system analysis is currently used in decision-making processes across scales, and identify ways in which the research - policy - decision-making relationship could be improved in the future.[1]

INTRODUCTION

Facilitating collective action is a central theme in a variety of research areas including public management, organisational studies, climate change and sustainability transitions, and evidence-informed decision-making. All of these fields are relevant to whole energy systems governance. The literature review presents an overview of the existing literature from the above-mentioned research areas. It is a first step towards developing an interdisciplinary knowledge base for addressing the problems arising from the tension between the current fragmented institutional landscape, and the requirements for successful integrated energy systems management. By doing so, it provides the basis for our research agenda which sets out the following objectives:

1. Describing how model linkages across scales could be improved, taking into account modelling and policy making processes;
2. Identifying opportunities and making recommendations for improved exchange and collaboration between actors and the methods for such engagement, which will lead to better informed decision-making;

[1] See https://www.birmingham.ac.uk/ASCEND.

3. Bringing mutual awareness among key stakeholders of the challenges and opportunities for whole-system modelling to support decision-making across scales in the UK;
4. Identifying where future research could be directed to have a wider impact on whole energy system change.

1. THE ORGANISATIONAL CONTEXT

1.1 Theory overview

1.1.1 Origins of fragmentation: Public sector reforms and the emergence of 'governance'

The idea that the policy making process in real-life situations cannot and indeed isn't controlled by the state as a monolithic entity, interest or actor started to emerge from the 1960's in the United States and the United Kingdom (Blanco et al., 2011; Bevir, 2011). Based on this polycentric perspective, a range of theories (rational choice, principal-agent theory and institutional and organizational theory and so on) were developed which placed more emphasis on the complex processes and interactions in policy making questioning the legitimacy of traditional interpretations on the functioning of bureaucratic hierarchies.

Such theories provided the backdrop for public sector reforms taking place from as early as the 1970's. The view that the welfare state has become overloaded and thus ineffective in handling global economic issues in the face of various waves of economic crises has become the dominant position among public administration scholars as well as practitioners of the era (Pollitt and Bouckaert, 2011). To respond to the emerging new challenges, the public sector was to be made more cost-effective and responsive to citizens' needs through the adoption of techniques borrowed from the market sector (Pollitt, 1990). The subsequent reorganisation of the state in many Western democracies later became known as the New Public Management (NPM; Pollitt and Bouckaert, 2004). The United Kingdom, along with the United States, was pioneering the NPM agenda. On the practical level, the NPM concept was translated into a toolbox of specific techniques, summarised by Pollitt and Bouckaert (2011) as follows: performance-oriented evaluation of service provision through output measurement and KPIs; organisational structure made up of small, specialised units; contracting out public services so that the state could focus on a smaller number of core functions, resulting in less hierarchical and authority-based coordination; introduction of market-type mechanisms to the public sector, such as competitive tendering, league tables, quality management and performance-related salaries for public officers; and the reconceptualization of service users / citizens as 'customers'.

By the 1990's it became clear that the reforms which intended to rationalise public policy making and implementation in order to enhance efficiency and effectiveness, ultimately resulted in a landscape of organisational fragmentation on an unprecedented scale. Fragmentation arising from

1. specialisation within public sector organisations;
2. the wide-spread contracting out of public services to arm's length bodies or agencies;
3. the demolition of public monopolies and opening up the playing field to market competition and
4. the privatisation of public assets

caused coordination problems (Head and Alford, 2013; Van de Walle and Hammerschmid, 2011; Dunleavy et al., 2005; Hood and Peters, 2004) as well as issues related to accountability (Osborne and Ball, 2010; Behn, 1998) and democratic quality (Drechsler, 2005; Box et al., 2001).

Efforts made to tackle some of the shortcomings of NPM, and as a result of acknowledging the related unintended consequences, led to the development of concepts such as 'governance' (Bevir, 2011), 'partnerships' (Miller and Ahmad, 2000), 'joined-up government' (Ling, 2002), 'whole of government' (Christensen and Lægreid, 2007) and so on. Moreover, increased the influence of non-governmental actors in public decision making and paved the way to a more strategic, 'steering' interpretation of public authority in most Western democracies (Osborne, 2010). Parallel to the changes taking place in practice, the focus of public administration research shifted to emphasise the complex processes and interactions involved in contemporary policy making, generating interest in the formulation, operation and management of networks involved in public policy making, implementation and service delivery.

1.1.2 Counteracting fragmentation: The network perspective

The concepts of 'networks' and 'governance' have been used in a variety of research contexts. In public policy and administration, 'governance networks' refer to a set of actors (public or private) involved in public policy making, implementation or service delivery (Torfing, 2005). The term 'governance' represents a shift from understanding decision-making as unicentric and based on hierarchical relationships ('governing') to a more pluricentric view where authority and powers are perceived to be dispersed between a variety of actors both from the public and private spheres. The network itself is a pattern of relationships between interacting actors (usually organisations), shaped and held together by mutual interdependency (Klijn and Koppenjan, 2012). 'Network governance' is then understood as a social coordination mechanism in which network relationships (collaboration patterns) gain prominence in the formulation of outcomes (Klijn and Skelcher, 2007).

The emergence of the network governance concept is attributed to an increasing recognition both in academia and in practice that neither the traditional bureaucratic hierarchies nor market-type mechanisms are adequate to deal with contemporary complex problems (Klijn and Koppenjan, 2015; Provan and Kenis, 2008; Duit and Galaz, 2008). In contrast to hierarchies and markets, networks are praised for creating space for interaction and multi-sectoral co-operation between various organisations; for facilitating informed decision-making based on knowledge exchange and deliberation between stakeholders; and for building engagement to achieve the negotiated goals. By doing so, network processes contribute to reducing uncertainties surrounding complex problems arising from the following issues characteristic of the present-time governance context (Koppenjan and Klijn, 2004).

1. Contemporary decision making involves multiple actors both from the public and private sector involved in various policy arenas as a result of organisational fragmentation and decentralisation (strategic uncertainty).
2. Stakeholders' understanding of the nature of the problems, the goals to be achieved and consequently the actions to be taken shows divergence (substantive uncertainty).
3. Roles and rules in the decision-making process are unclear, creating dynamic relationships and blurring boundaries between the public and private sector (institutional uncertainty).

'Fragmentation' is a central concept in the network governance literature and it is considered along multiple dimensions. First, vertically: in terms of authority dispersion between various levels of government. Second, horizontally: resulting from increased specialisation of functions, sectors and expertise (Klijn and Koppenjan, 2012, 2015). Complex problems arising in this multilevel governance context (Hooghe and Marks, 2001) do not match neatly with government scales and require joint action in various domains. Consequently, networks of collaboration are expected to emerge either organically, or are established by government or other leading organisations as coordination mechanisms to deal with uncertainties and complexity. This aspect emphasises the importance of resource dependency between actors with different levels and forms of authority, responsibility, and potential who operate at and between various geographical and organisational scales (Marks and Hooghe, 2003). Decision-making processes in multiactor settings are themselves complex and combine elements of deliberation as well as bargaining (Klijn and Koppenjan, 2015). In the absence of universally accepted problem definitions and goals related to complex policy problems, network actors' own frames of reference influence not only the formulation of solutions, but also the common problem definition (Klijn and Koppenjan, 2015). Negotiations within the networks in different stages of the collaboration process, in turn, affect actors' frames of reference and their associated strategies. Consequently, besides the existing resource dependency relationships external to the process, actors' relationships to each other and to the outcomes of the negotiation processes are also influenced by the nature and quality of interactions taking place in the networks.

1.1.3 Managing complex problems via network governance

Network governance is increasingly seen as the the 'best fit' in dealing with complex problems (Klijn and Koppenjan, 2015; Provan and Kenis, 2008; Duit and Galaz, 2008). However, the effectiveness of networks in the 'real life' depends on the extent to which they contribute to the reduction of the different types of uncertainties (substantive, strategic and institutional) resulting from complexity. In other words, meaningful networking processes must facilitate cognitive, strategic and institutional learning (Koppenjan and Klijn, 2004). Interaction between the various actors is therefore necessary if joint action is to be achieved: as Koppenjan and Klijn (2004:10) argue,

'[i]nteraction processes are considered to be searches wherein public and private parties from different organisations, levels of government and networks jointly learn about the nature of the problem, look at the possibility of doing something about it, and identify the characteristics of the strategic and institutional context within which the problem solving develops'.

They then go on to conclude that in most cases cooperation and learning behaviour does not emerge organically. Instead, it has to be facilitated and 'steered' through 'network management' (Klijn and Koppenjan, 2015; Klijn, 2008; Bueren et al., 2003; Gage et al, 1990). Network management is described as an intermediation process between participating actors with the aim of managing

1. substantive uncertainty related to content;
2. strategic uncertainty related to process and
3. institutional uncertainty related to a broader interpretation of institutions including formal and informal practices, techniques and procedures (Klijn and Koppenjan, 2015; Koppenjan and Klijn; 2004).

In terms of substantive uncertainty, this entails raising awareness about the plurality of perceptions and preferences; facilitating the consideration of a wide range of options through a deliberative process; and joint image building (Klijn and Koppenjan, 2015). Strategies to manage uncertainty related to the network process (strategic dimension) include the management of interactions through designing new interaction patterns or re-designing the existing ones (connecting and disconnecting actors or decision-making arenas); changing the 'rules of the game' (interpreted as factors exogenous to the networking process which have an impact on it); and enhancing the quality of interactions (Koppenjan and Klijn, 2004). Enhanced interaction; the promotion of institutional link creating between actors, sectors and domains; and recalibrating interdependencies between actors with the aim of changing resource allocation may help to manage institutional uncertainties (Koppenjan and Klijn, 2004).

1.2 Case: Networks of energy policy making in the UK

1.2.1 The UK energy and heat policy context

In this section an outline mapping of the policy documents, recommendations and strategies is presented which are relevant to energy transition in the United Kingdom on the sub-national, national and supra-national levels (see Table 1.2).

SCALE	NAME	YEAR	OBJECTIVE
European Union	2020 Climate & Energy Package	2009	The package sets three key targets: • 20% cut in greenhouse gas emissions (from 1990 levels); • 20% of EU energy from renewables; • 20% improvement in energy efficiency.
	EU Emissions Trading System (EU ETS) and National Emission Reduction Targets	2005	ETS covers large-scale facilities in the power and industry sectors, as well as the aviation. National Emission Reduction Targets cover sectors not included in the ETS (housing, agriculture, waste, transport exc. aviation); based on annual binding targets until 2020.
	Renewable Energy Directive	2009	Established an overall policy for the production and promotion of energy from renewable sources in the EU in order to achieve the 20% clean energy target by 2020.
	Energy Efficiency Directive	2012	Established a set of binding measures to help the EU reach its 20% energy efficiency target by 2020.
	CHP Directive	2004	Promotes the use of cogeneration in order to increase the energy efficiency and improve the security of supply of energy.
	2030 Climate Framework	2014	Contains a binding target to cut emissions in EU territory by at least 40% below 1990 levels by 2030.
United Kingdom	Climate Change Act	2008	Set out a binding target for carbon emissions reduction of 80% by 2050 (compared to 1990 baseline). Provided a framework for a system of five-yearly carbon budgets which introduce interim targets and recommend associated actions to achieve these.

United Kingdom	Energy White Paper	2007	Building on previous work (Energy Review 2006), the White Paper set out the priorities for future development of energy systems in a wider framework of carbon emissions reduction (60% by 2050) which include (1) energy security and reliability of supply; (2) clean and sustainable energy supply through appropriately designed market competition; and affordable energy supply to all.
	Low Carbon Transition Plans (Carbon Budgets)	2009 2011 2016	Five-yearly carbon budgets based on the recommendations prepared by the Committee on Climate Change (CCC). Interim targets were set to 23% by 2012; 29% by 2017; 35% by 2022; 50% by 2027; and 57% by 2032.
	Heat Strategy Framework	2012	Acknowledged that to meet the 2050 carbon reduction target emissions from buildings must be reduced to near zero and by 70% from industry, and that transition at this scale will imply a complete reorganisation of both domestic and industrial heat supply.
	Heat Strategy Action Plan	2013	Provided a systematic overview of the challenges of different heating requirements in a variety of sectors (industrial heat; heat networks; heating and cooling in buildings; grid and infrastructure).
	Clean Growth Strategy	2017	The strategy set out the opportunities to simultaneously achieve income growth and reduce carbon emissions in the UK through providing clean energy at an affordable price.
Scotland	Climate Change Act	2009	Created the statutory framework for greenhouse gas emissions reductions in Scotland by setting an interim 42 per cent reduction target for 2020, with the power for this to be varied based on expert advice, and an 80 per cent reduction target for 2050 (corresponding to the central UK target).
	Climate Change Bill	Forthcoming	Considers reduction targets of 80% and 90% by 2050 and related scenarios, based on the recommendations of the Committee on Climate Change.
	Draft Climate Change Plan	2017	Sets out the path to a low carbon economy while helping to deliver sustainable economic growth and secure the wider benefits to a greener, fairer and healthier Scotland in 2032
	Scottish Energy Strategy: The Future of Energy in Scotland	2017	Scotland's first Energy Strategy sets out the Scottish Government's vision for the future energy system in Scotland. It articulates six energy priorities for a whole-system approach that considers both the use and the supply of energy for heat, power and transport.

Birmingham	Big City Plan	2011	The Plan set out the strategy, priorities and regulatory frameworks for the transformational regeneration of Birmingham city centre to support 'sustainable growth'.
	Sustainable Energy Action Plan	2009	The SEAP was prepared as part of the process of joining the Covenant of Mayors. It expressed a strategy of meeting the 20-20-20 target required by the CoM and set a long-term carbon reduction target (60% by 2026) as well as an interim target (42% by 2020 based on 2005 data).
	Birmingham Energy Strategy – 'Common Evidence Base' and 'Strategic Issues and Options'	2010	Intended to provide a draft framework and common evidence base for the development of strategic leadership in the field of energy.
	Carbon Roadmap	2013	The Roadmap provides a framework for achieving Birmingham's (modified) 60% carbon reduction target by 2027 through active stakeholder involvement and concerted action along the following core themes: green growth; buildings and efficiency; energy and resources; transport and mobility; natural capital and adaptation.
Leeds	Leeds' Climate Change Strategy	2009	Expressed clear set of priorities to tackle the causes and impact of climate change in Leeds.
	Energy Policy and the Sustainable Energy Action Plan	2015 (?)	Set out a carbon reduction target of 40% by 2020 using a 2008/09 baseline. The Energy Policy's key objectives help to underline all planning and strategic activities and to clarify the goals of our energy policy
	Leeds Affordable Warmth Strategy	2007 (?)	Set out a strategy (updated in 2011 and 2017) for improving energy efficiency in buildings.
	Supplementary Planning Document (SPD) Building for Tomorrow Today	2011	Provided practical guidance for design and construction projects within Leeds aiming to achieve the highest possible levels of sustainability to support the city in achieving it's social, economic and environmental goals.

Table 1.2 Policy documents, strategies and recommendations influencing energy decision-making on different levels

1.2.2 Fragmentation within and across scales, sectors and organisations

The energy sector in the United Kingdom is highly centralised despite the importance of regional and local energy systems in the past (Winskel, 2015). Hundreds of previously separately operating private and municipal electricity and gas companies got initially consolidated into area boards in the 1920's, and later centralised and nationalised in the post-war period (Hannah, 1982). Market competition was introduced in the 1980's as part of the wave of industry liberalisation and privatisation of public assets by the Thatcher government. The adopted market rules, regulatory approach and policy priorities have been identified as barriers to the development of a decentralised energy infrastructure (Watson and Devine-Wright, 2011). As a result, energy markets have become dominated by a handful of supply companies (i.e. the 'Big Six'), owned primarily by international corporations (Hawkey et al., 2013). More recently, with the development and spread of distributed generation technologies the landscape is changing. However, progress is slow and over 70% of the country's heat demand is still met by natural gas through the centralised gas network (HM Government, 2013b). Cities such as Aberdeen, Bristol, London, Birmingham and Nottingham pioneered decentralised energy schemes across the UK; however, the share of local heat generation is still under 10% (Carbon Trust, 2013).

Policy making

The primary policy making role in the energy sector is performed by the Department for Business, Energy & Industrial Strategy (BEIS) which was created by the May government in 2016 through the merger between the Department of Energy and Climate Change (DECC) and the Department for Business, Innovation and Skills (BIS). Energy policies and legislation as well as the carbon budgets are informed by a series of yearly reports and recommendations produced by the Committee on Climate Change (CCC) established under the Climate Change Act 2008.

Regulation and operation

Energy markets are regulated on the central level by the 'Gas and Electricity Markets Authority' (GEMA) which oversees the work of the 'Office of Gas and Electricity Markets' (Ofgem)` and provides strategic direction. Day-to-day administrative tasks are delegated to Ofgem. Ofgem is a non-ministerial department within UK government, responsible for overseeing the everyday functioning of the UK energy market and for the protection of consumer rights by promoting and safeguarding market competition (Hassan and Majumder-Russell, 2014).

Operation, maintenance and improvement of the energy transmission systems (gas and electricity) is assigned to a single TSO (transmission system operator), National Grid Electricity Plc as natural monopoly on the level of Great Britain. National Grid is a private limited company owned by its shareholders. The regional electricity distribution networks are operated by 14 licenced DNOs (Distribution Network Operators) owned by six groups. Both the transmission and distribution networks are natural monopolies and therefore are regulated by Ofgem, in order to avoid potential abuse of monopoly power. The buying and selling of electricity is organised within the frames of competitive wholesale and retail electricity markets consisting of suppliers, generators, traders and consumers. Electricity supply companies are the central players in the market: they buy electricity from the wholesale market or directly from generators; arrange it to be delivered to consumers; set end user prices for unit of electricity and sell electricity to consumers. Electricity supply in the UK is dominated by the ‘Big Six’ (British Gas, EDF Energy, E-ON, npower, Scottish Power, SSE), the six largest and oldest energy supply companies.

The gas transmission system (NTS – National Transmission System) is owned and operated by National Grid Gas Plc as a natural monopoly. As in the case of electricity markets, National Grid is not involved in buying or selling gas. Regional distribution systems connect the high pressure NTS with end users and reduce the pressure in the pipes. There are eight regional distribution systems in operation, four of which are owned by National Grid. The gas markets, such as the electricity markets, have been privatised in the 1990’s. The gas market consists of producers, shippers, traders and suppliers. Licensed shippers buy gas from production companies (or importers) and are responsible for transporting gas between the production site and supply points to the National Transmission System. Shippers own the gas flowing through the transmission and distribution systems and pay fees to National Grid for the right to use the NTS. Gas supply companies buy gas for their customers from gas shippers, either through the wholesale market or directly. Just as in the case of electricity, the gas market is also dominated by the ‘Big Six’ energy supply companies.

Competence assigned to the devolved administration in Scotland

Energy matters are largely reserved under the Scotland Act 1998, and the Department for Business, Energy and Industrial Strategy is responsible for UK Energy Policy. However, the Scottish Government has responsibility for the promotion of renewable energy generation, energy efficiency, and the consenting of electricity generation and transmission development (Scottish Government, 2017a). It also has responsibility for the environmental impacts of energy infrastructure through planning controls. In addition, Scotland has a part to play in helping the UK meet global and European climate change targets (Scottish Government, 2017b).

Whilst thermal generation is reserved, planning consent is devolved; therefore, applications to build and operate power stations and to install overhead power lines are made to Scottish Ministers. Applications are considered where they are: for electricity generating stations in excess of 50 MW and for overhead power lines and associated infrastructure, as well as large gas and oil pipelines. Applications cover new developments as well as modifications to existing developments. For developments below these thresholds, applications are made to the relevant local planning authority. For marine energy (e.g. wave, tidal and offshore wind), applications are made to Marine Scotland.

The Scotland Act 2016 devolves further powers in relation to energy; including the management of licences to exploit onshore oil and gas resources in Scotland, and powers over supplier obligations regarding energy efficiency to the Scottish Government. There is also a consultative role for the Scottish Government and Parliament regarding renewables incentives. These powers have not yet been commenced, and will be by order of the Secretary of State for Scotland in due course – it is probable that secondary legislation for these powers would come before the Scottish Parliament's Economy, Jobs and Fair Work Committee.

The role of local governments

Due to the nationalisation and subsequent liberalisation of energy markets, local governments have not had a role in energy supply since the 1940’s. This situation started to change recently, due to the spread of decentralised energy technologies on the one hand, and the ongoing devolution agenda of the UK Central Government on the other. Devolution deals between the Government and Combined Authorities may, in the upcoming years, provide opportunities for local governments to establish themselves as key players in the local energy supply, i.e. through municipal companies or ESCOs (Energy Services Company). Their growing influence is particularly important in the heat sector, due to the territorial anchor of heat infrastructure, such as heat and power cogeneration and district heating networks.

A high-level mapping of key actors (organisations) operating within the multilevel context of energy governance, with a specific focus on heat, will be developed as part of the ASCEND project.

2. EVIDENCE-INFORMED POLICY MAKING

2.1 Theory overview

2.1.1 The use of evidence in policy making

Evidence-based policy making, based on the evaluation of scientific information has been dominating governments’ agendas in Western liberal democracies for decades (Mulgan et al., 2005; Stone, 2002; Hammond et al., 1983). The ever-increasing demand for knowledge has been driven by positive experiences in the past (e.g. with regards to economic development based on forecasting) societal changes (e.g. the rise of an educated, knowledgeable and active citizenry), changes in the political culture (e.g. to rationalise policy making and increase transparency) and structure (e.g. performance assessments of governments and policies prepared by international bodies such as the EU or the OECD; Mulgan et al., 2005). Consequently, public sector organisations involved in the policy making process devote significant financial resources to the production and analysis of relevant scientific information and advice (Stone, 2002). 'Policy formulation tools' (Turnpenny et al., 2015:4) are being developed in various domains to address tasks related to various phases of the decision-making process. Different types of tools may be used for

1. the collection of relevant data;
2. problem framing and structuring;
3. forecasting, foresight and scenario building and
4. recommending policy options based on impact assessment (Turnpenny et al., 2015; Dunn, 2015).

Examples of such tools and techniques used in the various stages of the policy making process are presented in Table 2.1.

Policy process phase	**Expected policy relevant information**	**Examples of tools**
Data collection	Baseline information	• Indicators (social, environmental, economic or topic-relevant) • Survey data • Statistical data
Problem framing and structuring	Information related to causational connections	• GIS (geographical information systems) • Mapping tools • Expert evidence (previous research)
	Evidence related to values and perceptions based on participation	• Brainstorming • Stakeholder workshops, focus groups • Opinion polls • Decision theatres
Definition of objectives	Envisioning desired future states and related pathways	• Scenario analysis

Options assessment and recommendations	Comparative assessment of different options and their impacts	• Cost-benefit analysis • Risk-benefit analysis • Multicriteria analysis
	Assessment based on past and possible future trends	• Economic forecasting • Delphi technique • Multi-agent simulations • Computerised models

Table 2.2. Overview of tools used in different stages of the policy making process (based on Turnpenny et al., 2015)

The benefits of the use of scientific evidence to inform policy making has been consistently questioned by a number of scholars (Sanderson, 2009; 2002; Hammond et al., 1983). The main criticism stems from the assertion that very little is known about the practical usefulness of this approach. Rather, commentators point to the common observation in empirical research that, although the collection and analysis of relevant information contributes to the reduction of uncertainty with regards to certain aspects of the policy problem in question, it simultaneously creates space for uncertainty with regards to others (Sanderson, 2009; Weingart, 1999). Moreover, there are limits to the information that can be collected in terms of its adequacy, validity and accurateness regarding any policy issue. In reality, (rational) judgement based on the analysis of available evidence is only one of the many factor influencing policy decisions – political expediency, restricted time frames and budgets, the perceptions, ideas and competency of the actors involved in the decision-making process, as well as many other 'practical' factors also shape the outcomes (Nagorny-Koring and Nochta, 2018). As Head (2008:9) puts it

'*Policy decisions are not deduced primarily from facts and empirical models, but from politics, judgement and debate. Policy domains are inherently marked by the interplay of facts, norms and desired actions*.'

However, governments and public-sector bodies (due, but not restricted, to the reasons mentioned in the beginning of this section) will certainly continue to demand analysis and scientific advice on how better decisions can be made. Thus, it is important to investigate not just the role of evidence in policy making in various domains, but also the ways in which it is used by policy makers to arrive to decisions.

2.1.2 The research-policy nexus

In addition to the complexity generated by the multiplicity of actors involved in the public policy making process and their interactions, the practice of evidence-based (or evidence-informed) decision-making opens up the process to researchers, analysts, scientific advisors and so on, creating a rather problematic interface between research and practice (Hoppe, 2005). This is, at least partly, due to the differences in terms of perceptions, objectives, frames of reference and techniques and practices between the public sector and academia. This situation often results in generating uncertainty and ambiguity about the value or relevance of research for policy makers (Stone, 2002:286). Nevertheless, through providing evidence on which decisions can be based, researcher enter the multiactor and multilevel context of decision-making. This issue is particularly relevant to decision-making about energy systems development (Stratchan et al, 2009).

2.1.3 The use of computer models in policy making

The use of computerised models to aid policy making has been rising steadily since the mid-20th century (Therond et al., 2009). In recent decades, the growing appreciation of complexity in relation to social coordination (and the functioning of society in general) has been paired with a surge in the need to reduce uncertainty around the formulation of public policy. Increasingly complicated computerised models -made possible by the sharp advancement in computation technologies- provide a potential (albeit partial; see Section 3) solution to this problem (van Ittersum and Sterk, 2015). Models aim to aid decision-making by building an understanding of possible future states of complex systems (such as healthcare, financial markets or energy supply) through integrating different types of knowledge from a variety of sources and disciplines to cope with uncertainty (‘*integrative assessment*’). By doing so, they offer a framework to highlight differences in impact, as well as trade-offs, between available policy options (‘*impact assessment’*) (Therond et al., 2009; Toth, 2003; Harris, 2002). In conceptual terms, van Ittersum and Sterk (2015) distinguishes between two contrasting approaches in dealing with future development of the systems under analysis: predictive (projective) and normative. The predictive approach aims to ‘predict’ the impact of various policy options in the basis of system evolution and offers forecast (i.e. a single alternative in case the process shows low uncertainty and high predictability on the basis of available data) or foresight (i.e. multiple possible alternatives if uncertainty rises and predictability falls). In contrast, the normative (explorative) approach takes a more exploration-oriented perspective and considers possible desired futures with the aim of building an understanding of the ways in which these may be achieved (scenarios or pathways). The predictive approach is usually applicable on shorter time scales (up to 10 years) as opposed to the normative approach used with regards to strategic issues covering longer periods (over 10 years; van Ittersum and Sterk, 2015).

In the energy policy domain, the pressing need for systems models to better understand the functioning of the increasingly complex sector started to develop from the 1970's. Triggered by the oil crises of the era, the view that integrated frameworks were necessary to make better decisions about energy systems, both in the public sector and in industry, became increasingly dominant (Strachan et al, 2016). Organisations like the IEA's Energy Technology Systems Analysis Program (ETSAP) or the International Institute for Applied Systems Analysis (IIASA) began developing systems models with the aim of providing information on the future development of energy systems, with particular emphasis on energy security and costs involved (Pfenninger et al., 2014). Many of the models originating from this period are still currently relevant for decision-making in several countries, as well as on the supra-national level. For example, the MARKAL family of models has made a significant contribution to decision-making on multiple scales (Taylor et al., 2014; Pfenninger et al., 2014). MARKAL is a bottom-up normative/explorative energy systems model (Kannan and Strachan, 2009) which was originally aimed at providing an assessment of

'*the long-term role of new technologies in the energy systems of the participating countries and thereby provide focus for current research-and-development (R&D) support*' (Fishbone and Abilock, 1981:353).

Since the millennium, the proliferation of climate change concerns to the forefront of the international political agenda has given a new direction to energy systems modelling and research. Consequently, developing emissions mitigation scenarios and assessing the impact of various policy options in terms of their potential to contribute to the decarbonisation of energy supply has become central to studies conducted in recent years. This change in terms of objectives and context fuelled the development of new approaches (f.e. qualitative/interpretative and mixed-methods as opposed to the traditional exclusively quantitative perspective; Trutnevyte et al., 2014) and new modelling techniques (f.e. agent-based models; Busch et al., 2017).

2.2 The use of models as 'evidence' in energy policy making in the UK

In an overview of the academic literature on energy modelling, Hall and Buckley (2016) found nearly 100 different models which have been applied in the context of the United Kingdom on different scales. In contrast, only a very small portion of the models identified (14) were referenced in the policy documents surveyed (Hall and Buckley, 2016). Reviews demonstrate that the models used most extensively to support energy policies in the UK include the varieties of MARKAL; a model progressed by the Energy Technologies Institute called ESME; the Energy Department's (previously DECC, now BEIS) own tools such as the DECC Energy Model and the 2050 Pathways; and one developed by the consultancy Redpoint called RESOM (Hall and Buckley, 2016; Winskel, 2015; Taylor et al., 2014).

The MARKAL model was originally developed by the IEA's Energy Technology Systems Analysis Program (ETSAP) in which the United Kingdom participated through the involvement of the UK Atomic Energy Authority (UKAEA; Taylor et al., 2014). The model was initially used to understand the interplay between cost-effectiveness (total cost of maintenance, operation and improvement) and energy security (oil import dependency) (Taylor et al., 2014; Kannan and Strachan, 2009). MARKAL has been adapted to and used in the UK context already in the 1980's, and played an important part in developing energy policies and strategies on the national level since. The most important contributions include the 2003 Energy White Paper, the 2007 Energy White Paper, the 2008 Climate Change Act, the 2009 Low Carbon Transition Plan as well as various reports prepared by the Committee on Climate Change (Taylor et al., 2014). Variations of the original model were developed by the UK Energy Research Centre (UKERC; Strachan et al., 2009). For the assessment of longer term energy futures in related to the 2011 Carbon Plan, three energy systems models were used including MARKAL, ESME (techno-economic optimisation model developed by the Energy Technologies Institute; ETI) and the 'DECC Pathways Calculator' developed by the Department for Energy and Climate Change (Winskel, 2015).

3. MODELS AND NETWORKS

3.1 Coping with uncertainty: Models as boundary objects

3.1.1 The boundary object concept

The use of energy systems models (MARKAL in particular) has been connected to the 'boundary object' concept by Taylor et al (2014). 'Boundary objects' are defined by Star (2010:602) as

'*a sort of arrangement that allow different groups to work together without consensus*' through being '*flexible enough to adapt to local needs and the constraints of the stakeholders employing them, yet specific enough to maintain a common identity across different interpretations*' (Fong et al., 2007:11).

As such, they offer a means of 'boundary spanning' across knowledge-action systems (Cash et al, 2002).

The need for collective knowledge-formulation to facilitate action reflects the way in which contemporary problems are thought about and dealt with in the wider public administration literature. Contemporary complex problems transcend boundaries between

- science (knowledge) and policy (action);
- disciplines within the research community;
- organisational bodies within the policy making sphere;
- geographical and organisational scales and
- the private and public sector (Fong et al., 2007; Cash et al, 2002).

Successfully dealing with issues related to fragmentation (as detailed above) is only possible through counteracting the multiple dimensions of fragmentation in contemporary multi-actor and multi-scale social systems. Boundary objects have the potential to create linkages across silos through connecting '*communities of practice that have different institutional and professional logics and rationales*' (Taylor et al., 2014:34). They can take various forms, such as directories (repositories, databases), materialised representations of systems (f.e. objects or models), representations of boundaries (such as maps, designs) and standardised methods (Trompette and Vinck, 2009).

Facilitating collective problem formulation, framing and action entails the reduction of different types of uncertainties identified in the network governance literature, along substantive, strategic and institutional dimensions (Klijn and Koppenjan, 2015; Koppenjan and Klijn, 2004). Arguably, tools which make use of a large body of relevant information (repositories) may contribute to the reduction of uncertainty related to the content of policy decisions (substantive dimension). Strategic uncertainty can be made manageable through tools providing representations of boundaries as well as objects and models which contain relevant (and comprehensible) information across different contexts. Standardised methods and techniques offer potential solutions to reduce institutional uncertainty.

3.1.2 Requisites of successful boundary spanning: building salience, legitimacy and credibility

It is argued by Taylor et al. (2014) that energy systems models can only become successful boundary objects if they are seen as credible and legitimate and respond to the demands of both spheres of research and practice; in other words, they hold political (and scientific) salience. This argument refers to a broader debate in the literature on integrated knowledge-production to support policy-making, i.e. how to develop knowledge that is deemed ‘useful’ and ‘usable’ across sectors, scales and disciplines (Dilling and Lemos, 2011; see also Section 2.1.2). The concept of ‘credibility’ concerns the use of information which is considered scientifically approved and technically adequate. ‘Salience’ refers to the perceived relevance of information in various contexts: information which responds to ‘real’ demand, i.e. offers solution to pressing issues and is contextually appropriate and feasible, holds high salience. ‘Legitimacy’ relates to the quality of the process of knowledge-production and it is obtained through incorporating contextually relevant values, interests, concerns, and specific circumstances in a fair, unbiased and transparent way (Cash et al., 2003; 2002). Several empirical studies found that the three concepts were interrelated and, consequently, trade-offs existed between them posing significant challenges to successful boundary management (Sarkki et al, 2014; White et al, 2010; Girod et al, 2009; Cash et al., 2002).

Cash et al. (2002:7) note that

‘[…] the most successful efforts to connect knowledge to action are those that are not only effective at engendering favorable perceptions of salience, credibility, and legitimacy, but are also effective at balancing tradeoffs among these three attributes such that none of the three attributes falls below thresholds that will trigger the rejection of information or the resistance to recommended action.’

Thus, active boundary management is needed to balance salience, credibility, and legitimacy in the knowledge-production process. Objects, such as models, may contribute to managing boundaries between communities of knowledge (Taylor et al., 2014). Nevertheless, the majority of available empirical evidence points to the crucial importance of ‘boundary organisations’ which '*provide a space for the creation and use of boundary objects, which are hybrid constructs that integrate elements from scientific and political worlds to facilitate the negotiation and exchange of multiple types of knowledge and action*' (White et al., 2010:221).

3.2 Boundary management: intermediation via objects, organisations and individuals

3.2.1 Boundary organisations: achieving threshold levels of salience, legitimacy and credibility

'Threshold' levels of credibility, salience and legitimacy can only be achieved through active boundary management (White et al, 2010; Girod et al., 2009; Fong et al., 2007; Cash et al., 2002). Cash et al (2003) argued that managing interfaces between various communities of practice involves

1. active, iterative, and inclusive communication across boundaries;
2. the translation of knowledge to make it accessible for non-specialists and
3. mediation between conflicting problem perceptions, interests and objective.

Based on case studies from a range of policy fields they concluded that

'*systems [which] invested in communication, translation, and/or mediation […] more effectively balanced salience, credibility, and legitimacy in the information they produced*' (Cash et al., 2003:8089).

Boundary organisations were found to be more successful in communicating, translating and mediating between separate communities in cases were dual accountability was established: making boundary managers accountable to the policy as well as the scientific community (e.g. by forming contractual relationships) increased the perceived legitimacy of the knowledge-production process through facilitating higher levels of engagement and inclusion of interests, concerns, and perspectives of actors with different backgrounds (Cash et al., 2003). Moreover, the boundary management process contributed to the production of boundary objects (models) which were seen as credible, legitimate and responding to salient issues. In turn, boundary objects developed this way enhanced the success of the collaboration process (Cash et al., 2003). The studies conducted by Cash et al. (2002; 2003) suggest that facilitating successful boundary management between and within the spheres of science and policy making involves the use of a combination of boundary objects as well as boundary organisations.

3.2.2 Boundary organisations in the sustainability transitions literature: 'intermediaries'

The role of some form of boundary management has also been recognised in the climate change literature concerned about capacity building within and across scales and sectors to facilitate low carbon development (Kivimaa, 2014; Hamann and April, 2013; Hodson and Marvin 2010). The emphasis on 'intermediation' in the sustainability transitions research is related to the acknowledgement of the dispersion of knowledge, capacity, authority and competence among multiple actors operating at and between various geographical and organisational scales. The sum of coordination mechanisms taking place in such organisational landscapes was termed 'multilevel governance' by Hooghe and Marks (2001). Intermediaries (individuals, groups or organisations) in the multilevel context '*facilitate relationships between key actors and enable sharing and pooling of knowledge'* (Bush et al., 2017:138) and resources to build capacity for action. Empirical studies of intermediation for low carbon development highlighted the issue that the multilevel governance context which creates the space and necessity for boundary management also constrains the potential of boundary organisations to successfully coordinate collaborative processes. Constraints include limited financial and human resources, capabilities and the lack of established powers (Bush et al., 2017; Hawkey et al., 2013; Hodson and Marvin 2010). Work conducted in this field thus highlights the issue that the boundary organisation itself is part of the fragmented multilevel governance landscape and its potential to facilitate effective boundary management is dependent on the context in which it operates and which it aims to change.

4. SUMMARY AND CONCLUSIONS

The literature review revealed the central position of the concepts of 'network management', 'boundary management' and 'intermediation' across the various strands of literature including governance and policy networks; knowledge production and management; and sustainability transitions. All three fields emphasise the role of boundary organisations in the process of boundary management, albeit from different perspectives. In the context of governance and policy networks, coordination and process steering have been identified as the main tasks of the network manager in facilitating collaboration. The relationship between the boundary organisation and the relevant actors also received particular attention. In reality, boundary organisations do not operate in vacuum; rather, they are part of a network of actors and, therefore, interactions within the network influence their possibilities for intermediation. In the literature on sustainability transitions it has been recognised that boundary organisations' capability to act also depends on the specific resources available to them, such as financial and human resources, appropriate organisational structures and cultures, relevant knowledge base and competence among staff, platforms for communication and opportunities for developing local / contextual presence and visibility (Hodson and Marvin, 2010). The work on knowledge production and knowledge management has provided a meaningful way of connecting the intermediation process to impact through the concepts of salience, credibility and legitimacy. Moreover, in contrast with the other two approaches, it recognised the opportunities that boundary objects offered in supporting collaboration processes between the (network) actors.

Research into energy systems modelling in the United Kingdom so far has been limited to the assessment of model use in the policy making process; the introduction of the boundary object concept into the literature on modelling; and the assessment of governance processes and their relationships to the development of various energy and climate change futures. However, little information is available on

1. the actors from different sectors (public, private, research) involved in energy policy making operating at various sub-national, national and supra-national scales;
2. the ways in which they interact with each other;
3. the nature and quality of such interactions and
4. their impact on outcomes in relation to energy policies and strategies.

Questions surrounding the role, identity and resources of boundary organisations remain unanswered as well. Arguably, developing a better understanding of the structure of such networks, their operation and the perceptions of the actors involved may contribute to a more efficient use of available energy systems models across scales and sectors to support energy and heat policy making and strategy development.

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