The great reconfiguration: A comparative, socio-technical analysis of speeds and pathways in unfolding UK low-carbon transitions in electricity, mobility and agro-food systems

Frank W. Geels (University of Manchester)
Bruno Turnheim (University of Manchester, KCL, LISIS)

Abstract

Greenhouse gas emissions in the UK decreased by 42% between 1990-2016 and are envisaged to decrease further. Low-carbon progress has been fastest in electricity, and much slower in mobility and agro-food domains. This paper aims to compare UK low-carbon transitions in electricity, mobility and agro-food systems, and explain differences in speed and patterns. Addressing this empirical puzzle, we also aim to make several conceptual contributions to the sustainability transitions literature: a) shift the relative emphasis from (single) innovations to existing systems and regimes, b) make socio-technical 'whole system' analyses, which span production and consumption, c) show that existing systems are not inert, monolithic entities, but experience many ongoing processes, which matter for low-carbon transitions, d) change the conceptual transition imagery from singular disruptive innovation to gradual system reconfiguration, e) compare between systems rather than countries. Following Geels (2004), each domain will be analysed along three dimensions: a) tangible socio-technical elements (e.g. artefacts, infrastructures, supply-chains, end-use functionalities) and longitudinal trajectories, b) the strategies and concerns of the main social groups (incumbent firms, mainstream users, policymakers); the importance of climate change is an empirical question rather than assumption, c) rules and institutions, and how these influence production and consumption actors. For each domain, we also describe low-carbon niche-innovation, assess their breakthrough potential, and assess the speed and character of whole system reconfiguration.

1 Introduction

Greenhouse gas emissions in the UK decreased by 42% between 1990-2016 and are envisaged to decrease by 80% in the 1990-2050 period, according to the 2008 Climate Change Act (CCC, 2017). A low-carbon transition is thus arguably beginning to unfold in the UK. The speed of this change process varies greatly between different socio-technical systems: electricity has made most progress, while domains like heat/buildings, mobility or agri-food present a more complex and tainted picture, including some recent rises in transport and buildings) (Figure 1).

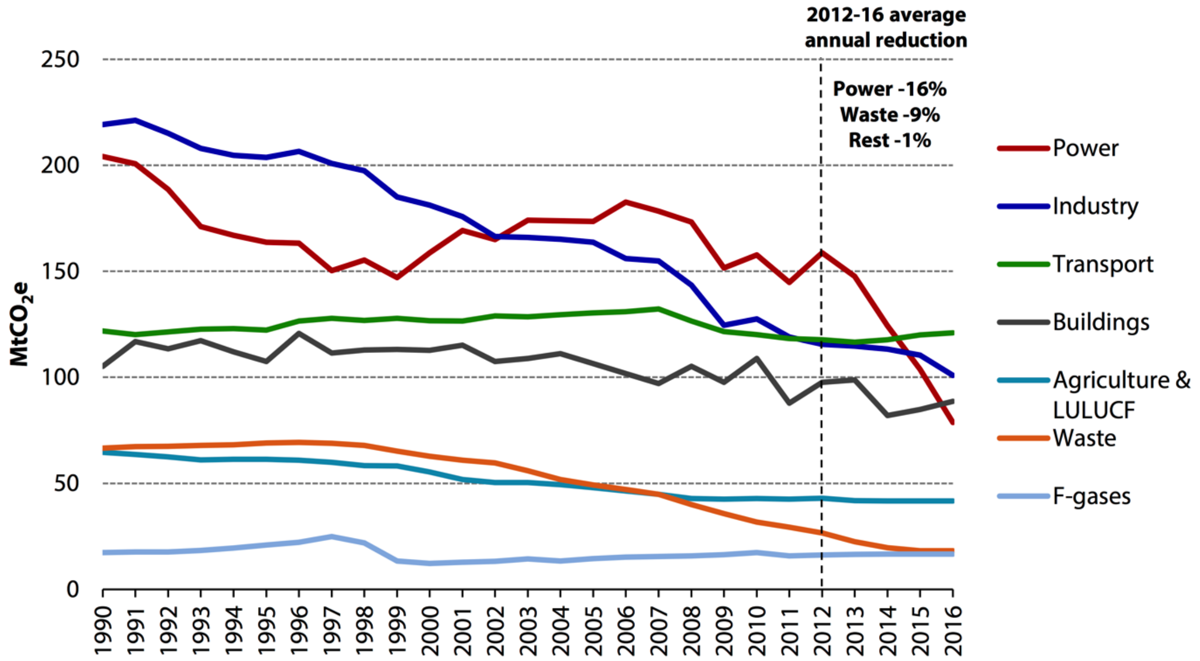

Figure 1: GHG emissions reductions in the UK, by sector (CCC, 2017:10)

Engaging with this empirical puzzle, this paper addresses two questions: 1) how can we explain the different speeds of low-carbon transitions in four/three different systems: electricity, mobility, agri-food, and heat/buildings, 2) do these transitions follow different patterns?

To answer these questions, we use the Multi-Level Perspective (MLP), which suggests that socio-technical transitions come about through interacting processes within and between three analytical levels (Geels, 2002; Geels et al., 2017; Rip and Kemp, 1998): a) radical niche-innovations (e.g. technologies, business models, social innovations), emerging in protected spaces (Kemp et al., 1998; Smith and Raven, 2012), b) socio-technical systems, which are reproduced by incumbent actors acting in the context of socio-technical regime, c) socio-technical landscape, which refers to exogenous, secular dynamics (shocks or gradual pressures) that influence dynamics at niche and regime levels.

With regard to transition speed, the MLP draws analytical attention to degrees of lock-in and path dependence of existing systems, which slow down transitions, but also to persistent problems, tensions, and degrees of reorientation of incumbent actors, which may accelerate transitions (Geels, 2004). The momentum of niche-innovations (e.g. price/performance improvements, investments, policy support, expanding coalitions) and favourable landscape developments can also speed up transitions.

In terms of transition pathways, the MLP has been differentiated to distinguish four transition pathways (Geels and Schot, 2007): technological substitution, regime transformation (through successive incremental changes), regime reconfiguration (through incorporation of niche-innovations), and de-alignment and re-alignment (through early external shocks that destabilize regimes, following by gradual realignment around a promising niche-innovation). Scholars subsequently differentiated these pathways in terms of enactment and actor roles, suggesting in particular that incumbent actors may drive technological substitution patterns if they strategically reorient towards new capabilities and business models (Bergek et al., 2013; Berggren et al., 2015; Geels et al., 2016).

While the MLP thus appears useful for addressing our research questions, we also propose several extensions that go beyond dominant tendencies in the socio-technical transitions literature.

- While many studies in the socio-technical transitions literature focus on (single) niche-innovations, we shift the focus to socio-technical systems, which is where low-carbon performance improvements ultimately need to be made. We thus return to the field's initial interest in system innovation (Elzen et al., 2004; Geels, 2005).
- We will analyse 'whole systems', because low-carbon improvements can be made in production and consumption sub-systems. This thus goes beyond the supply-side focus, which (still) dominates empirical studies in the socio-technical transition literature (which is also visible in Bergek et al., 2013; Berggren et al., 2015; Geels et al., 2016). 'Whole system' analysis is well-established in modelling, which focuses on functional flows and interlinkages between all relevant technologies. Our socio-technical 'whole system' analysis aims to maintain the focus on multiple technologies (although focused more on innovation trajectories than functional flows), but also addresses actors and institutions (Geels, n.d.; McMeekin et al., n.d.).
- While recognizing stabilising path dependencies, we take a dynamic view of systems which acknowledges on-going processes on multiple dimensions. This deviates from views of existing systems as static, inert monolithic entities that create 'barriers' to change', which can sometimes be found in niche-focused studies. This dynamic systems view has two wider implications. First, we do not assume that climate change is the only or necessarily most important concern for various incumbent actors (firms, consumers, policymakers). Instead, we assume that actors are engaged in various on-going processes, and that climate change is initially as an additional issue. It is an empirical question how important this new issue is (and becomes) compared to other on-going processes and concerns. Second, we assume that the diffusion of niche-innovations often substantially depends on alignments with on-going processes in existing systems and regimes (Geels, 2002, n.d.), which is a further argument for our analytical focus on the latter rather than the former.
- Last, but not least, we conduct comparative analysis, which goes beyond the single domain, single country focus. While country comparative studies are beginning to emerge (e.g. Altenburg et al., 2015; Geels et al., 2016), there are no systematic comparisons of transition dynamics between domains, which thus forms a novel contribution. We hypothesize that differences in speed and pathways of low-carbon transition, at least to some degree, relate to deep-structural differences in system architectures (e.g. how production and consumption relate), dominant actor coalitions and institutions and governance styles.

The paper is structured as follows. Section 2 describes the basic categories of our conceptual framework, which we will use to describe and analyse the different socio-technical systems. Section 3 discusses methodological considerations. Sections 4, 5, 6 and 7 respectively analyse speed and pathways of low-carbon transitions in UK electricity, agro-food, heat and mobility systems. Section 8 compares and interprets the findings. Section 9 concludes.

2 Conceptual framework

We use the MLP and its conceptual repertoire (niche-regime-landscape) as overarching framework for our research. But, as indicated above, we shift the relative focus to socio-technical systems, for which we investigate stability and change. This analysis includes niche-innovations but does not assume they are the only driver of change.

Our empirical analysis will be guided by the three ontological dimensions that characterize the socio-technical transition approach (Geels, 2004): a) tangible elements that make up a socio-technical system, b) social groups (e.g. firms, policymakers, civil society organizations, users) whose actions maintain, improve, repair and change system elements (through research, technology development activities, purchasing, debates, policymaking), c) rules and institutions (regimes) that shape actors preferences, strategies and actions (Figure 2). These three dimensions apply to both niche-innovations and existing systems, but differ in terms of stability (Geels and Schot, 2007): institutions and social networks are fluid, small and 'seamless' (Hughes, 1986) for emerging niche-innovations, but stabilized, large and differentiated/seamfull for systems and regimes. We will further discuss these three dimensions and how they relate to transition speed.

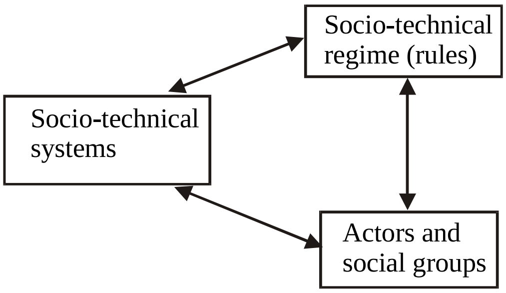

Figure 2: Three ontological dimensions of socio-technical approach (Geels, 2004:903)

2.1 Socio-technical system

Socio-technical systems are broader than industries, sectors or innovation; they are defined as the configuration of "elements necessary to fulfil societal functions (e.g. transport, communication, nutrition)" (Geels, 2004:900). Figure 3 provides a schematic representation, which spans production, distribution and end-use. Despite this 'whole systems' focus, many empirical transition studies have focused more on production than, end-use, which is one issue this paper aims to rectify.

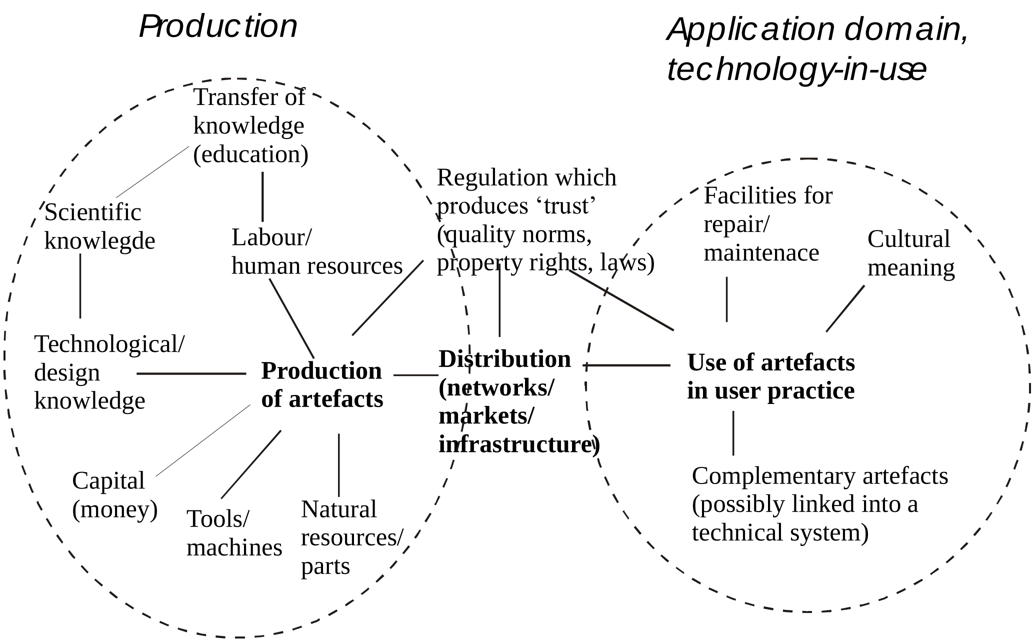

Figure 3: Basic elements of socio-technical systems (Geels, 2004:900)

The elements of socio-technical systems are not static and inert, but have "internal dynamics, which generate fluctuations and variations (e.g. political cycles, business cycles, technological trajectories, cultural movements and hypes, lifecycles of industries)" (Geels, 2004:913). These ongoing processes are usually constrained and guided along incremental trajectories, because lock-in mechanisms generate create path dependencies (Arthur, 1989; Dosi, 1982). Strong lock-ins and path dependencies stabilize existing systems and are likely to lower the speed of low-carbon transitions.

- Material lock-ins refer to the artefacts and infrastructures that provide socio-technical systems with 'hardness' and momentum (Hughes, 1994), because of obduracy (Hommels, 2005) or complementarities between components and sub-systems (Rycroft and Kash, 2002).
- Economic lock-ins refer to sunk investments (in infrastructure, factories, supply chains, people), economies of scale (Arthur, 1989), and favourable price/performance characteristics of existing technologies (which makes it difficult to dislodge them in mainstream markets).

The following processes may weaken techno-economic lock-ins and thus increase transition speed: a) increasing technical or functional problems, b) increasing negative externalities (like environmental, health or social problems) that do not hinder the systems internal functioning, but do create pressures for change (if the externalities lead to mobilizations for change), c) shrinking markets and decreasing returns on investment (Perez, 2002).

Promising niche-innovations may also enhance transition speeds, especially they can replace system components or can be incorporated as add-on. Tangible (techno-economic) drivers that improve the momentum of niche-innovations are: a) investments in R&D or deployment, b) improving price/performance characteristics, c) growing markets.

2.2 Actors and social groups

Socio-technical systems do not function autonomously, but are the outcome of activities of actors and social groups like manufacturing firms, suppliers, researchers, policymakers, consumers, civil society groups. "These groups have their own perceptions, preferences, aims, strategies, resources, etc. Actors within these groups act to achieve their aims, increase their resource positions, etc. Their actions and interactions can be seen as an ongoing game in which they react to each other" (Geels, 2004:909). Actors are thus likely to pay most attention to incremental innovations and new product launches (to defend or conquer market share), societal debates, policy adjustments, evolving consumer preferences and dynamic markets.

The following lock-in mechanisms may also stabilize existing systems and negatively affect transition speed:

- Incumbent firms may be locked-in by: a) routines, standard-operating procedures and technological capabilities (Nelson and Winter, 1982), b) established networks (with suppliers, distributors) that constitute 'organizational capital', c) market power and vested interests (assets, positions, reputations). These lock-in mechanisms may lead firms to ignore climate change or actively resist low-carbon transitions (Geels, 2014). Cut-throat low-cost competition may also make firms reluctant to address climate change (because it costs money and creates risks).
- User practices may stabilize existing systems when particular technologies are embedded in routines and life styles (Shove, 2003), e.g. using the car to commute to work, bring children to school, shopping, and visit friends. Compared to other concerns (e.g. busy schedules, financial problems, hobbies), people may also not be deeply interested in climate change or the intricate performances of energy systems.
- Political lock-in mechanisms are: a) existing regulations that favour incumbents and create an uneven playing field (Unruh, 2000), b) closed policy networks, which often provide easy access for incumbent firms but shout new entrants or complainants, c) lobbying from vested interests, who use corporate political strategies to shape policies in their favour (Levy and Egan, 2003), d) struggles between climate change/environmental Ministries and transport/energy/agriculture

ministries; because the latter traditionally prioritise other concerns, environmental policy integration is notoriously difficult (Jordan and Lenschow, 2010).

To explain the (high or low) speed of low-carbon transitions, it is important to understand these lock-in mechanisms and the other concerns of incumbent/mainstream actors besides climate change.

Using similar categories as above, processes that could speed up low-carbon transitions are: a) reorientation of incumbent firms to low-carbon innovations (e.g. in response to policy incentives, perceived market opportunities or eroding confidence in the status quo), b) challenge or overthrow of incumbent firms by new entrants, who pioneer and deploy low-carbon innovations, c) changes in mainstream consumer practices, based on increasing climate change concerns or other motivations (e.g. health, air pollution), which thus create new market opportunities, d) changes in policy networks (e.g. creation of new ministries, inviting new actors around the policy table), which lead to stronger climate policies in specific domains.

2.3 Rules and institutions

Actors are not entirely free to act as they want. Their preferences, strategies and activities are shaped (but not determined) by rules and institutions (Powell and DiMaggio, 1991), which in turn are shaped by institutional entrepreneurship and power struggles (Battilana et al., 2009). Institutions are not only a strategic context for actions, but also entail "a shared set of understandings that affects the way problems are perceived and solutions are sought" (Thelen, 1999:371). Existing institutions are the legacy of earlier conflicts (Thelen, 1999), and often difficult to change because of path dependence and lock-in mechanisms (Pierson, 2000). Because of our interest in 'whole systems', we take a broader view than historical institutionalism (which tends to focus on political institutions) and organizational sociology (which tends to focus on institutional logics) and distinguish three analytical categories:

- *Policies and governance styles*: Policies are formal rules and regulations, while governance styles or 'policy paradigms' refer to deeper informal institutions, which include the hierarchy of policy goals and interpretive frameworks (Hall, 1993). Changes in the setting of existing policy instruments are relatively common (based on negotiations or policy learning); the introduction of new policy instruments is less common, and often involves political struggles; changes in policy paradigms and governance styles are rare, and often involve strong societal pressures, heated debates and intense struggles (Hall, 1993). Since climate change is an externality to the focal systems, accelerations of low-carbon transitions are likely to depend on stronger policies (e.g. performance standards, subsidies for low-carbon innovations, carbon taxes) and perhaps even changes in policy paradigms (e.g. climate change rising on policy agendas, more interventionist governance styles).
- *Societal debates and public discourses* are ways to articulate public understandings of particular issues. The framing of issues and the degree of public attention influence their salience (and sense of urgency). Multiple issues and problems compete for public attention (Hilgartner and Bosk, 1988). A few social problems achieve 'celebrity status', attracting much attention; a larger number of problems command some public attention, due to continued activities from professionals, activists, and interest groups; the majority of social problems remains on the margins of public discourse (Hilgartner and Bosk, 1988). The issue-attention cycle literature suggests that problems can rise and fall on public agendas, depending on social mobilization, discursive framing strategies, and drama (associated with scandals, shocks, protests) (Bigelow et al., 1993). If climate change remains a peripheral problem compared to other concerns, the speed of low-carbon transitions is likely to be low. Increasing public attention to climate change (and appealing low-carbon innovations) may accelerate transitions (Penna and Geels, 2015).
- *Cultural conventions* are the shared frames of meaning and families of ideas (e.g. about comfort, cleanliness, convenience, morality) that underpin consumption and everyday life practices (Hand

et al., 2005; Shove, 2003). Low-carbon (demand-side) transitions can be accelerated in two ways: a) changes in cultural conventions, e.g. shifts towards frugality, thrift, sufficiency, simplicity, de-growth, care for nature (Brown and Vergragt, 2016; Princen, 2005), b) discursive alignments of low-carbon innovations with non-climate conventions (e.g. health, quality of life). We suspect that the second option to be substantially more viable than the first (Geels et al., 2015).

2.4 Transition pathways

With regard to the second research question, we suggest that the focus on niche-innovations, which characterizes many socio-technical transition studies, often leads to 'point source' understandings of change (Geels, 2018), in which singular radical innovations disrupt the existing system. While this disruptive substitution pattern may occur for partial or delimited systems (e.g. in electricity generation or auto-mobility), we suggest it is less suited for 'whole systems' such as the electricity system or the (land-based) mobility system. Instead, low-carbon transitions in whole systems are better analysed as reconfiguration processes (Geels et al., 2015), which are dispersed, stepwise processes that involve various change mechanisms such as:

- incremental improvement of system components ('transformation')
- (modular) substitution of system components by radical niche-innovations
- selective translation, in which regime actors selectively adopt elements of niche-innovations into existing systems (Smith, 2007)
- add-on and hybridisation, in which niche-innovations combine with existing system components (Geels, 2002)
- knock-on effects, where a component replacement triggers further innovation cascades (Berkers and Geels, 2011), which may ultimately change the system architecture.

Compared to the Geels and Schot (2007) typology, this means that we see reconfiguration as the overarching master process for 'whole system' change, in which technological substitution and incremental transformation pathways can be partial sub-processes. We will empirically investigate the relative importance of these change mechanism for low-carbon transitions in three systems.

We will also explore if the shape of system architectures (*how* various elements link together) has implications for transition pathways. Berkers and Geels (2011), for instance, suggest that technological substitution patterns may be more likely for systems that are organized around a 'core' technology (e.g. aviation systems around aircraft) and that stepwise reconfiguration is more likely for 'distributed systems' that function through the interplay of multiple technical components (e.g. medical care systems or greenhouse horticulture). By implication, the 'seamless web' (Hughes, 1986) metaphor may have outlived its usefulness, especially for existing systems (although may it still hold relevance for emerging innovations, which are more fluid). Instead, we suggest that existing systems are 'seam*ful* webs' and that the patterns of seams matters.

3 Methods

To answer our research questions, we will make a socio-technical 'whole system' analysis of the three domains: electricity, mobility and agro-food. This analysis will be guided by the above conceptualisation, which suggests that speed and transition pathways are the result of multi-dimensional and multi-level processes. For each domain, we will collect information for the following analytical categories, using various data-sources

- Tangible system elements. Using the schematic template from Figure 3, we will make more specific socio-technical system representations, describe the main elements and map relevant longitudinal trajectories to substantiate our dynamic approach to systems. We will make extensive use of quantitative indicators and collect data from public sources (e.g. government statistics).

- Actors and social networks: Using data from domain-specific secondary literatures, we will describe the main social groups, their interactions, strategies, and coalitions.
- Rules and institutions: Using data from domain-specific secondary literatures, we will describe specific policies, governance styles, societal debates and cultural conventions.
- Low-carbon innovations and alternative configurations. We will use quantitative data from public sources and qualitative information from technology-specific secondary sources.
- Assessment of overall reconfiguration speed and pattern. We analyse the various data against core mechanisms, described in section 2, to generate informed assessments of whole system reconfiguration patterns.

The first three categories aim to map and understand the dominant deep-structural trends in existing systems, regimes and networks. The importance of climate change and low-carbon innovations in these categories may vary between the empirical domains. The fourth category explicitly addresses low-carbon changes, and the fifth category discusses if and how the various changes lead to low-carbon system reconfiguration.

While a comparative 'whole system' system analysis is a novel contribution to the socio-technical transition literature, the empirical task is daunting, as each system is hugely complex and differentiated. The focus on breadth has obvious trade-offs for depth: many interesting intricacies and nuances have to left out. We hope, however, that the 'zooming out' strategy offers sufficiently interesting insights to, at least partially, compensate for this limitation.

Luckily, we do not start from scratch. In the past decade, socio-technical transition scholars have made many in-depth analyses of specific low-carbon innovations, on which we can build in our aggregate analysis. For our system analysis, we can also build on (socio-political and techno-economic) interpretations from domain-specific experts, many of whom have started to use the MLP as analytical frame, which facilitates our task. The interpretation of these empirical 'building blocks' inevitably introduces subjectivity, but it also allows for creativity, which is necessary to make sense of the many heterogeneous data.

4 Electricity domain

4.1 Systems and longitudinal trajectories

The UK electricity system is an integrated system, because power production and consumption need to be balanced in real-time to prevent blackouts. Various upstream inputs (coal, gas, nuclear material, biomass, wind) are transformed into a single homogenous product (electricity), which may be used for many different end-uses. In terms of system architecture, the grid not only mediates between production and consumption (Figure 4), but also acts as a *buffer* in the sense that consumers hardly notice 'upstream' changes in power generation (in terms of performance quality).

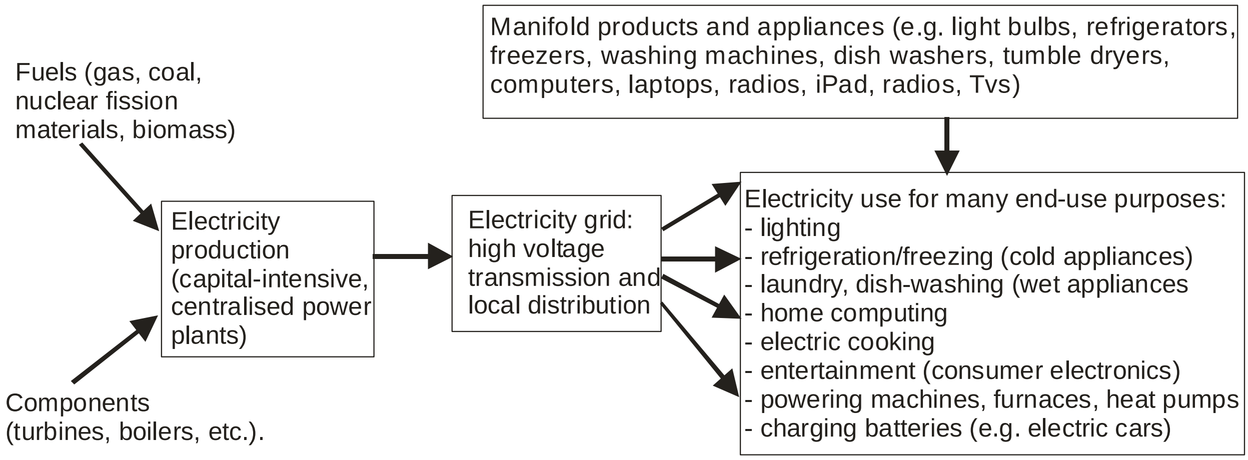

Figure 4: Schematic representation of the dominant socio-technical system for electricity in the UK

The ***generation sub-system*** traditionally consists of large, centralised base-load units (coal, nuclear or large gas turbines), complemented with flexible units for peak-load generation (e.g. smaller gas turbines). Power generation is a complex, engineering-heavy, and capital-intensive activity, linked upstream to specialised supply-chains for different fuels (coal/uranium mining, oil/gas drilling, extraction and refinery) and equipment manufacturing, installation and maintenance (e.g. thermal/nuclear reactors, turbines, boilers). Although small fuel mix changes are common (based on fluctuating fuel prices), large changes tend to be more gradual, because sunk investments and long power plant lifetimes (30-50 years) create path dependencies and stability. Figure 5 shows several longitudinal fuel mix changes: expanding nuclear power since the 1970s followed by gradual contraction, decreasing oil use (except for the period around the 1984 miner's strike), the 'dash for gas' after the 1990 privatisation, increasing renewable energy technology (RET) deployment after 2008, and declining coal use (which is scheduled to be phased out by 2025). A low-carbon transition is thus beginning to unfold on the generation side.

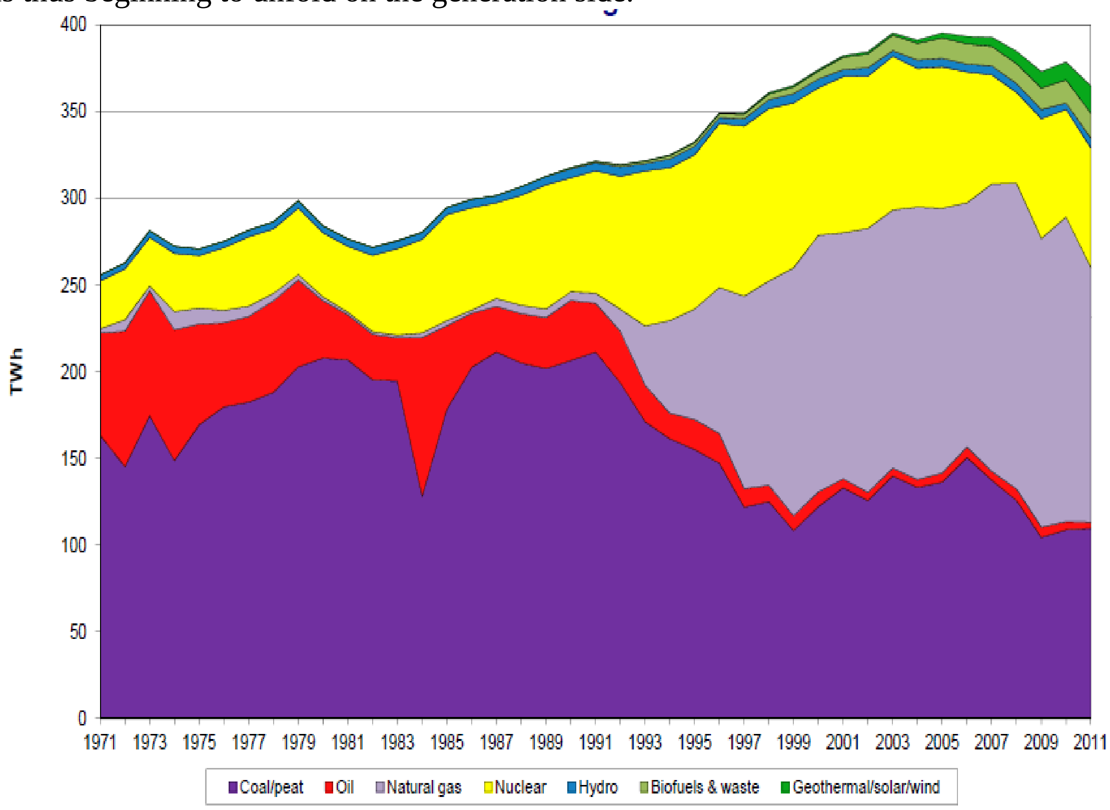

Figure 5: UK electricity generation system (data from IEA, 2013)

The ***consumption sub-system*** involves the deployment of electric appliances and the performance of routinized practices to achieve end-use functionalities like lighting, heating, freezing/cooling, washing, drying, cooking, entertainment, electronics, and mechanical work in households, the commercial sector and industry. Electricity is a clearly versatile energy carrier enabling many uses. Appliance manufacturing industries (e.g. TVs, radios, computers, refrigerators) are economically important and technically dynamic, leading to high degrees of product innovation along many quality and performance dimensions. The number of appliances has increased dramatically since the 1970s (Figure 6), because of various trends: manufacturing efficiencies and cost decreases increased affordability; multiple household ownership of some appliances (e.g. fridges, TVs, computers); introduction of new products (e.g. juicers, tablets, game consoles) (McMeekin et al., n.d.). Electricity demand increased until about 2006, but then started declining (Figure 5), due to the combined effect of energy efficiency innovations (see below), the financial crisis (and austerity policies), and offshoring (which reduced industrial demand) (Hardt et al., 2018, 2017).

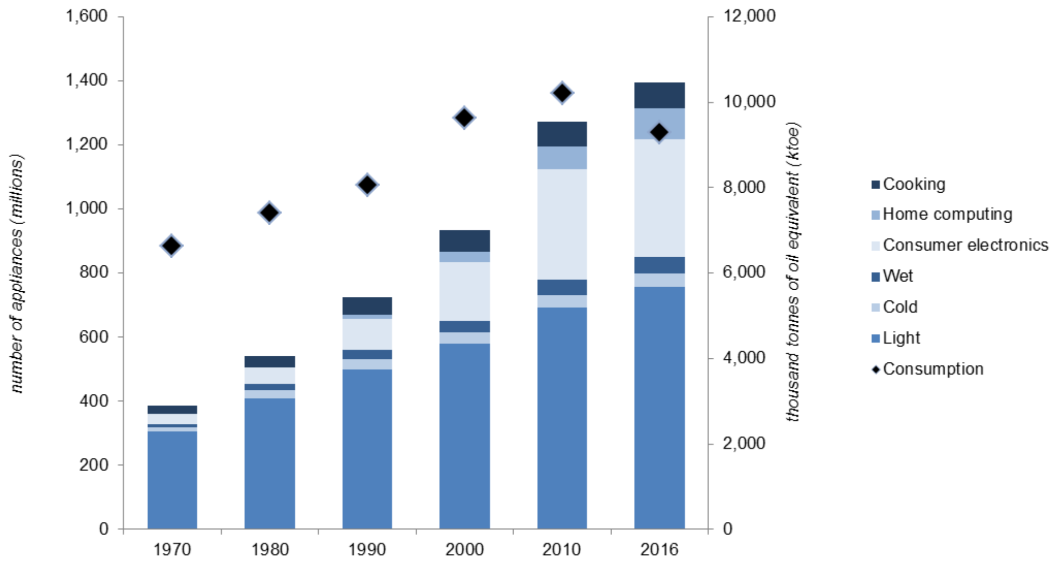

Figure 6: Total number of electrical appliances owned by UK households and total domestic electricity consumption (right hand axis) (BEIS, 2017:27)

The GB ***distribution sub-system*** consists of a high-voltage *transmission* network with 26,000 km of overhead lines for bulk electricity transfer from centralized power stations to 575 sub-stations, and a low-voltage *distribution* network for localized electricity delivery from sub-stations to end-users.[1] The electricity grid took decades to build, involves deep techno-managerial skills (e.g. for real-time load management), and represents major sunk investments that create strong path dependencies.

4.2 Actors and networks

Policymakers. The government privatised (1990) and liberalised (1998) the electricity supply industry, adopted a hands-off approach and disbanded the Department of Energy in 1992. An independent regulator, Ofgem, was created to ensure that markets were sufficiently competitive and to protect consumer interests (Kern et al., 2014).

In the 2000s, climate change became an additional policy concern, which was layered on top of existing neo-liberal arrangements, leading to an emphasis on market-oriented trading policies (e.g. the technology-neutral 2002 Renewables Obligation and support for the 2005 European Emissions

[1] Northern Ireland has its own grid.

Trading Scheme). The chosen policies were relatively ineffective, because they stimulated close-to-market options, neglected innovation, and created uncertainties about longer-term policy commitment (Woodman and Mitchell, 2011). The RO also disadvantaged new entrants, because the trading of Renewable Obligation Certificates created financial uncertainties, which were easier to manage for incumbent utilities.

Energy security rose on the agenda after the 2005 Russia-Ukraine gas dispute. In the context of rising oil and gas prices, UK electricity policy was increasingly framed in terms of an ‘energy trilemma’, which aimed to simultaneously address three goals: low cost, energy security and climate change. Following the 2008 Climate Change Act, electricity policies became more interventionist (Kern et al., 2014) and provided attractive financial incentives for low-carbon options such as RETs, nuclear power and Carbon Capture and Storage (CCS).

While *policy* momentum increased, *political* counter-trends gathered pace in the 2010s as the financial-economic crisis enhanced concerns about jobs, competitiveness and energy prices. In 2013, a full-scale political row over rising energy bills led the government to reduce various green policies (Geels et al., 2016). The 2015 ‘energy policy reset’ slashed subsidies for onshore wind, bio-energy, solar-PV and CCS, and signalled a desire for less interventionism.

While electricity consumption receives far less UK policy attention than supply, EU policymakers have (long) pursued energy efficiency policies for appliances. The 2009 EU Eco-Design Directive stipulated legally-binding minimum standards for the environmental performance of energy-using products. And the 2010 EU Energy Labelling Directive mandated that comparable energy-efficiency ratings should be provided on energy-related products to encourage consumers to choose more energy-efficient products.

Firms: Following privatisation (1990) and liberalization (1998), the UK electricity supply industry consolidated into the ‘Big Six’ electricity companies (EDF, E.ON, SSE, British Gas, Scottish Power, N-Power). Their strategies came to focus on price competition, sweating assets, decreased R&D spending, and fuel flexibility in response to fuel price fluctuations (Pearson and Watson, 2012). In the absence of clear product differentiation, competition mainly occurs on costs, and to lesser extent on consumer relations, green profiles, etc. The Big Six, which are vertically integrated (i.e. they own both generation and retail), dominate the market, but since 2013 new entrants (like First Utility, Ovo Energy, Sainsbury’s Energy) have begun to gain market share (Figure 7), which has increased competition. Organizations with new business models (e.g. community energy, transition towns) have remained small in the UK[2], because “key features of socio-technical regime for electricity provision continue to favour large corporations and major facilities” (Strachan et al., 2015:106).

[2] Although there were more than 5000 UK community energy groups in 2014, their cumulative renewable electricity generation capacity (60 MW) was small (DECC, 2014b), compared to 82.662 MW total capacity.

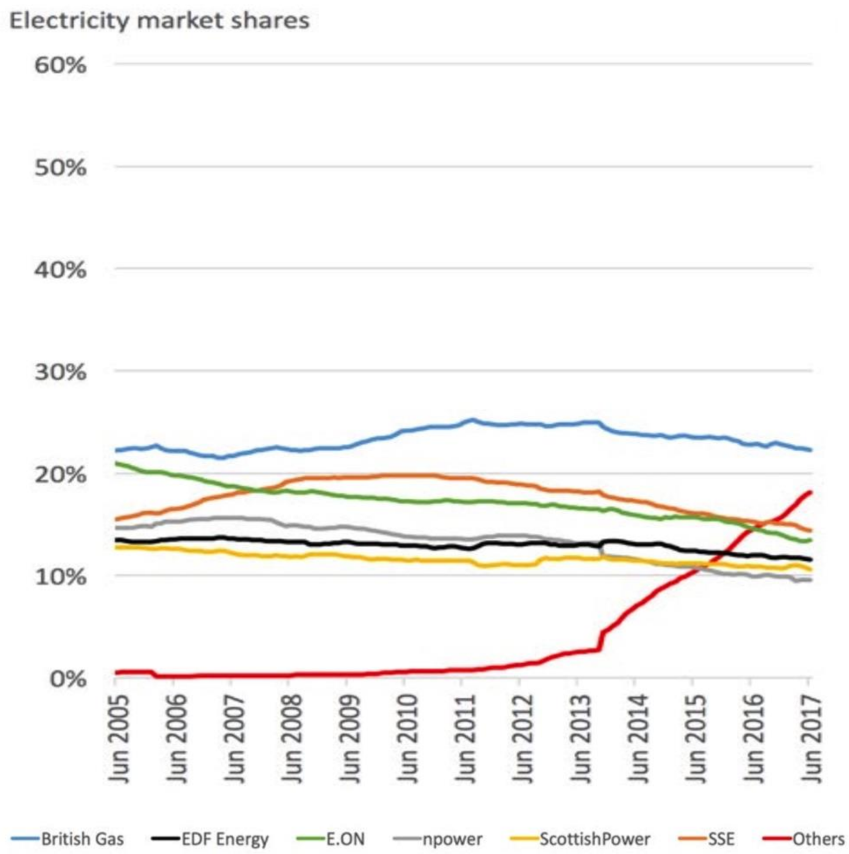

Figure 7: UK market share evolution of energy companies (Ofgem, 2017:21)

In response to attractive government incentives, electricity generators have begun to reorient towards large-scale renewables like biomass combustion in converted coal-plants, onshore and offshore windparks (Geels et al., 2016), leading to steadily increasing investments, which reached $25.9 in 2015 (Figure 8). But since the 2015 energy reset private investments have plummeted by 60%, because the weakened renewables policies slashed financial support and created uncertainty about long-term commitments.

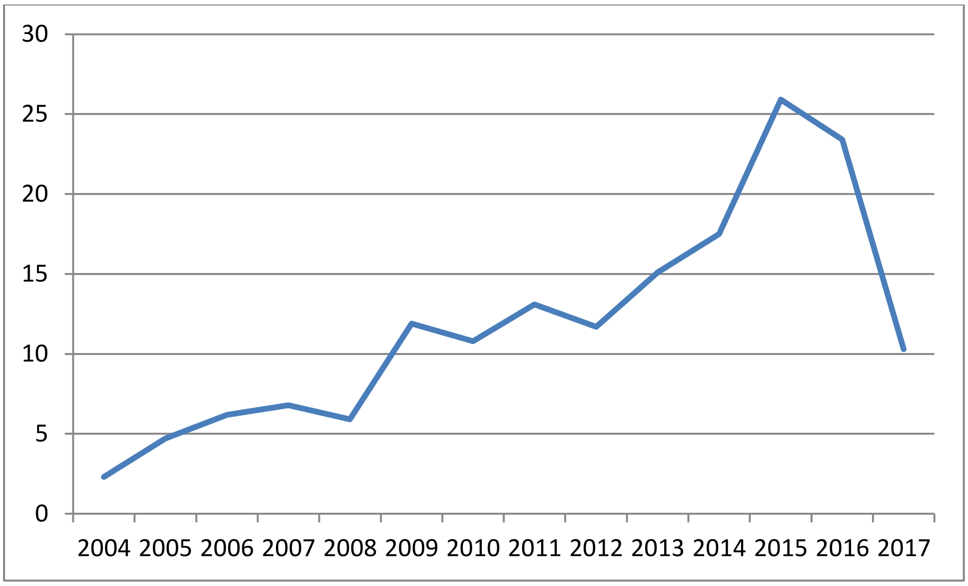

Figure 8: New investment, in $bn, in UK clean energy technologies (offshore and onshore wind, solar-PV, other) (based on data from BNEF, 2018)

The transmission grid is managed by a single system operator (National Grid) and three regional Transmission Network Operators (TNOs). The local distribution system is organized into 14 regional area monopolies, run by 14 Distribution Network Operators (DNOs), who traditionally manage one-directional electricity flows, involving limited direct interaction with users and minimal network monitoring (Lockwood, 2016). The post-liberalisation focus on efficiency and cost reduction stimulated TNOs and DNOs to 'sweat the assets' (by postponing network investments) and downscale R&D investments to 0.1% of revenue by 2004 (Jamasb and Pollitt, 2008). Ofgem has tried to stimulate innovation through the Innovation Funding Incentive (2005-2010), Low-carbon Network Fund (2010-2015) and revised regulatory RIIIO framework (Regulation = Incentives + Innovation + Outputs). Nevertheless, DNOs in particular have remained relatively resistant to change, because of various lock-in mechanisms: they are risk-averse, have lost technical skills, and lack incentives to develop and implement major, long-term innovations (Bolton and Foxon, 2015; Lockwood, 2016).

In the consumption sub-system, appliance manufacturers have implemented successive *incremental* innovations, in response to strengthening EU policies, which substantial improved energy-efficiency performance in various appliances (BEIS, 2017a).

Consumers. Around 27.5 million household users and 2.7 million business users (industry and commercial) represent around 35% and 65% of total electricity users, respectively (Cornwall Energy, 2016:10). Most electricity consumption is routine, taken-for-granted and detached from material supply realities: most users know little about the worlds behind the socket (how it works, where it comes from, how it is organised). Consumers mainly interact with suppliers through meters and bills, supplier choice, and the occasional need for electrical repair. Consumer switching between suppliers was very limited (and mainly confined to decision moments like house-moves), but this is beginning to change, which creates competitive pressure in the market (Ofgem, 2017). Climate change is of far less concern than electricity bills: few consumers opt for 'green' electricity suppliers. Although most consumers do not actively choose renewables, they ultimately pay for the £billions of investments in RETs and grid innovations, through their bills and general taxation (which financed government subsidies to generators). This 'invisible' market demand, which has been created through regulations and billing practices, is a major explanation for the higher speed of low-carbon transitions in electricity, compared to other domains (where consumers need to make deliberate choices to buy electric cars, insulate homes, or change food purchases).

4.3 Rules and institutions

Policy and governance style. Privatisation and liberalisation dominated UK electricity policy since the 1990s, based on the idea that market competition would improve efficiency and drive prices down. In terms of hierarchy of policy goals, energy security and climate change increased their salience since the mid-2000s, leading to greater interventionism and the 'energy trilemma' notion. But the 2015 'energy policy reset' signaled a desire to return to less interventionism and embraced low costs as the most important policy goal.

In terms of specific policies, the 2008 Climate Change Act was a radical change, which introduced demanding overall targets (80% GHG-reduction by 2050), and created new organisations like the Department of Energy and Climate Change (DECC) and the independent Committee on Climate Change (CCC). DECC subsequently developed specific targets for electricity generation (e.g. 30% renewable electricity in 2020), a raft of policy plans (like the 2011 Carbon Plan, 2012 Energy Bill, and 2013 Electricity Market Reform), and specific implementation instruments like the amended Renewables Obligation (2009) that offered technology-banded support rates (which especially supported large-scale options like onshore wind, offshore wind, and biomass conversion of coal plants), Feed-in-Tariffs (2010) for small-scale generation, and Contracts-for-Difference (2013), which guarantee that low-carbon electricity generators receive a stable and predictable 'strike price' for long periods.[3] The strike prices vary for different low-carbon technologies, but are relatively generous for large-scale options such as offshore wind, biomass conversions, and nuclear power (with the Hinkley C plant receiving a guaranteed strike price of £92.50 per MWh, twice the wholesale price, for 35 years).

These policies represented a shift from hands-off market policy style towards greater degrees of interventionism (Kern et al., 2014) and market shaping, which was meant to attract private investors. These specific targets, implementation policies, substantial (technology-specific) financial support mechanisms, and drive from dedicated organisations (DECC) are important explanations for the greater speed of low-carbon transitions in electricity, compared to other domains. The speed has slowed down after the energy policy reset, and the slashing of support policies.

The underlying governance style has several characteristics that explain the focus on large-scale technologies: a) policymaking is highly centralized (Westminster system), b) close-knit policy networks are relatively open to industry actors (Big Six, National Grid, TNOs, DNOs), but closed for outsiders and new entrants, leading to a 'working with incumbents' policy style (Geels et al., 2016), c) engineering and economic planning rationalities dominate decision-making, leading to some neglect of 'softer' dimensions such as social acceptance, d) implementation sometimes has a confrontational 'bulldozer' style (Geels et al., 2016) aimed at pushing through concocted plans rather than consulting with citizens and societal actors; this has created social acceptance problems for onshore wind, Big Biomass and shale gas/fracking.

Societal debates. Public attention for climate change increased rapidly between 2003-2008, but subsequently declined as the financial crisis and austerity increased concerns about jobs, growth and energy costs. Cost concerns underpinned various specific debates about: a) rising energy bills, which led to a political row in 2013 and subsequent efforts to limit renewables spending ('green crap'), b) energy poverty and vulnerabilities of people on standard tariffs (which are the ones energy companies most increase), c) market power abuse and pricing strategies by incumbents, which feeds distrust of utilities, d) dysfunctional markets creating insufficient price competition, e) excessive subsidies for Hinkley C. There are thus multiple other societal debates than climate change. There

[3] If the wholesale electricity price is below the agreed 'strike price', the generator receives a top-up payment to make up for the difference. If the wholesale price is above the strike price, the generator pays the surplus back.

are also debates about specific low-carbon innovations such as onshore wind turbines (spoiling the countryside, insufficient involvement of residents in planning, leading to local protests), shale gas/fracking (water and noise pollution, industries invading the countryside, insufficient stakeholder engagement) and biomass burning in converted power plants (sustainability of imported wood pellets).

Cultural conventions. Electricity has become a taken-for-granted background to modern life. Increased appliance use is associated with progress and associated electricity consumption rarely questioned. Underlying end-use practices are linked to broader cultural conventions like convenience (e.g. heating food in microwaves), cleanliness (e.g. washing at high temperatures) and relaxation/entertainment (e.g. TV, radio, games) (Shove, 2003).

4.4 Low-carbon innovations and system reconfiguration

Overview of low-carbon performance. CO2-emissions from the power sector decreased by 62% since 1990 and 55% since 2008 (Figure 9). Declining CO2-emissions in the 1990s were due to fuel switching (from coal to gas) in electricity generation (Figure 5). Since 2008, declining CO2-emissions resulted from both decreasing electricity consumption (Figure 6) and decarbonisation of electricity generation.

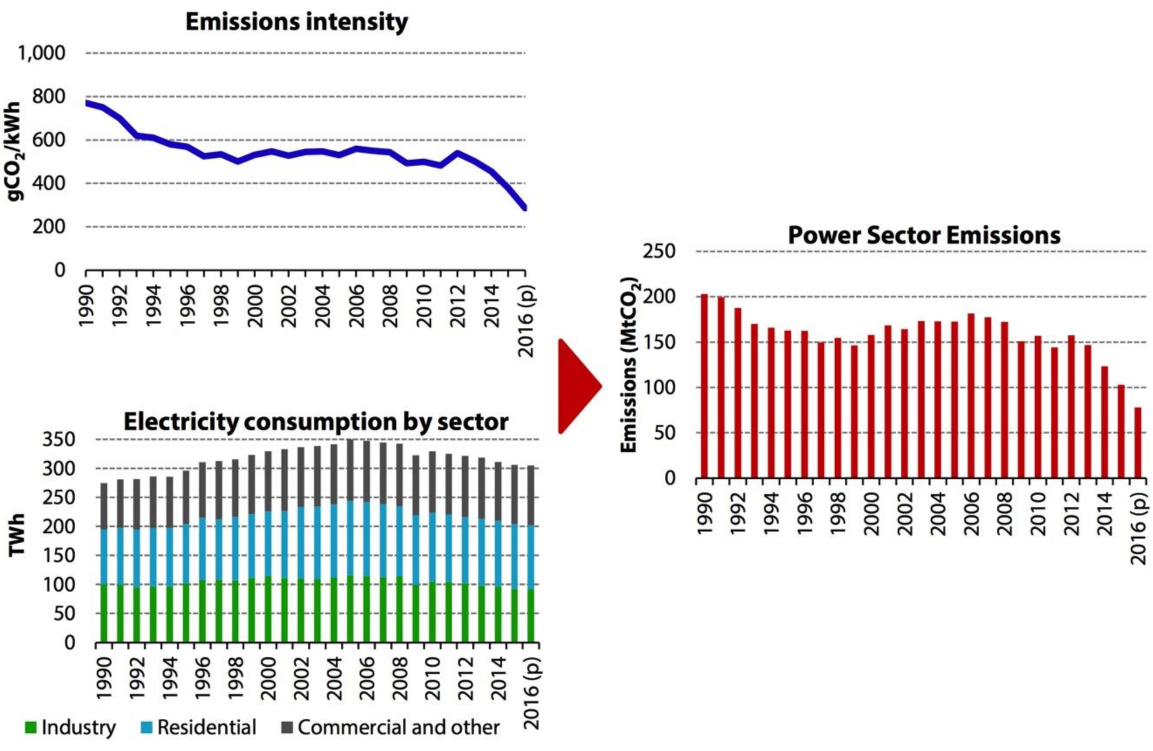

Figure 9: Emission intensity, electricity demand, and CO2 emissions from the power sector (1990-2016) (CCC, 2017:44)

Main low-carbon innovations. The impressive supply-side CO2-reductions are due to an unfolding low-carbon transition from coal towards gas and renewable energy technologies (RETs), while existing nuclear power plants also increased generation (Figure 5). The three most important RETs are onshore wind, offshore wind and biomass combustion in converted coal-plants (Figure 10), which are mostly large-scale options deployed by incumbents (Big Six utilities, project developers, foreign energy companies) and stimulated by various government subsidies. In response to social acceptance problems, the government announced a post-2020 moratorium on new onshore wind turbines (which are the cheapest RET). Biomass combustion also faces some social acceptance problems and reduced subsidies.

The 2010 Feed-in-Tariff stimulated unexpectedly rapid diffusion of solar-PV, deployed by new entrants (households, farmers, communities), but the recent slashing of support policies is slowing rates of change.

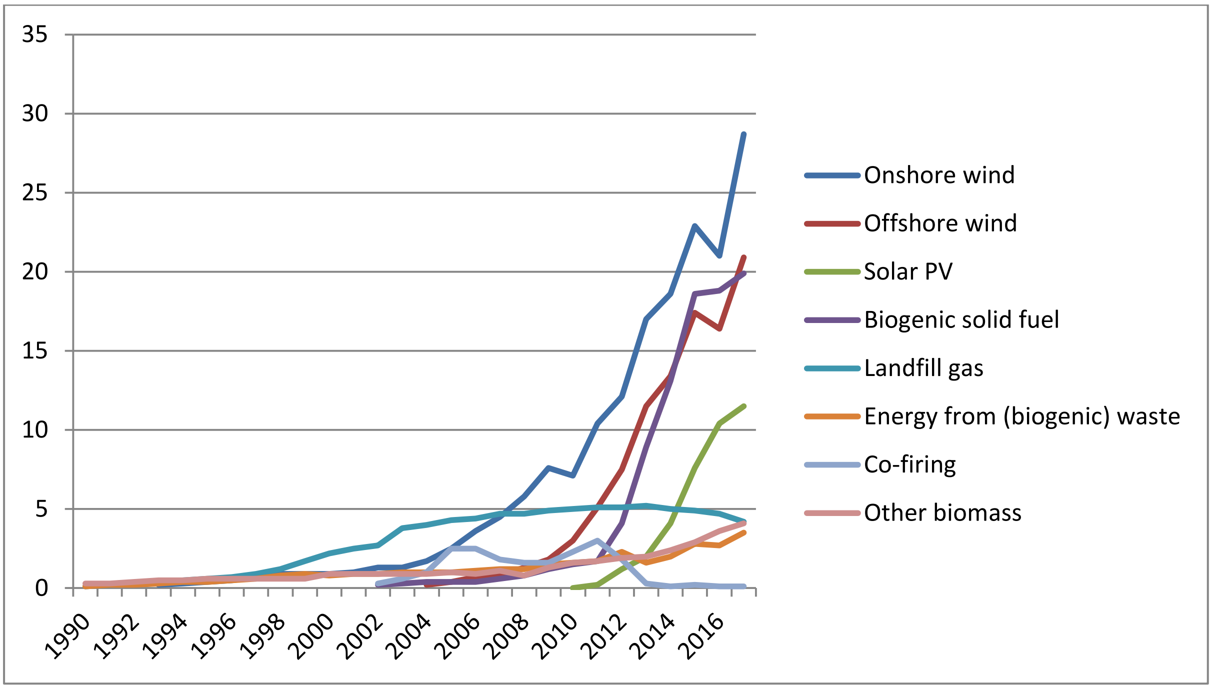

Figure 10: UK power production from RETs, excluding hydro, in TWh, 1990-2017 (data from data from DUKES)

Coal is declining because old 'retiring' plants are not replaced, due to a combination of market and policy pressures (UK Carbon Floor Price, European Large Combustion Plant Directive). The UK government has also committed to phasing-out unabated coal by 2025. The possibility of CCS (with coal) has been a core plank of UK energy policy since 2008, but development has been very slow. Subsidies for CCS-development were scrapped in 2015.

Plans for a 'nuclear renaissance' were also announced in 2008, leading to proposals for 16 GW or 8 new plants by 2025. The opening of the first new 3.2 GW plant (Hinkley C) has been delayed repeatedly from 2018 to 2025, while complaints about its high costs are eroding the political feasibility of subsequent nuclear power plants.

Declining electricity consumption since 2006 (partly) relates to *incremental* innovations that substantially improved energy-efficiency performance in 'cold' appliance (refrigerators, freezers) and 'wet' appliances (dishwashers, washing machines) (BEIS, 2017a). In lighting, manufacturers implemented more *radical* innovations, shifting from incandescent lightbulbs to Compact Fluorescent Lighting and now towards light-emitting-diodes (Franceschini and Alkemade, 2016). Despite increasing numbers of appliances (Figure 6), these innovations have reduced overall electricity consumption in some categories (wet, lighting) and stabilized in others (Figure 11).

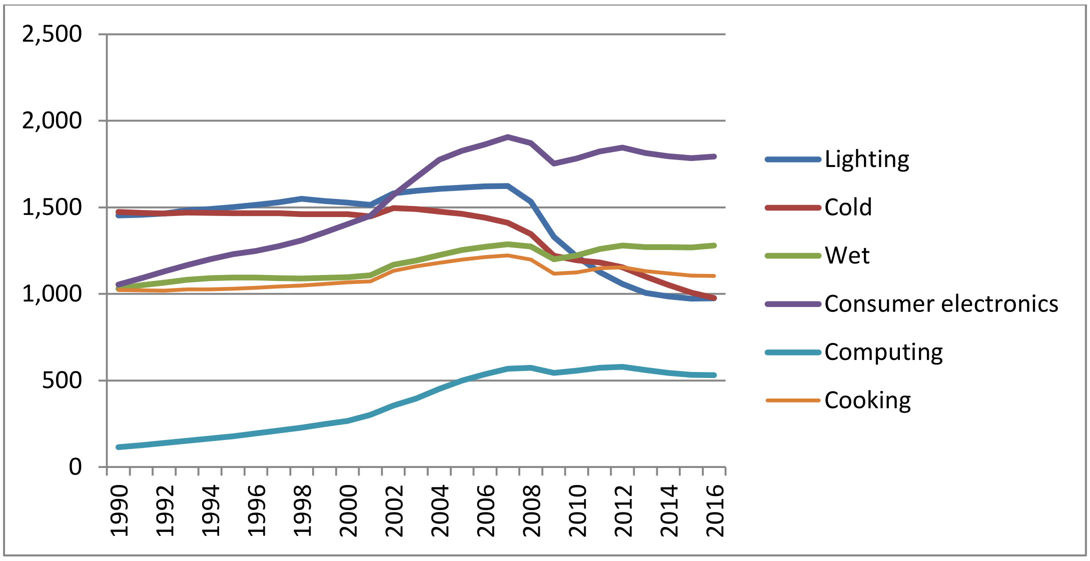

Figure 11: Electricity consumption in UK households by appliance category, in kilotons of oil equivalent (based on data from BEIS, 2017)

Stimulated by promises that smart meters might help reduce energy demand by 5-15% (Darby, 2006), the government mandated in 2009 the roll-out of 53 million smart meters by 2020 for all households and small businesses, at an estimated cost of £10.927 billion. Despite a series of (technical, organisational and social) obstacles and delays (Sovacool et al., 2017), 9.56 million smart meters were implemented by the end of 2017 (Figure 12). Although demand-reduction expectations have been downscaled to 1-3%, new promises have gained salience, particularly in relation to smart grids, peak shifting, and demand-side response, in which feedback from smart meters and new kinds of tariffs (e.g. time-of-use or real-time 'dynamic' tariffs) may modulate demand to accommodate fluctuations in electricity supply (from intermittent renewables).

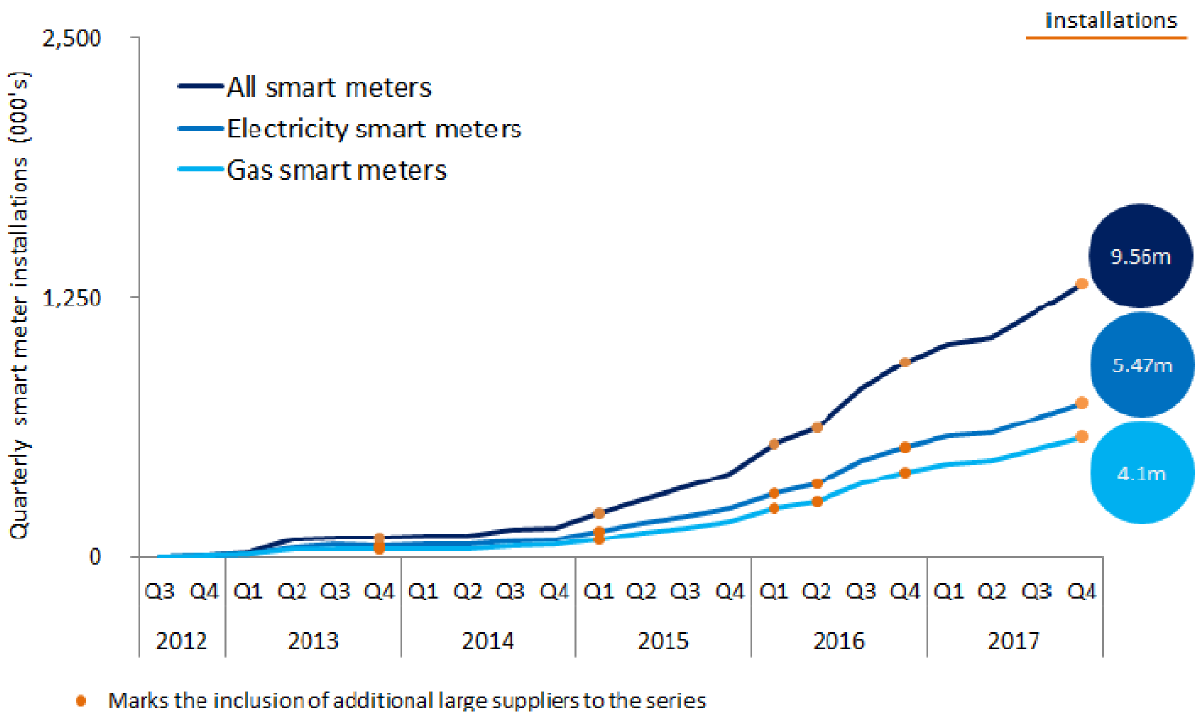

Figure 12: Domestic UK smart meter installation, 2012-2017 (BEIS, 2017b:11)

In response to RET-deployment, TNOs and the National Grid have started to implement *incremental* innovations in onshore transmission networks (e.g. extensions to link remote Scottish windparks, reinforcements of North-South connections) and the creation of new offshore networks (to connect offshore windparks). Between 2010-2013, £16 billion was invested in onshore and offshore transmission grids and £1 billion in inter-connection projects (to other countries). For 2014-2020, another £35 billion is scheduled for grid investment and £2.4 billion for interconnectors (DECC, 2014). The expansion of *distributed generation* (roof-top solar-PV, community wind energy, small waste-to-energy or dedicated biomass plants) also creates pressures on distribution networks, especially the management of intermittent generation and two-way electricity flows. Although there are smart grid roadmaps (SGF, 2014) and R&D projects on sensors, automatic switches, and power electronics (Jenkins et al., 2015), real-world implementation of smart grids is slow, because of DNO resistance to major change (Lockwood, 2016). To address increasing intermittency in power generation (from wind and solar-PV), grid actors also pay more attention to storage (batteries) and back-up capacity, for which regular capacity market auctions have been held since December 2014.

Low-carbon system reconfiguration. The UK electricity system is being reconfigured through various change processes (McMeekin et al., n.d.), which are summarised in the first row of Table 1. The radical component substitutions in electricity generation are increasingly having knock-on effects in the consumption and infrastructure sub-systems, where incremental changes (energy efficiency improvements, grid extensions) are increasingly complemented with radical niche-innovations (smart meters, storage, smart grids) that create opportunities for wider changes (demand-side-response, bi-directional flows, intelligent load management, peak shifting) that strengthen the linkages between the three sub-systems and potentially generate a different system logic (in which demand-follows-supply rather than the other way around).

	Generation	**Consumption**	**Grid**
System	Radical technical component substitutions: - large-scale niche-innovations replacing regime technologies (coal) - fuel switch (coal to gas) - niche-regime hybridisation (coal-biomass conversion)	- Incremental efficiency improvements in appliances - Niche-innovation add-on (smart meters) with potential knock-on effects (e.g. demand-side-response)	- Incremental innovations (onshore and offshore grid extensions, interconnectors) - Niche-innovation add-ons (storage, smart grids, back-up capacity) with architectural knock-on effects (bi-directional flows, flexibility)
Actors	- Mainly gradual reorientation of incumbent actors, incentivized by policymakers - Negotiations in relatively closed networks (incumbents, policymakers) - Consumers relatively disengaged	- Gradual reorientation of appliance manufacturers, incentivized by (EU) policymakers - Consumers relatively disengaged	- TNOs and National Grid gradually reorienting - DNOs more reluctant to change - Negotiations in relatively closed networks (incumbents, policymakers)
Rules and institutions	- Strong policy interventions since 2008 - Recent weakening - Top-down, technocratic policy style creating social acceptance problems	- Gradual strengthening of EU energy efficiency regulations - Electricity use underpinned by cultural conventions - Electricity consumption less salient in UK energy policy than supply, except for smart meter roll-out, which is driven by specific targets	- Revised regulatory frameworks to stimulate innovation layered on top of neo-liberal market arrangements

Table 1: Summary of core patterns in UK electricity system reconfiguration

Since 2008, the speed of change, especially in generation, has been relatively high because of the following drivers:

- Strong policy interventions through specific performance targets and policy implementation strategies, backed up with large financial incentives.
- Climate change ranked high on electricity policy agendas, although has dropped in recent years compared to other goals (low cost, energy security).
- Strategic reorientation of incumbent actors towards low-carbon innovations, in response to policy incentives and perceived economic opportunities, resulting in high investments (tens of £billions).
- 'Market demand' in the sense that consumers (ultimately) pay for low-carbon innovations through energy bills and taxation, even though they do not make active purchase decisions. This relates to specificities of the electricity system architecture, where the grid separates supply and demand.
- The availability of low-carbon niche-innovations, which benefitted from decades of R&D investment and more recent economies of scale and price decreases, was also a crucial enabler.

In sum, the unfolding transition is primarily a negotiated and controlled transformation of the existing regime, based on reorientation of incumbent actors (utilities, grid actors, appliance manufacturers, policymakers), who gradually adjust their beliefs, capabilities and (investment) strategies. One threat to the transition are (frequent) political U-turns and weakening support policies (to reduce costs and protect vested interests). Another threat are social acceptance problems (of particular innovations and rising costs), which are partly caused by a top-down technocratic policy style. A third threat is that slow development in nuclear power and CCS and the onshore wind moratorium create capacity problems in 2025 when unabated coal will be phased-out. A fourth threat is the social and political challenge of mobilizing £200-300 billion investments that the low-carbon electricity transition is estimated to require between 2010 and 2030 (Watson et al., 2014), based on evaluating scenarios from seven organisations, including DECC, Ofgem, National Grid). While investments have increased substantially since 2010, the roll-out of low-carbon options and system reconfiguration will require much greater expenditures in the next 15 years, which is challenging in the climate of austerity, public cutbacks and cost debates.

5 Agro-food domain

5.1 Systems and longitudinal trajectories

Agro-food systems are inherently complex because of a large variety of heterogeneous products (e.g. grain, meat, dairy, fruit and vegetables, processed food, beverages), sub-products classes, product differentiation criteria (e.g. price, quality, taste, health, nutrition, degree of processing, origin, labels), production processes and supply-chains, because of inherent linkages to the natural environment, and because consumption practices and preferences are significantly culturally embedded and determined. Figure 3 provides an overview of the dominant features of socio-technical configurations for agri-food in the UK. Compared to other domains, agri-food systems are further characterised by long (often global) supply-chains with numerous actors, and an increasingly central role of the retail sector, which assumes a *de facto* mediating role (Grin, 2012).

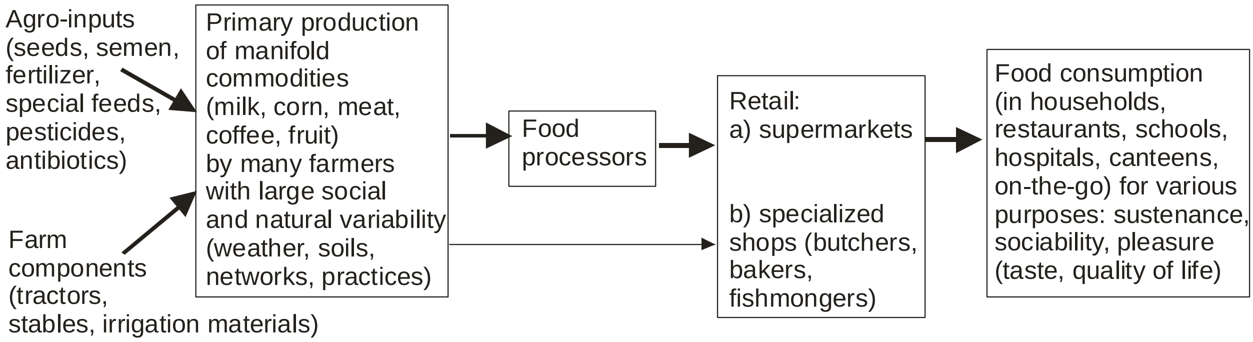

Figure 13: Schematic representation of the dominant socio-technical configuration for agri-food in the UK

Primary (agricultural) production takes place on farms of significantly different sizes (from small family-farms to large industrial farms) producing a variety of different crops. Agriculture interacts closely with nature (soil, weather and climate conditions, photosynthesis, nutrients, seeds, growth cycles) (Marsden and Morley, 2014). There has been a long-term tendency for ironing out local specificities through increased human control, homogenisation, industrialisation, and intensified external input (Friedmann and McMichael, 1989), oriented towards maximising yields and reducing natural variability. This has contributed to increased food availability for growing urban populations, but also produced significant environmental degradation (Cumming et al., 2014). The intensification of farming (the dominant model) relies on a combination of inputs: mechanical and infrastructural (tractors, harvesters, irrigation, farms, greenhouses), genetic (selective breeding, seed supply, GM), chemical (fertiliser, pesticides) and pharmaceutical (antibiotics). The globalisation of food chains, enabled by its commodification, has led to significant regional specialisation (e.g. bananas, coffee) and increasing year-round availability of produce, international trading[4], more asymmetric competitive pressures on struggling farmers, and increasing reliance on imported foods.[5] The lengthening of food chains in time and space (van Otterloo, 2005) was enabled by innovations in preservation (e.g. chemicals, refrigeration, drying), transport and logistics, and has tended to concentrate power in distribution and retail activities.
Agricultural products are increasingly processed and packaged within a ***processing (or manufacturing) sub-system***, enabling global transportation and increased shelf life, to make non-edible products edible, or in the context of specialty (often regional) products like wine and cheese (see Table 1 for a food classification). Food processors are important actors in many chains (e.g. butchers and meat dealers in food chain, milk processors in the dairy chain). Food manufacturing is particularly important in the UK, representing around 25% of gross value added but just over 5% of labour input in the food sector (DEFRA, 2017a). While the food and beverage industry has grown to capture a significant share of the food market, there is also increasing stress as “shoppers [are] turning away from products that delighted earlier generations […] in favour of cheaper store brands or healthier offerings”[6].

[4] Four global companies (the ‘ABCD group’) command 70% of bulk trade in agricultural commodities (foodstuffs, feed and biofuels), and together own most of the transport and distribution infrastructure and strategic processing activities (Heinrich-Böll-Stiftung et al., 2017:26).
[5] UK food consumption has become increasingly reliant on imports (from 36% to 48% between 1987 and 2008) (de Ruiter et al., 2016).
[6] FT 20180216_Food industry giants struggle to keep up with changing tastes

Table 1: Summary of NOVA food classification (based on Monteiro et al., 2016)

NOVA classification	Definition	Examples
Unprocessed or minimally processed foods	Edible part of plants or animals, after separation from nature, with processing limited to mechanical separation, drying, freezing, pasteurising, or packaging	seeds, fruits, leaves, muscle, offal, eggs, milk (raw, dried, frozen, etc.)
Processed culinary ingredients	Substances used for the preparation, seasoning or cooking of meals obtained from unprocessed foods through processes such as pressing, refining, grinding, milling, and spray drying	salt, sugar, honey, vegetable oils, butter, starches
Ready-to-consume processed foods	Relatively simple products made by adding culinary ingredients to unprocessed foods to increase their durability or modify their sensory qualities, i.e. through preservation, cooking methods and non-alcoholic fermentation	canned vegetables and fruits, salted nuts and seeds, cured and smoked meats, cheeses, fresh bread
Ultra-processed food and drink products	Industrial formulations typically with five or many more ingredients to create products that are ready to eat, to drink or to heat, liable to replace both unprocessed or minimally processed foods that are naturally ready to consume	carbonated drinks, packaged snacks, ice-cream, candy, cereal bars, mass-produced breads, ready to heat products, reconstituted meat

Distribution and retail subsystems link production and consumption. Supermarkets developed rapidly in Western Europe in the 1960s (Oosterveer, 2012), leading to a concentration of grocery sales. Supermarket chains dominate food retail activities, especially in the UK where independent food retail shops have almost vanished since the 1980s (see Figure 16), and exert considerable influence on the configuration of agri-food systems (up- and down-stream). This retail model implies significant challenges to manage the purchase, stocking, display and sale of a large variety of goods – exacerbated in the context of perishables (milk, bread, vegetables, meat) –, which have been met with innovations in logistics and standard-setting (e.g. in the context of own-brands).
Food consumption sub-systems, located downstream from supply-chains, link food with its primary natural functions (eating, bodily health). Food consumption is an inherently cultural practice, traditionally associated with positive meanings (e.g. joy, quality of life, sociability, pleasure, sharing). User engagement is far greater than for other domains (where users are comparatively ‘passive’) with food shopping, cooking and eating practices, but also a relatively low degree of consumer knowledge (about e.g. food provenance), because supply-chains have become increasingly complex, heterogeneous, long, focussed on seamless convenience, and difficult to scrutinise. Kitchens are central bottlenecks where meals are prepared by combining and cooking ingredients, whether in the home or in restaurants. ‘Convenience food’ (e.g. takeaways, ready-meals, processed cooking ingredients) has grown in importance (Carrigan et al., 2006). The explosion of ready-meal consumption is a particularly British phenomenon, dominated by retailers:

> “while the demand for ready-meals across Europe rose by 29% between 1998 and 2002, the UK market increased by 44% over the same period. In the UK, supermarket own-brand products dominate the ready-meal market […] taking an estimated 90% market share” (Jackson and Viehoff, 2016:3)

Food consumption habits have changed to incorporate a greater amount of processed or convenience foods (through e.g. snacking, heating of ready-meals, labour-saving preparation), as well as fatty and sugary foods and drinks. The UK is leading Europe with a growing tendency for the consumption of processed foods (Monteiro et al., 2018), which are linked with increasing likelihood of health problems such as obesity, and are relatively cheap in as compared to other countries (Moubarac et al., 2013). Healthier foods have also become consistently more expensive in the UK from 2002 to 2012 (Jones et al., 2014).

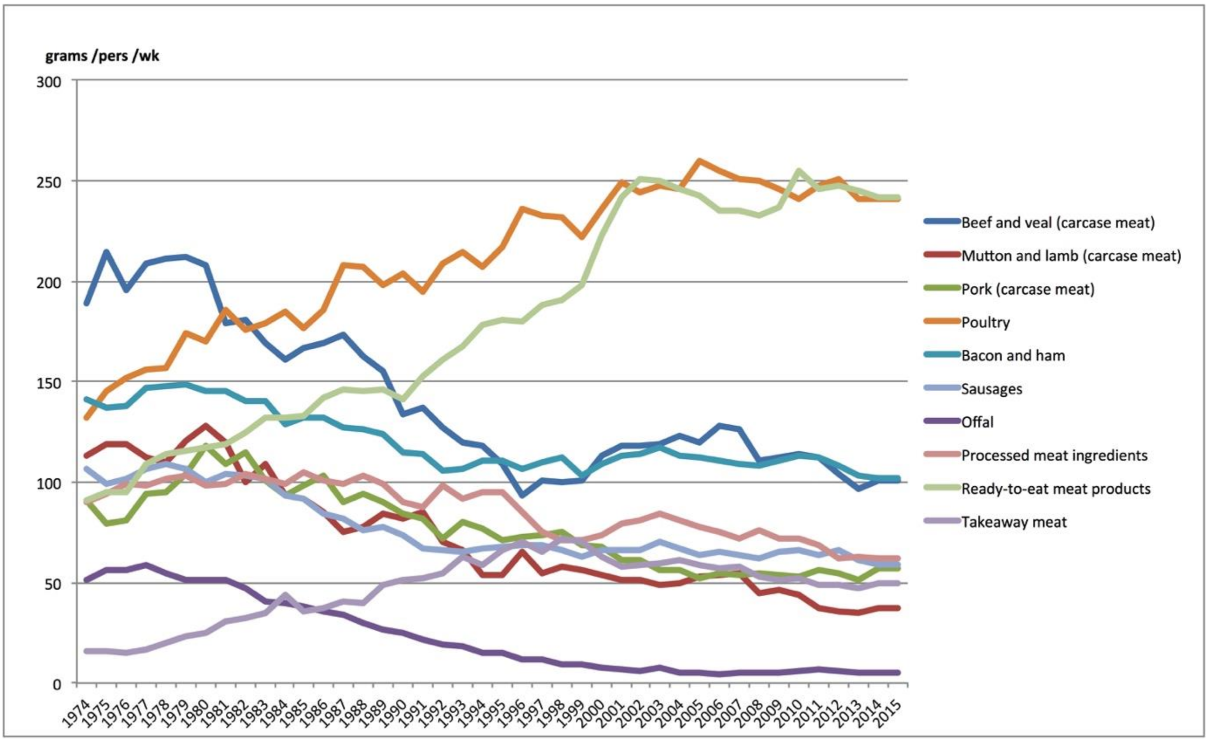

Figure 13: Per capita weekly meat consumption in the UK (1974-2015) (data: DEFRA Family Food statistics)

5.2 Actors and networks

The food domain is characterised by a large number of actors involved in relatively long (often global) and multiple supply chains (see Figure 14). The current configuration results from three long-term trends: a) a lengthening of chains (more actors, longer distance), b) a differentiation of activities (specialisation of actors with industrialisation), c) a condensing of steps (increasing co-dependence through processes, contracts, markets) (Friedmann and McMichael, 1989; van Otterloo, 2005). These processes have been largely enacted and captured by corporate interests (Marsden and Morley, 2014) in what has been described as a 'corporate food regime' (Friedmann and McMichael, 1989), which is attracting increasing criticism from alternative movements pushing for re-configuration (Giménez and Shattuck, 2011).

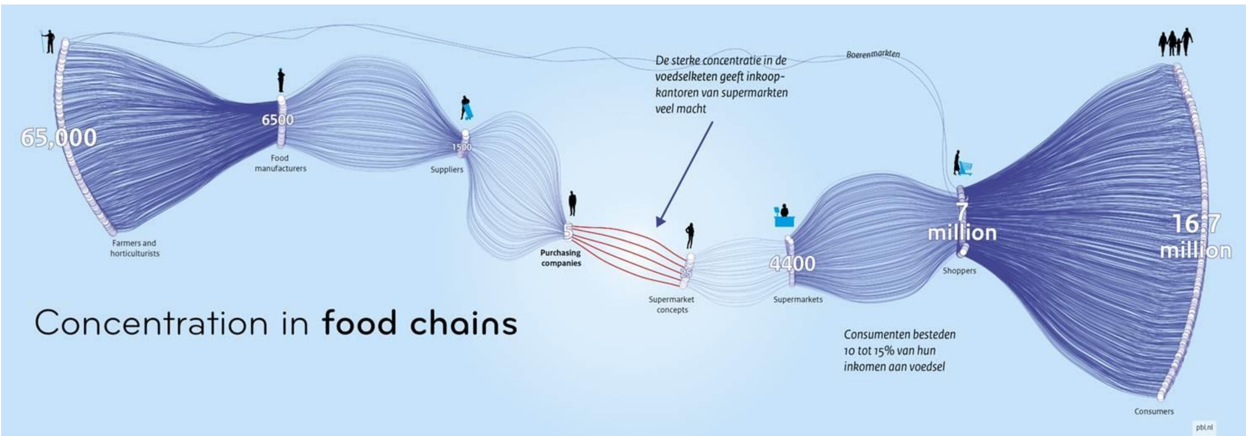

Figure 14: Concentration and relative power positions of commodity chains in the Dutch food system (PBL, 2013: 104-105)

Agriculture and farming in the UK underwent significant changes since the 1950s, including a significant increase of crop area for wheat production (namely 1960-1990), a steady decline of orchards since WWII, a decline of the total number of cattle since 1975 (Bolton et al., 2015). The number of domestic agricultural workers has declined steadily from 900,000 to around 200,000 between 1950 and 2000 (Bolton et al., 2015), due to productivity increases and increasing reliance on imports. European agriculture has undergone significant transformations, and new trends are emerging (Table 2).

Table 2: Longitudinal trends in European farming (based on Atkins and Bowler (2001))

Established trends	**intensification**	increased external inputs, higher yields, less labour
	concentration	larger holdings, economies of scale
	specialisation	monoculture (crops, livestock), genetic homogenisation, regional specialisation
Emerging trends	**diversification**	new crops, on-site processing, new activities (e.g. tourism)
	extensification	lower input, post-productivist, ecological farming

Processing and manufacturing activities, dominated by global agri-food corporations represent an increasing proportion of profits and innovation. There are over 8,000 food and drink manufacturing companies in the UK, representing over 400,000 employees (Lang et al., 2017). The food and drinks industry is the UK's largest manufacturing sector, representing a gross value added over £25bn, and a significant export value. The sector is very diverse (Figure 15). Activities with the highest degree of processing (e.g. food products, meat products, spirits, bakery) tend to be the most profitable (Grant Thornton, 2017). It is a fast-paced industry with a significant degree of innovation (e.g. high number of new product launches), but these are mostly low-tech process innovations (e.g. relatively low investment in R&D, collaborative and incremental innovation) (Trott and Simms, 2017).

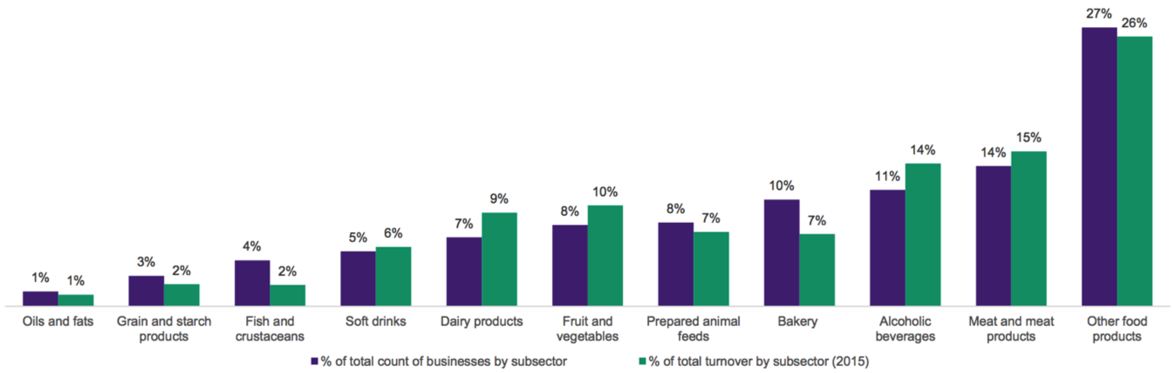

Figure 15: Percentage of businesses and turnover by subsector (Grant Thornton, 2017:17)

Distributers and retailers currently assume a central powerful role (see Figure 14), because of their access to capital to generate economies of scales, and an ability to control food production and processing activities. They constitute a 'focal organisation' group (Dewick and Foster, 2018) with both extensive power (ruling and governing supply-chains) and transformative potential (leveraging influence). Supermarket chains make up over 90% of food and non-alcoholic drink purchases in the UK, with a clear dominance of 'Big Four' retailers in the UK (Tesco, Sainsbury's, Asda, Morrisons), while independent retailers have receded to a negligible fraction of grocery purchases (see Figure 16).

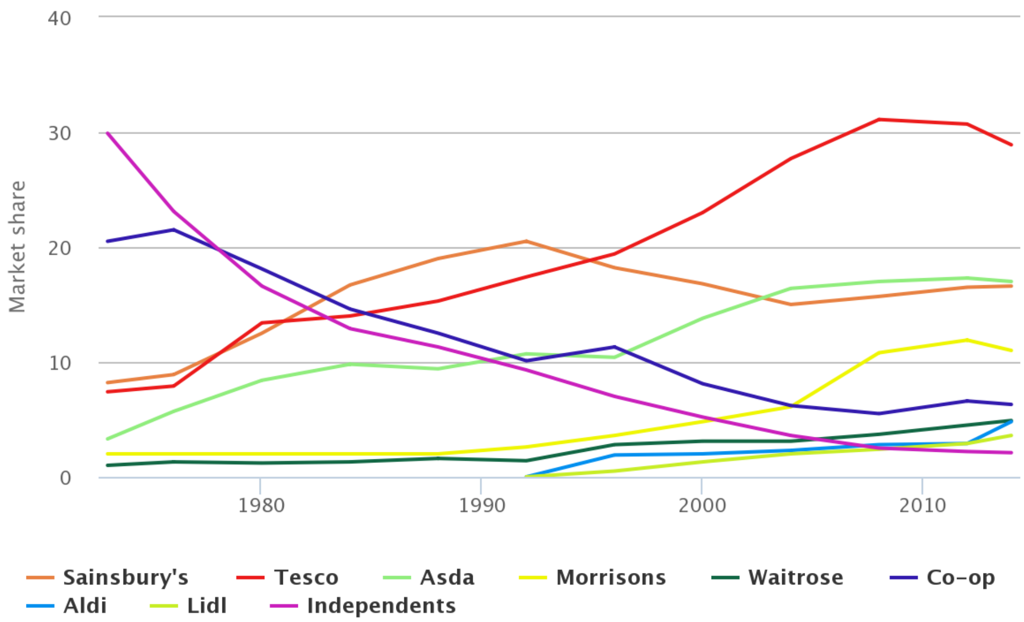

Figure 16: UK grocery industry in the last 40 years (from: http://marumarket.co.uk/the-future-of-the-grocery-industry/).

Large retailers exert influence well beyond their 'traditional' retailing role (Oosterveer, 2012; Spaargaren et al., 2012a): a) upstream, retailers have expanded their business by developing own-brands, imposing product standards (quality, safety, environmental) and other conditions on suppliers in exchange for premium contracts (Dewick and Foster, 2018), b) downstream, retailers increasingly engage with consumers by introducing new products, closely monitoring consumer trends (namely enabled by ICT, e.g. loyalty cards) and editing choice. This enables them to set trends, and to capture and frame emerging visions (as evidence by the adroit accommodation of alternative food visions such as organic food) (Marsden, 2012). We however also note emerging pressures, competition (between retailers), which are underpinning shifts in business models (e.g. away from the suburban hypermarket and towards smaller, more central shopping units)[7], and a growing market for online food shopping (Hoolohan et al., 2016).

Consumers. Food consumption in the UK has increased from 985 to 1148 kg/cap/yr between 1987 and 2008 (de Ruiter et al., 2016). UK consumers spend around 10% of their income on food, rising to 16% for poorer households (DEFRA, 2017b), which remains relatively low by European standards. Lee and Worth (2017) suggest four broad long-term food consumption trends: a) 'utilitarian' (rationing in the 1950s and ensuring food security thereafter), b) 'exotic' (e.g. towards more adventurous ingredients in the 1960s), c) 'convenience' (ready meals and product innovation in the 1970s and 1980s), and d) 'healthy' (organic, free from etc. in the 2000s and 2010s). We see these as overlapping rather than sequential trends. Compared to other domains, food consumers face much greater choice, yet consumption patterns are characterised by routine purchases and taken-for-granted behaviours, which suggests a tendency for only gradual change in the absence of stronger signals (e.g. price, legitimacy, societal and health concerns).

Overall milk consumption reduced and shifted to lower-fat milks from the 1980s, denoting increasingly health-aware behaviours in line with dietary recommendations, while an emerging market for plant-based milks has emerged more recently. Total meat consumption has substantially risen since the 1950s (Hoolohan et al., 2016), followed by a slight decrease from the 1980s, and significant shifts (from red meat to poultry during the 1980s and 1990s, towards more processed and ready-to-eat meats from the 1990s) (Figure 13).

---

[7] FT 20120823_Outside the big box

Attitudes to food consumption are also evolving, including a renewed popular interest in food (evidenced by e.g. increasing media coverage of recipes, restaurants, celebrity chefs, 'foodie culture') over the past 10 years, increased consumer distrust in food systems with numerous crises and scandals related to food safety (Kjaernes and Torjusen, 2012:86-9), and increasingly reflexive and environmentally-aware consumers. This is generating scope for further food differentiation (e.g. organic, local, fairtrade, heritage), the development of substitutes (e.g. plant-based proteins, plant-based milk), dietary shifts (e.g. less meat), and greater attentions to issues like food waste.

Policymakers. Policymakers played a strong strategic role in agricultural planning oriented towards achieving food security and productivity increases through technological innovation (i.e. productivism) until the 1980s. With the advent a neo-liberal agenda, policymakers have receded in the background and focussed primarily on supporting the development and consolidation of agri-food chains, the commodification of markets, relying on regulation (at increasingly supra-national level) and self-regulation to generate stability and address externalities. Since 2010, the UK Government has effectively "den[ied] its own powers in influencing agri-food" (Marsden and Morley, 2014:17), and has accordingly become significantly influenced by agenda-setting from the food industry:

> "While representatives of the powerful food industry meet regularly with Defra officials and ministers, there is no comparable regular engagement with representatives of public health, consumer or environmental interest groups" (Lang et al., 2017:38)

Accordingly Government has taken a long-term hands-off approach to food governance:

> "Except for some public campaigns on climate change, the UK government has persistently chosen for a hands-off approach when it comes to increasing sustainability in food provision. There has been little leadership from the Government" (Oosterveer, 2012:166)

5.3 Rules and institutions

Policy and governance styles. UK Agri-food policy traditionally focussed on affordable food (Lang and Schoen, 2016), agricultural production and farmers, delivered via a technologically-driven agenda of productivity improvements (productivism) (Marsden, 2013), addressing the needs and interests of farmers (exceptionalism, namely with the Common Agricultural Policy) (Tosun, 2017), and market liberalisation as means to drive food costs down. The rise of global food chains and the emergence of new forms of environmental, health, and sanitary concerns have considerably extended the scope of agri-food governance (i.e. from 'farm to fork'), blurring existing boundaries between agricultural, health and environmental policy (Loeber, 2011), and international trade and competition constraints (Havinga et al., 2015b). In the UK, agri-food governance is characterised by a 'hands-off' approach (Oosterveer, 2012), aligned with a liberal market economy model (Hall and Soskice, 2001), in which retailers have assumed a central role.

Risk-based food safety regulation and standards are particularly important in the UK context (e.g. Food Act 1984, Food Safety Act 1990, creation of the UK Food Standards Agency (FSA) in 2001). The BSE and other sanitary crises strengthened the role of legislation – notably the 2002 General Food Law (Self, 2017) and the creation of the European Food Safety Authority (EFSA). Food safety concerns have been met by increasingly hybrid form of governance in the UK (Marsden, 2012) underpinned by a new social contract by which "[p]roducers and suppliers have become primarily responsible for food safety, while national governments have become responsible for controlling the adequacy of risk controlling mechanisms of companies in the food chain" (Havinga et al., 2015a:12). Accordingly, agri-food governance is characterised by a combination of public, private, and hybrid regulation, and the proliferation of standards and labels initiated by industry, trade association, or civil society.

The global food commodity crisis (2007-8) triggered the Food Matters report (Cabinet Office, 2008), highlighting inherent problems in the food system, and charting a new direction for healthier and low-carbon food supply. This was followed by a number of reviews into the challenges and possible futures of food and farming (e.g. DEFRA, 2013, 2010; Foresight, 2011), suggesting key actions such as supporting dietary changes to address health concerns, sustainable food supply (including a new emphasis on localism), and reducing environmental impacts from food and farming (including cutting back on waste). These objectives and roadmaps have so far fallen short from systematic translation into specific targets, commitments, interventions and responsibilities (Refs), besides soft policy measures such recommendations and guidelines for healthy and sustainable food consumption behaviours (Gonzalez Fischer and Garnett, 2016),[8] experimentation with carbon labelling of food products (Refs), voluntary pledges, programmes to raise awareness and tackle food waste[9], the recent introduction of a levy on sugar-based drinks, or local public procurement (e.g. school meals) to support more local or organic food consumption. The limited nature of policy interventions addressing the *structure* of food systems has been credited to the strong opposition of industry, retailers and farmers to more stringent action (Refs), budgetary cuts on relevant governmental departments, and more recently the disruptive Brexit context. Brexit has shifted priorities towards increasing domestic food supply (e.g. reduce EU imports) and bolstering the international competitiveness of British exports (e.g. around values of pride and heritage). There are concerns that a Food Brexit may lead to a lowering of UK food standards as it aligns further to its main non-EU trade partners (Lang et al., 2017) and mitigates the impending risks of food insecurity.

Societal debates. Agri-food systems are characterised by a multiplicity of overlapping societal debates, with shifting emphasis over time (Table 3). Current concerns include rising costs of food products (food security and food banks, especially since 2007-8, and more recently with Brexit), food scandals and food scares (e.g. BSE, dioxin, horsemeat), animal welfare, the countryside, and health (e.g. obesity, malnutrition, toxicity, carcinogenicity). Environmental issues are largely restricted to local problems (e.g. water or air pollution) and problems with strong health-environment interactions (e.g. pesticides, GM-crops), while climate is less central.

Table 3: Layering of societal concerns around food (after Spaargaren et al., 2012a)

Period	New societal concern
1950s-1960s	Safe, convenient, cheap
1970s-1980s	Fertilizers, pesticides
1980s-1990s	Risk, taste
2000s-2010s	Animal welfare, fair trade
2010s-beyond	Sustainability, climate, security

Concerning the societal voices advocating for agro-ecological change, we note the long-term role of traditional environmental NGOs (e.g. RSPB), more media-savvy NGOs (Friends of the Earth, Greenpeace, WWF), scientists, and private advocates on these matters. Together, they have contributed to raising the profile of re-thinking food chains (e.g. questioning meat consumption) in public organisations (e.g. FAO's landmark report *Livestock's Long Shadow* (Steinfeld et al., 2006))

[8] The Ministry of Food issues nutrition advice, particularly since wartime food shortages and rationing. The Committee on Medical Aspects of Food and Nutrition Policy (COMA) report issued nutritional recommendations and introduced Dietary Reference Values. More recently, the "The Health of the Nation" report (1991) led to the set up a nutrition task force, "The Balance of Good Health" was launched in 1994, revised and renamed "The Eatwell plate" in 2007.

[9] See campaigns and action plans delivered by the Waste and Resources Action Programme (WRAP) since 2007 http://www.wrap.org.uk/ (notably the "Love Food Hate Waste" awareness campaign). The Food Waste (Reduction) Bill, introduced in 2015, never made it past the first Commons reading.

and with the public (e.g. the 'Meat Free Monday Campaign' established in 2009 (Morris et al., 2014)).

There is evidence of the emergence of new kinds of food consumption patterns, with 'empowered' consumers expressing new demands (Spaargaren et al., 2012c) and value-based orientations (e.g. health, sustainability, fairness, community). In this context, food consumption has become the location for a new kind of politics centred around *consumer-citizens*. This is leading to ambivalent results: on the one hand, it can support emerging practices by which food consumers engage in new ways with agro-food systems, by-passing or challenging conventional systems (capitalist, industrial) in favour of alternative practices (short circuits, farmers' markets, direct sale, etc.); on the other hand, emerging consumer demands for healthier, more sustainable produce have generated new markets (for organic foods, fairtrade, local foods, etc.) that have largely become captured by retailer-dominated systems for which labelling and certification schemes have been instrumental (Oosterveer, 2012).

Cultural conventions.
Link to broad conventions, e.g.
- Positive value associations (nurturing, good health, pleasure, conviviality, family)
- Changing meaning of the meal (decline of the family meal, rise of snacking), linked with broader socio-economic patterns (family structures, urbanisation, working patterns)
- Increasing focus on convenience (Carrigan et al., 2006)
- Meat and milk have until recently largely been associated with positive meanings (e.g. nutritional value of animal protein)
- Gendering of food, with e.g. meat representing a "totem of virility and strength" (Newcombe et al., 2012), gendered attitudes to healthy eating (Jensen and Holm, 1999), etc
- Significant variability of eating practices depending on income (Refs), and age
- various eating practice typologies (e.g. Poulain 2002, Fischler 1990, xxxx), suggesting that they vary over times and situations.

Such conventions have become institutionalised through e.g. dietary recommendations (Foster and Lunn, 2007)
- advice on importance of milk consumption (a pint a day),
- similar advice on meat

5.4 Low-carbon innovations and alternative configurations

Overview of low-carbon performance. The highest climate impacts are observed with meat and dairy products (Notarnicola et al., 2017, see also Figure 10). While UK agriculture contributes only a small fraction of total UK CO2 emissions, it generates over 70% and 50% of national Methane (CH4) and Nitrous Oxide (N2O) emissions, respectively (DEFRA, 2017a). The bulk of food-related GHG emissions in the UK are linked to methane (CH4) emissions from enteric fermentation and animal waste, and direct Nitrous Oxide (N2O) emission, largely from fertilised land. Comparatively, food-related CO2 emissions are primarily derived from energy-intensive processes (e.g. mechanised farming, freight, distribution, processing, packaging).

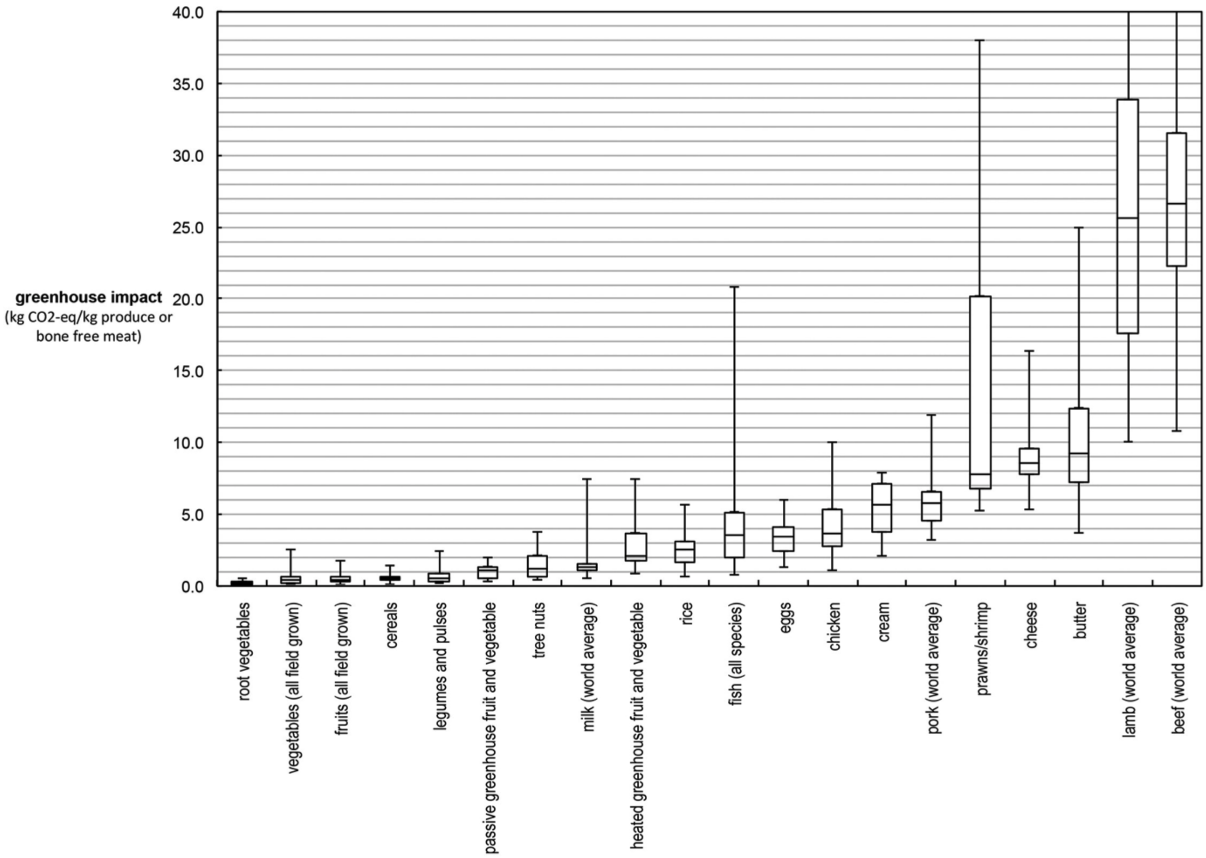

Figure 17: Global Warming Potential of broad food categories (Clune et al., 2017)

Figure 18 shows a decline of emissions from domestic agriculture since 1990. However, shifting the focus from domestic agricultural production to the requirements of domestic food consumption reveals important unaccounted impacts. Indeed, growing per capita and total UK food consumption and an increasing reliance on imports has led to an overall displacement of environmental impacts (de Ruiter et al., 2016), which are not reflected in national inventories (Audsley et al., 2009), but represent between 15 and 28% of national GHG emissions in developing countries (Garnett, 2011).

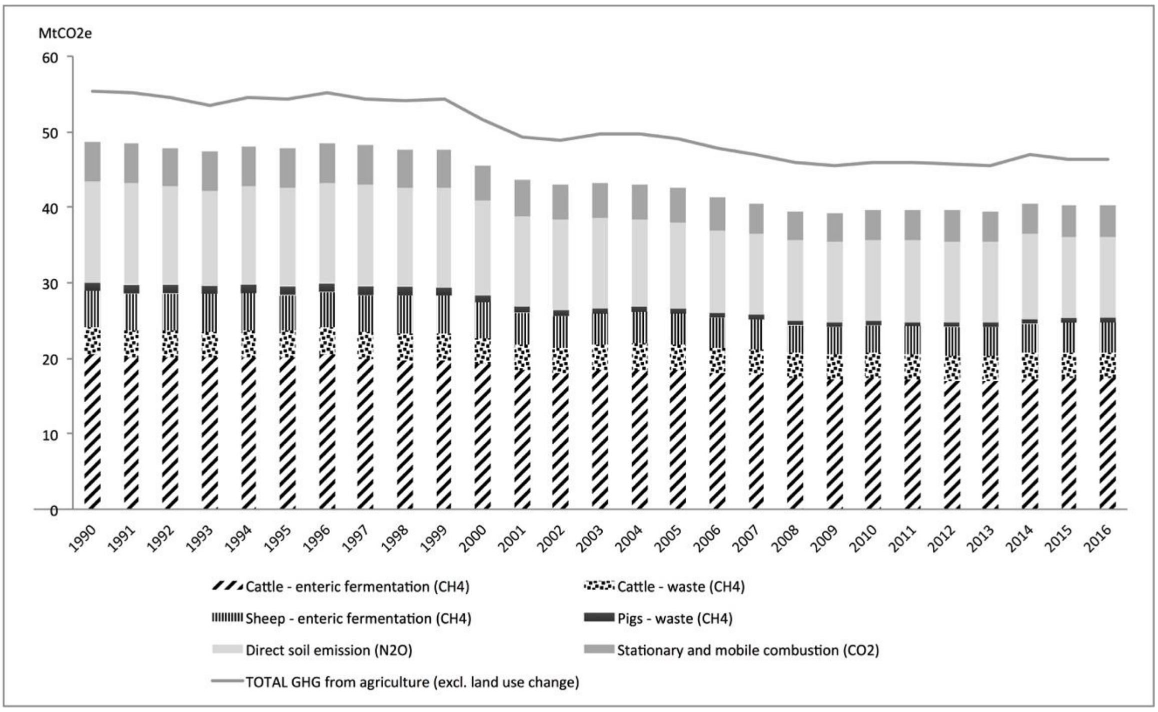

Figure 18: GHG emission from UK agriculture, selected emission sources (Data: BEIS, 2018)

Main low-carbon innovations.
What, then, are the main opportunities for climate mitigation within agri-food systems, what is their potential, and how can we evaluate their momentum? Table 4 presents an overview of GHG mitigation options in different parts of agri-food chains, illustrating the wide variety of possible approaches and entry points.

Table 4: An overview of GHG mitigation in agri-food chains (based on (Audsley et al., 2009; Bryngelsson et al., 2016; EEA, 2017; Garnett, 2011; Smith et al., 2007)

	Production	**Processing and distribution**	**Consumption**
Carbon sinks, removals and indirect emissions	Degraded land restoration, afforestation, reduced tillage		Avoid foods contributing to deforestation (e.g. palm oil, some livestock)
Efficiency, productivity and optimisation	Optimise input use (e.g. precision farming, synergistic crop rotations) Yield improvements (e.g. optimised breeding, feed, pest management)		Reduce overconsumption Eat no more than needed to maintain a healthy body weight
Circularity (reduce loss and waste)	Re-use of outputs (e.g. manure, biomass) through new processes (composting, anaerobic digestion) Livestock production based on by-products (eliminate specialised feed) Permaculture, organic agriculture	Reduce food losses and waste Retail waste reduction (e.g. discounts, improved inventories, donations) Recycling and re-use (e.g. valorisation) Reduce packaging	Avoid and reduce food waste Better food planning Manage unavoidable waste properly Consume products and by-products (e.g. all meat cuts)
Reduce fuel inputs	Energy efficiency improvements Shift towards cleaner fuels	Energy efficiency improvements (transport, refrigeration, processing) Shift towards cleaner fuels Reduce food transportation	Eat more local, seasonal, field-grown rather than high-input foods (cultivation, refrigeration, transport) Cook in batches

			Shop by foot or online
Agro-ecological system shifts	Organic and sustainable agriculture Sustainable intensification Ecosystem-based management Local production	Sourcing, labelling, and availability of organic and sustainable products Shortening food chains	Organic and sustainable food consumption Seasonal and local consumption
Support dietary shifts	Reduce enteric CH4 emissions from ruminants Shift to low-input low-impact crops (e.g. away from rice)	Meat substitutes (e.g. fungal protein, tofu, pulses) Diary substitutes (e.g. plant-based)	Reduce (red) meat and dairy consumption Accept variability (e.g. seasonal) of food supply

While to date, most focus has been set on voluntary measures and efficiency improvements, there is growing scientific consensus about the need for dietary shifts, more attention to issues of waste reduction throughout food chains, and more ambitious agro-ecological transformations.

Low-carbon innovations in agri-food chains concern a) productivity-oriented sustainable intensification of agriculture (e.g. selective breeding, feeding, GMs), b) the re-use of outputs (e.g. biomethane production from enteric fermentation or anaerobic digestion), c) supply-chain optimisation, and d) the development of substitutes (e.g. meat and dairy alternatives).

Amongst dietary shifts, reducing (red) meat consumption presents significant potential (de Ruiter et al., 2017; Hedenus et al., 2014; Herrero et al., 2016), because livestock (and particularly cattle) represents 70% of land use and over 50% of GHG emissions from agriculture (Audsley et al., 2009; Steinfeld et al., 2006). Dietary shifts are primarily driven by behaviours and preferences, but can significantly be enabled by innovation (e.g. plant-based substitutes). However, there is only limited evidence that such dietary shifts (e.g. vegetarian diets, less meat, local and seasonal products) is happening on the ground. UK meat consumption has been relatively stable in the last 10-20 years. Insofar as dietary shifts have happened, they are probably more related to health and cost concerns than to environmental considerations (Refs). Meat substitutes remain a small market (< 5%), primarily among vegetarians and meat reducers (Apostolidis and McLeay, 2016). Morris et al. (2014) further suggest that whilst meat reduction initiatives are diffusing in the UK, they remain a relatively radical proposition with a small niche base.

Reducing food waste throughout food chain presents an important measure for decarbonisation (WRAP, 2017), presenting low-hanging fruits and win-win situations (e.g. associated cost reduction, reputational gains). It has however been claimed that tackling waste may have less decarbonisation potential than dietary shifts or technological options (Bryngelsson et al., 2016), suggesting that efficiency measures will not be enough to support significant decarbonisation of food systems (Green et al., 2015).

Agro-ecological transformations (e.g. organic, ecosystem services, permaculture) are relevant avenues for change that could underpin a paradigm shift in favour of leaner modes of production and consumption. Organic produce has experienced significant growth in recent years Figure 19. In the UK, these innovation and alternative propositions are largely becoming incorporated within the current (retail) regime (e.g. as additional product lines and diversification around new consumer choices, generating market opportunities and further legitimation) (Marsden and Morley, 2014), although we also note the continued growth of an undercurrent of "direct marketing outlets such as farmers' markets, farm shops, and vegetable box schemes" (Kjaernes and Torjusen, 2012:95), and a growing share of independent retailers on the organic market (nearly 30%) (Soil Association, 2018).

Figure 19: UK sales of organic products (million GBP) (Soil Association, 2018:5)

Low-carbon reconfigurations.

The agro-food is a distributed system, both in terms of network chain (inputs, primary production, processing, retail, consumption, waste) and technologies/innovations (there is not one dominant technology that can be replaced, but there are many innovations that together make the system work). This means that transitions are likely to follow a gradual reconfiguration pattern where many innovations need to be aligned (Meynard et al., 2017), rather than a disruptive substitution pattern. Low-carbon agri-food transitions are likely to emerge from the framing of alignments between various transformation agendas (Gordon et al., 2017), but currently such alignments are not clearly emerging, in part due to the inherent variety of actors and products involved.

In terms of alternative options, there are no niche-innovations currently enjoying sufficient momentum to break through. So, instead, we see three parallel developments: 1) the gradual tightening of standards/regulations, which mostly lead to incremental reform, e.g. ecologization of agricultural policy (Lamine, 2011), with a tendency to further lock out alternative niches (Vanloqueren and Baret, 2009), 2) the proliferation of many small niches (Marsden, 2013) which tend to be fragmented (focused on different issues, and enacted by different movements), and 3) in-between, certification and labelling schemes (organic, fairtrade) were introduced to regain consumer trust and orient choices (van Otterloo, 2012), with a tendency for reproducing or exacerbating existing power asymmetries:

> “the situation in the UK is primarily an example of the leading role retailers can play in the promotion of more sustainable food provision. This has not resulted in a radical transformation in food provision but essentially a rearrangement of socio-technical characteristics of food production, trade and retail and of the images on food quality and sustainability constructed at the shop floor. The overriding orientation in this rearrangement is towards responding better to public and consumer concerns” (Oosterveer, 2012:166)

Dietary shifts, which may the one option with the largest potential, is also perhaps the most difficult option for which to envisage legitimate and effective interventions, due to its inherent link to behaviours and preferences.

So, radical normative food visions have become translated into:

- an increase in product differentiation and quality distinctions (labels, provenance, growing methods), along largely **<u>incremental and progressive-reformist paths</u>**, dominated by large retailers
- the emergence and growth of alternative practices and networks along **<u>more radical or even revolutionary paths</u>**, which however still remain small but are growing steadily.

6 Heat domain

TO BE DONE

6.1 Systems and longitudinal trajectories

6.2 Actors and networks

6.3 Rules and institutions

6.4 Low-carbon innovations and alternative configurations

7 Mobility domain

TO BE DONE

7.1 Systems and longitudinal trajectories

7.2 Actors and networks

7.3 Rules and institutions

7.4 Low-carbon innovations and alternative configurations

8 Comparative analysis and discussion

We have analysed low-carbon transitions in three different domains, evidencing different speeds and patterns of change. A comparative analysis allows us to provide some explanation in terms of deep-structural differences in system architectures, the position of dominant actor coalitions, and the influence of institutions and governance styles. Table 5 presents an overview of main trends for the electricity and agri-food systems, based on the conceptual categories introduced in section 2.

[This section is currently based on the analysis of electricity and agri-food systems only]

8.1 Static domain comparison of systems, actors, institutions

Socio-technical **system configurations** are very different. The UK electricity system is highly integrated around a single homogenous product, for which the grid acts as a buffer. The agri-food system is much looser and complex, characterised by a large variety of product classes with numerous (often global) supply chains. Supermarket retail has assumed an increasingly central role. These contrasts suggest that there may be greater scope for focussed interventions in the electricity system, which appears more simply structured, whilst the inherent complexity of the agri-food system is much more difficult to seize. Recognising the central role of food retail appears as a sound entry point for more focussed transformation strategies.

Dominant **actor coalitions** are also different. The electricity system is largely structured around a small number of large and powerful incumbents in power generation, distribution and appliances, who interact closely with policymakers; users are largely passive, captive and disengaged. Whilst there has been some opening up to new entrants in recent years, and some interest in small-scale (user or community-led) systems, the socio-technical regime for electricity favours large-scale organisations. Similarly, the agri-food system is dominated by tens of thousands of farmers (of varying sizes), large global food (processing) industry actors, a few large oligopolistic actors in retail, and millions of consumers. A number of trends are challenging this dominant mode of organisation: the rise of online shopping, a renewed interest in independent retail, and the (limited) development of alternative food networks (e.g. direct sale, farmers' markets). Food consumers are more engaged than in the electricity domain, because food is a culturally embedded and more active practice. But consumers are also disempowered because food systems are difficult to scrutinise.

Institutions and governance styles in both domains are characterised by neo-liberal frameworks. However, while agri-food is characterised by a strong 'hands-off' governance approach, electricity has experienced significant strategic intervention and government influence (although this recently weakened). Agri-food policymaking has prioritised soft interventions (e.g. information, labels, awareness campaigns) and has become almost entirely reliant on industry self-regulation and certification, influenced by persistent industry lobbying. The downsizing of government capabilities in this domain is further limiting its ability to generate direction and incentives for prospective system transformations. In the electricity domain, there is also a strong tendency for negotiations in relatively closed networks involving large incumbents and policymakers, but policy interventions are much more significant and ambitious.

Climate change considerations are not equally important across domains. Climate change has become an important issue and core driver of change in electricity, but not in agri-food, where climate change competes with numerous other societal concerns (e.g. health, sanitary crises, food security, animal welfare, countryside concerns), which many agro-food actors find more important than climate change. For this reason, a number of advocates suggest that low-carbon agri-food transitions may best be pursued by focussing on alignments and linkages between issues, for which climate mitigation would be a co-benefit.

8.2 Speed of change

The speed of change towards low-carbon reconfigurations is also very different. The electricity domain has made most progress, particularly on the generation side (where RET niche-innovations are beginning to replace established technologies like coal), but also on the demand side (where incremental efficiency improvements substantially reduced electricity consumption) and increasingly on the grid side (where architectural reshaping is envisioned).

Comparatively, low-carbon reconfiguration is rather limited in agri-food. There are a number of promising options and niches (e.g. meat-free diets, meat substitutes, local food), some of which have grown quantitatively as they have become assimilated by supermarkets (e.g. organic), but these are overshadowed by persistent negative trends.

These differences can be explained by intersecting mechanisms in different dimensions. **Rules and institutions** are perhaps the most important difference. There is a longer history of societal debates and activism around climate change and energy, which has become a core issue for electricity generation in particular. Large stationary point-sources were the first target of climate policy. The development of RETs to replace fossil fuels (a technological solution) has long been established as the preferred course for action, supported by policy incentives and industry visioning and development in a largely technocratic fashion. The ramp-up of climate policy in 2008 has significantly accelerated the rate of change.

Comparatively, climate change is more of a peripheral issue for agri-food: normative activism focuses on many other issues (e.g. health, animal welfare) and policy is largely disengaged besides fire-fighting on food security issues. While there is growing scientific consensus about the "meat problem" as a central source of food-related GHG emissions, and some public awareness about this, it primarily calls for notoriously difficult behavioural shifts (in diets) in a domain characterised by culturally-laden preferences or large technological solutions (e.g. bio-methane production). Other options (e.g. agro-ecology, sustainable intensification, local and seasonal) are relevant and interesting, but have more diffuse climate benefits. So, the absence of a clear course of action or consensual solution, and the large number of competing visions are further slowing change down.

Systems configurations also present significant differences. In electricity, there has been a long-term interest in technological alternatives to fossil fuels, which generated significant interest since the 1970s oil shocks, benefitted from continued R&D investment, the development of niche markets in different countries, and substantial price/performance improvements, which all contributed to the momentum of a variety of RETs, which are now mature enough to compete with conventional technologies.

Comparatively, low-carbon food alternatives (e.g. meat substitutes, vegetarian diets, agro-ecology, local/seasonal, waste reduction) have not attracted significant capital investments that could command price/performance improvements or significant market creation. Organic food is one exception to this trend, which has emerged in alternative networks primarily driven by grassroots organisations and has recently become mainstreamed as large retailers have shown interest in an expanding market, but it is only indirectly linked to climate benefits. Meanwhile, conventional industrial agri-food systems continue to display economic attractiveness, further reducing the potential for a rapid shift. Indeed, agri-food in the UK is largely determined by deep structural trends (lengthening, differentiation, condensing of chains; intensification, concentration, specialisation of farming; shift towards convenience and processed foods) that are still on-going.

Differences in the underlying **actor coalitions** further explain varying pace of change. In electricity, incumbent firms have recently taken a more active stance in carbon reductions, investing in RET to diversify their portfolios (i.e. strategic re-orientation) and actively engaging with policymakers (in relatively closed networks) to retain their influence on the transition agenda. This has contributed to a clearer transition path.

Comparatively, dominant agri-food actor coalitions (e.g. large retailers and industrial farming) have not engaged significantly with carbon reductions. A combination of low societal/policy pressure for change and a relatively lax governance style further strengthens the status quo. Alternative food networks, primarily focussed on by-passing conventional agri-food systems and building on the emergence of consumer-citizens provide a radical counterpoint to these trends, but are not yet showing signs of momentum significant enough to threaten the established regime. Additionally, different generations of alternative food agendas have become absorbed and mainstreamed into conventional food chains (von Oelreich and Milestad, 2017) in a seesaw pattern – further watering down their transformative claims.

8.3 Reconfiguration patterns

Our analysis also highlights significant differences in terms of reconfiguration patterns.
In the electricity system, the main pattern is and incumbent-led, controlled and negotiated transformation. It involves a combination of radical technical component substitution in power generation, which is triggering a knock-on effect on the distribution grid faced with a need for architectural re-shaping to cope with emerging RET-related challenges. So, this pattern is beginning to shift from diffusion of new technology to wider system reconfiguration, including architectural change.

In the agri-food system, the reconfiguration pattern is rather erratic and unambitious, as it is characterised by the overlapping and competition of many issues, with no clear option or portfolio of options achieving consensus, and a lack of political will to guide change in a clear, long-term direction and develop appropriate signals. The deep-seated corporatist food regime engages in slow, incremental change (gradual transformation), but shows little sign of radical change, despite significant criticism about systemic food challenges. Indeed, the agri-food system’s ability to minimise pressure for change, avoid blame, selectively translate emerging innovations (e.g. organic certification), and influence consumer preferences is remarkable.

Table 5: Dominant configurations, niche developments and reconfiguration patterns in UK electricity and agri-food

			Electricity	Agri-food
Dominant configuration	**Systems**	**Production**	Radical technical component substitutions (large-scale RETs, fuel switches, hybridisation)	Ambiguous (continued intensification, mainstreaming of alternatives like organic via standards)
		Distribution /retail	Incremental innovation and add-on niche innovations Knock-on effects: stress on current architecture	Continuation of trends (increased processing, packaging, transport) Incremental diversification (e.g. organic)
		Consumption	Incremental efficiency improvements and add-ons Knock-on effect: focus on demand	Early signs of stabilising negative trends (e.g. meat consumption) Emergence of new behaviours and markets (organic, meat/dairy substitutes)
	Actors	**Production**	Policy-led gradual reorientation of incumbents Closed networks	Hands-off policy style benefits intensive farmers, confuses smaller alternative farmers Increasing stress?
		Distribution /retail	Gradual reorientation of distribution actors Closed networks	Continued dominance of large retailers engaged in BAU and marginal co-opting of new consumer demands (e.g. organic) Emergence of new entrants (small retail, online retail, closed circuits)
		Consumption	Disengaged consumers Policy-led gradual reorientation of appliance manufacturers	Relatively active consumers but problematic price signals Disempowered consumers (increasing awareness of problems, but difficulties navigating)
	Rules and institutions	**Production**	Strong policy push has recently weakened Top-down technocratic style Knock-on effect: low social acceptance	Reformist orientation (farmer subsidies, sanitary regulation, landscape requirements) Domestic food security as potential new source of change Limited support for exploration (e.g. domestic food security, organic) Multiplication of standards (e.g. organic) and concerns about 'watering down'
		Distribution /retail	Incremental change towards innovation support within neo-liberal market arrangement	Neoliberal corporate regime with reformist orientation (standards and self-regulation) Limited intervention (policy reluctance and industry opposition)
		Consumption	Gradual strengthening of standards Low salience of demand-side (besides smart meters)	Increasing recognition of problems and co-benefits (e.g. environment and health) Limited intervention (policy reluctance and industry opposition) Policy focus on information, advice, encouragement
Niches		**Systems**	Small-scale RETs, self-generation	Agro-ecology, precision farming, organic farming, behavioural shifts (e.g. meat-free, dairy-free) supported by substitutes
		Actors	Community initiatives, individuals, ESCOs	Agro-food networks (closed circuits, direct sales, box schemes) Emergence of engaged citizen-consumers seeking to challenge industrial regime
		Rules and institutions	Unstable incentives (recent cutback) Legal barriers hindering development (e.g. requirements to supply to grid)	Radical values (e.g. re-invest profits, social economy) ≠ mainstreaming (standardisation and certification) Low policy support (led by citizen-consumer)
Implications for reconfiguration		**Speed of low-carbon transition**	Low-carbon transformation under way, with increasing momentum and speed	Very early stage: increasing problem recognition, and emerging niches but continued growth and stability of dominant configuration
		Overall transformation pathway	Incumbent-led, controlled and negotiated transformation Shifting gear: from incremental RET diffusion to system reconfiguration	Erratic and unambitious: many issues, no clear option, no clear political will/agency Difficulties escaping corporatist regime and neo-liberal orientation 2 emerging trajectories for niche-innovation: - mainstreaming co-opting - radicalisation (alternative food networks and short chains)

9 Conclusion

We started this paper from the observation of varying speeds and patterns of low-carbon transitions in different domains. Seeking to understand and explain these comparative differences, we proposed to build on the Multi-Level Perspective but attend more specifically to *whole system reconfigurations*, and to harness the potential from *domain comparisons*. We here conclude on the value and potential of such an approach.

Empirically, we observed significant progress with decarbonisation since the 1990 (see Figure 1). However, this progress is very unbalanced, and mainly concerns the electricity sector. Other domains displayed slow decarbonisation rates, as well as some worrying negative trends. The UK therefore does not appear to be on track to meet its long-term decarbonisation objectives. The slow rates of change can largely be explained by a combination of three processes. First, hands-off governance styles and neo-liberal market logics tend to reinforce existing (unsustainable) socio-technical configurations and fail to a) provide strategic guidance for transformative change, b) support the development of alternatives, c) incentivise proactive citizen, users, business, and d) constrain high-carbon developments. Second, all domains are characterised by the concentration of power in a small number of large corporate actors ("Big Business") in oligopolistic market structures. This further reproduces the status quo, and tends to constrain decarbonisation processes to incremental changes (efficiency, optimisation, or technological component substitutions), rather than opening up prospects for broader and deeper reconfiguration patterns (e.g. radical component substitution, architectural change). Oligopolistic market power also raises market entry barriers for radical challengers and new entrants. Third, the momentum of radical alternatives remains relatively low and diffuse, except in the electricity domain. The multiplication of fragmented alternative models (especially in agri-food) further weakens the drive for substantial reconfiguration.

Conceptually, we suggest that a whole system reconfiguration approach is relevant for understanding low-carbon transitions, generating several insights. First, it is relevant to focus on 'whole systems' (encompassing production and consumption), as opposed to individual actors or niche-innovations, because it allows us to understand change dynamics beyond conventional boundaries, and attend to the big picture. It is nonetheless useful to identify smaller sub-systems (where specialised activities take place), how they relate to each other, and analyse the degree and direction of change therein. Doing so allows us to better understand where reconfiguration is likely to emanate from and how it may be transmitted, supported, or obstructed by the wider system. Second, it is relevant to analyse different dimensions of low-carbon transitions (systems, actors, institutions), as they relate to different change mechanisms. Such an analysis makes it possible to identify where change dynamics are particularly strong/weak, fast/slow, radical/incremental. For instance, we see limited empirical evidence of deep cultural changes (e.g. voluntary downshifting, frugality, thrift, sufficiency, de-growth) that proponents of 'great transformation' advocate (Brown and Vergragt, 2016; Göpel, 2016; Raskin, 2016). Our three-dimensional analysis also points to the generally undervalued role of consumers and civil society as potential motors of reconfiguration (e.g. Maarten Hajer's 'energetic society'), which is worrying. Third, a 'whole system' reconfiguration approach allows us to consider low-carbon transitions in relation to wider contexts and related deep-structural trends, which is often neglected. Our analysis shows that we cannot assume that low-carbon objectives constitute the overriding, or even a core driver of change in any particular domain. Attention to wider contextual change points to the competition and overlap of multiple issues. Actors are engaged in continuous struggles and are faced with conflicting signals: societal issues like climate change are only one dimension orienting business strategies, consumer behaviours, or policymaking rationales.

Lastly, even when a societal concern like climate change becomes a central driver of long-term orientation (as it has become in electricity), such contextual driver has to be considered as dynamic and prone to ups and down.

Despite the many challenges and the substantial differences between the systems, we want to end on an optimistic note: the rapid decarbonisation of the electricity system shows that substantial progress *can* be made with strong policies (ambitious targets, implementation strategies, specific instruments, resource mobilisation) that stimulate incumbents to reorient. This requires a shift from hands-off to more interventionist governance styles that actively shape market conditions. While this shift does not yet appear to be imminent in other domains, the electricity system shows that it can be done, even in liberal market economies like the UK.

References

Altenburg, T., Schamp, E.W., Chaudhary, A., 2015. The emergence of electromobility: Comparing technological pathways in France, Germany, China and India. Sci. Public Policy 43, 464–475.

Apostolidis, C., McLeay, F., 2016. Should we stop meating like this? Reducing meat consumption through substitution. Food Policy 65, 74–89. doi:10.1016/j.foodpol.2016.11.002

Arthur, W.B., 1989. Competing technologies, increasing returns, and lock-in by historical events. Econ. J. 99, 116–131.

Atkins, P., Bowler, I., 2001. Food in Society: Economy, Culture, Geography. Arnold, London.

Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., Williams, A., 2009. How low can we go? An assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050.

Battilana, J., Leca, B., Boxenbaum, E., 2009. How actors change institutions: towards a theory of institutional entrepreneurship. Acad. Manag. Ann. 3, 65–107.

BEIS, 2018. Final UK greenhouse gas emissions national statistics 1990-2016.

BEIS, 2017a. Energy Consumption in the UK. London.

BEIS, 2017b. Smart Meters: Quarterly Report to end December 2017. London.

Bergek, A., Berggren, C., Magnusson, T., Hobday, M., 2013. Technological discontinuities and the challenge for incumbent firms: Destruction, disruption or creative accumulation? Res. Policy 42, 1210–1224.

Berggren, C., Magnusson, T., Sushandoyo, D., 2015. Transition pathways revisited: Established firms as multi-level actors in the heavy vehicle industry. Res. Policy 44, 1017–1028. doi:10.1016/j.respol.2014.11.009

Berkers, E., Geels, F.W., 2011. System innovation through stepwise reconfiguration: the case of technological transitions in Dutch greenhouse horticulture (1930--1980). Technol. Anal. Strateg. Manag. 23, 227–247.

Bigelow, B., Fahey, L., Mahon, J., 1993. A typology of issue evolution. Bus. Soc. 32, 18–29.

BNEF, 2018. Global Trends in Renewable Energy Investment 2018.

Bolton, P., Baker, C., Keep, M., 2015. Agriculture : historical statistics. House Commons Libr. 12.

Bolton, R., Foxon, T.J., 2015. Infrastructure transformation as a socio-technical process - Implications for the governance of energy distribution networks in the UK. Technol. Forecast. Soc. Change 90, 538–550. doi:10.1016/j.techfore.2014.02.017

Brown, H.S., Vergragt, P.J., 2016. From consumerism to wellbeing: toward a cultural transition? J. Clean. Prod. 132, 308–317.

Bryngelsson, D., Wirsenius, S., Hedenus, F., Sonesson, U., 2016. How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture. Food Policy 59, 152–164. doi:10.1016/j.foodpol.2015.12.012
Cabinet Office, 2008. Food Matters: Towards a Strategy for the 21st Century.
Carrigan, M., Szmigin, I., Leek, S., 2006. Managing routine food choices in UK families : The role of convenience consumption. Appetite 47, 372–383. doi:10.1016/j.appet.2006.05.018
CCC, 2017. Meeting Carbon Budgets: Closing the policy gap. 2017 Report to Parliament.
Clune, S., Crossin, E., Verghese, K., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. J. Clean. Prod. 140, 766–783. doi:10.1016/j.jclepro.2016.04.082
Cornwall Energy, 2016. Competition in British Business Energy Supply Markets, An independent assessment for Energy UK.
Cumming, G.S., Buerkert, A., Hoffmann, E.M., Schlecht, E., von Cramon-Taubadel, S., Tscharntke, T., 2014. Implications of agricultural transitions and urbanization for ecosystem services. Nature 515, 50.
Darby, S., 2006. The effectiveness of feedback on energy consumption: A review for DEFRA of the literature on metering, billing and direct displays. Oxford.
de Ruiter, H., Macdiarmid, J.I., Matthews, R.B., Kastner, T., Lynd, L.R., Smith, P., 2017. Total global agricultural land footprint associated with UK food supply 1986–2011. Glob. Environ. Chang. 43, 72–81. doi:10.1016/j.gloenvcha.2017.01.007
de Ruiter, H., Macdiarmid, J.I., Matthews, R.B., Kastner, T., Smith, P., 2016. Global cropland and greenhouse gas impacts of UK food supply are increasingly located overseas. J. R. Soc. Interface 13, 20151001. doi:10.1098/rsif.2015.1001
DECC, 2014. Delivering UK Energy Investment. London.
DEFRA, 2017a. Agriculture in the United Kingdom 2016.
DEFRA, 2017b. Food Statistics Pocketbook 2016.
DEFRA, 2013. Sustainable Consumption Report: Follow-Up to the Green Food Project. London.
DEFRA, 2010. Food 2030. London.
Dewick, P., Foster, C., 2018. Focal Organisations and Eco–innovation in Consumption and Production Systems. Ecol. Econ. 143, 161–169. doi:10.1016/j.ecolecon.2017.07.012
Dosi, G., 1982. Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Res. Policy 11, 147–162.
EEA, 2017. Food in a green light: A systems approach to sustainable food. European Environment Agency, Copenhagen. doi:10.2800/884986
Elzen, B., Geels, F.W., Green, K., 2004. System innovation and the transition to sustainability: theory, evidence and policy. Edward Elgar Publishing.
Foresight, 2011. The Future of Food and Farming : Challenges and choices for global sustainability.
Foster, R., Lunn, J., 2007. 40th Anniversary Briefing Paper : Food availability and our changing diet. London.
Franceschini, S., Alkemade, F., 2016. Non-disruptive regime changes�The case of competing energy efficient lighting trajectories. Environ. Innov. Soc. Transitions 21, 56–68.
Friedmann, H., McMichael, P., 1989. Agriculture and the State system: The rise and decline of national agricultures, 1870 to the present. Sociol. Ruralis XXIX.
Garnett, T., 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy 36, S23–S32.

Geels, F.W., 2018. Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective. Energy Res. Soc. Sci. 37, 224–231. doi:10.1016/j.erss.2017.10.010

Geels, F.W., 2014. Regime Resistance against Low-Carbon Transitions: Introducing Politics and Power into the Multi-Level Perspective. Theory, Cult. Soc. 31, 21–40. doi:10.1177/0263276414531627

Geels, F.W., 2005. Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. Technol. Forecast. Soc. Change 72, 681–696. doi:10.1016/j.techfore.2004.08.014

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. Res. Policy 33, 897–920. doi:10.1016/j.respol.2004.01.015

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274. doi:10.1016/S0048-7333(02)00062-8

Geels, F.W., n.d. Low-carbon transition via system reconfiguration? A socio-technical multi-level analysis of unfolding trajectories in Great Britain’s passenger mobility system (1990-2016). Energy Res. Soc. Sci. (under Rev.

Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., Wassermann, S., 2016. The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990-2014). Res. Policy 45, 896–913. doi:10.1016/j.respol.2016.01.015

Geels, F.W., McMeekin, A., Mylan, J., Southerton, D., 2015. A critical appraisal of Sustainable Consumption and Production research: The reformist, revolutionary and reconfiguration positions. Glob. Environ. Chang. 34, 1–12. doi:10.1016/j.gloenvcha.2015.04.013

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417.

Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017. Sociotechnical transitions for deep decarbonization. Science (80-.). 357, 1242–1244.

Giménez, E.H., Shattuck, A., 2011. Food crises, food regimes and food movements: Rumblings of reform or tides of transformation? J. Peasant Stud. 38, 109–144. doi:10.1080/03066150.2010.538578

Gonzalez Fischer, C.G., Garnett, G., 2016. Plates, Pyramids, Planet. Developments in National Healthy and Sustainable Dietary Guidelines: A State of Play Assessment. Rome.

Göpel, M., 2016. The Great Mindshift: How a New Economic Paradigm and Sustainability Transformations go Hand in Hand. Springer.

Gordon, L.J., Bignet, V., Crona, B., Henriksson, P.J.G., Holt, T. Van, 2017. Rewiring food systems to enhance human health and biosphere stewardship OPEN ACCESS Rewiring food systems to enhance human health and biosphere stewardship. Environ. Res. Lett. 12.

Grant Thornton, 2017. FDF Economic contribution and growth opportunities [WWW Document]. URL https://www.fdf.org.uk/publicgeneral/FDF-Economic-contribution-Full-report.pdf

Green, R., Milner, J., Dangour, A.D., Haines, A., Chalabi, Z., Markandya, A., Spadaro, J., Wilkinson, P., 2015. The potential to reduce greenhouse gas emissions in the UK through healthy and realistic dietary change. Clim. Change 129, 253–265. doi:10.1007/s10584-015-1329-y

Grin, J., 2012. Changing governments, kitchens, supermarkets, firms and farms: Th governance of transitions between spocial practices and supply systems, in: Spaargaren, G., Oosterveer, P., Loeber, A. (Eds.), Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity. Routledge, New York, pp. 35–59.
Hall, P.A., 1993. Policy paradigms, social learning, and the state: the case of economic policymaking in Britain. Comp. Polit. 275–296.
Hall, P.A., Soskice, D. (Eds.), 2001. Varieties of Capitalism: The Institutional Foundations of Comparative Advantage. Oxford University Press, New York.
Hand, M., Shove, E., Southerton, D., 2005. Explaining showering: A discussion of the material, conventional, and temporal dimensions of practice. Sociol. Res. Online 10, 1–13.
Hardt, L., Barrett, J., Brockway, P., Foxon, T.J., Heun, M.K., Owen, A., Taylor, P.G., 2017. Outsourcing or efficiency? Investigating the decline in final energy consumption in the UK productive sectors. Energy Procedia 142, 2409–2414.
Hardt, L., Owen, A., Brockway, P., Heun, M.K., Barrett, J., Taylor, P.G., Foxon, T.J., 2018. Untangling the drivers of energy reduction in the UK productive sectors: Efficiency or offshoring? Appl. Energy 223, 124–133.
Havinga, T., Casey, D., van Waarden, F., 2015a. Changing regulatory arrangements in food governance, in: Havinga, T., van Waarden, F., Casey, D. (Eds.), The Changing Landscape of Food Governance: Public and Private Encounters. Edward Elgar, Cheltenham, pp. 3–18.
Havinga, T., van Waarden, F., Casey, D. (Eds.), 2015b. The Changing Landscape of Food Governance: Public and Private Encounters. Edward Elgar, Cheltenham.
Hedenus, F., Wirsenius, S., Johansson, D.J.A., 2014. The importance of reduced meat and dairy consumption for meeting stringent climate change targets. Clim. Change 124, 79–91. doi:10.1007/s10584-014-1104-5
Heinrich-Böll-Stiftung, Rosa-Luxemburg-Stiftung, Friends of the Earth Europe, 2017. Agrifood atlas.
Herrero, M., Henderson, B., Havlík, P., Thornton, P.K., Conant, R.T., Smith, P., Wirsenius, S., Hristov, A.N., Gerber, P., Gill, M., Butterbach-Bahl, K., Valin, H., Garnett, T., Stehfest, E., 2016. Greenhouse gas mitigation potentials in the livestock sector. Nat. Clim. Chang. 6, 452–461. doi:10.1038/nclimate2925
Hilgartner, S., Bosk, C.L.., 1988. The Rise and Fall of Social Problems : A Public Arenas Model. Am. J. Sociol. 94, 53–78.
Hommels, A., 2005. Unbuilding Cities: Obduracy in Urban Sociotechnical Change. MIT Press, Cambridge, Massachusetts.
Hoolohan, C., McLachlan, C., Mander, S., 2016. Trends and drivers of end-use energy demand and the implications for managing energy in food supply chains: Synthesising insights from the social sciences. Sustain. Prod. Consum. 8, 1–17. doi:10.1016/j.spc.2016.06.002
Hughes, T.P., 1994. Technological momentum, in: Smith, M.R., Marx, L. (Eds.), Does Technology Drive History? The Dilemma of Technological Determinism. MIT Press, Cambridge, Massachusetts, pp. 101–113.
Hughes, T.P., 1986. The Seamless Web: Technology, Science, Etcetera, Etcetera. Soc. Stud. Sci. 16, 281–292.
Jackson, P., Viehoff, V., 2016. Reframing convenience food. Appetite 98, 1–11. doi:10.1016/j.appet.2015.11.032
Jamasb, T., Pollitt, M., 2008. Liberalisation and R&D in network industries: The case of the electricity industry. Res. Policy 37, 995–1008.

Jenkins, N., Long, C., Wu, J., 2015. An overview of the smart grid in Great Britain. Engineering 1, 413–421.
Jensen, K.O., Holm, L., 1999. Preferences, quantities and concerns. Socio-cultural perspectives on the gendered consumption of foods. Eur. J. Clin. Nutr. 53, 351–359.
Jones, N.R. V, Conklin, A.I., Suhrcke, M., Monsivais, P., 2014. The Growing Price Gap between More and Less Healthy Foods : Analysis of a Novel Longitudinal UK Dataset 9. doi:10.1371/journal.pone.0109343
Jordan, A., Lenschow, A., 2010. Environmental policy integration: a state of the art review. Environ. policy Gov. 20, 147–158.
Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technol. Anal. Strateg. Manag. 10, 175–198.
Kern, F., Kuzemko, C., Mitchell, C., 2014. Measuring and explaining policy paradigm change: the case of UK energy policy. Policy Polit. 42, 513–530.
Kjaernes, U., Torjusen, H., 2012. Beyond the industrial paradigm? Consumers and trust in food, in: Spaargaren, G., Oosterveer, P., Loeber, A. (Eds.), Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity. Routledge, New York, pp. 86–106.
Lamine, C., 2011. Transition pathways towards a robust ecologization of agriculture and the need for system redesign. Cases from organic farming and IPM. J. Rural Stud. 27, 209–219. doi:10.1016/j.jrurstud.2011.02.001
Lang, T., Millstone, E., Marsden, T., 2017. A Food Brexit : Time To Get Real.
Lang, T., Schoen, V., 2016. Food, the UK and the EU: Brexit or Bremain? Food Res. Collab.
Lee, D., Worth, I., 2017. 75 years of Family Food, 50 years of the British Nutrition Foundation. Nutr. Bull. 207–211. doi:10.1111/nbu.12275
Levy, D.L., Egan, D., 2003. A Neo-Gramscian Approach to Corporate Political Strategy: Conflict and Accommodation in the Climate Change Negotiations. J. Manag. Stud. 40, 803–829.
Lockwood, M., 2016. Creating protective space for innovation in electricity distribution networks in Great Britain: The politics of institutional change. Environ. Innov. Soc. Transitions 18, 111–127. doi:10.1016/j.eist.2015.05.007
Loeber, A., 2011. The food chain reforged: Novel food risk arrangements and the metamorphosis of a metaphor. Sci. Cult. (Lond). 20, 231–253. doi:10.1080/09505431.2011.563571
Marsden, T., 2013. From post-productionism to reflexive governance: Contested transitions in securing more sustainable food futures. J. Rural Stud. 29, 123–134. doi:10.1016/j.jrurstud.2011.10.001
Marsden, T., 2012. Food systems under pressure: Regulatory instabilities and the challenge of sustainable development, in: Spaargaren, G., Oosterveer, P., Loeber, A. (Eds.), Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity. Routledge, New York, pp. 291–312.
Marsden, T., Morley, A., 2014. Current food questions and their scholarly challenges: Creating and framing a sustainable food paradigm, in: Marsden, T., Morley, A. (Eds.), Sustainable Food Systems. Earthscan, London, UK, pp. 1–29.
McMeekin, A., Geels, F.W., Hodson, M., n.d. Mapping the winds of whole system reconfiguration: Analysing low-carbon transformations across production, distribution and consumption in the UK electricity system. Res. Policy (under Rev.
Meynard, J.M., Jeuffroy, M.H., Le Bail, M., Lefèvre, A., Magrini, M.B., Michon, C., 2017. Designing coupled innovations for the sustainability transition of agrifood systems. Agric. Syst. 157, 330–339. doi:10.1016/j.agsy.2016.08.002

Monteiro, C.A., Cannon, G., Levy, R., Moubarac, J.-C., Jaime, P., Martins, A.P., Canella, D., Louzada, M., Parra, D., Ricardo, C., Calixto, G., Machado, P., Martins, C., Martinez, E., Baraldi, L., Garzillo, J., Sattamini, I., 2016. NOVA. The star shines bright. World Nutr. 7, 28–38.

Monteiro, C.A., Moubarac, J.C., Levy, R.B., Canella, D.S., Da Costa Louzada, M.L., Cannon, G., 2018. Household availability of ultra-processed foods and obesity in nineteen European countries. Public Health Nutr. 21, 18–26. doi:10.1017/S1368980017001379

Morris, C., Kirwan, J., Lally, R., 2014. Less Meat Initiatives: An Initial Exploration of a Diet-focused Social Innovation in Transitions to a More Sustainable Regime of Meat Provisioning. Int. J. Sociol. Agric. Food 21, 189–208.

Moubarac, J.-C., Claro, R.M., Baraldi, L.G., Levy, R.B., Martins, A.P.B., Cannon, G., Monteiro, C.A., 2013. International differences in cost and consumption of ready-to-consume food and drink products: United Kingdom and Brazil, 2008–2009. Glob. Public Health 8, 845–856. doi:10.1080/17441692.2013.796401

Nelson, R.R., Winter, S.G., 1982. An Evolutionary Theory of Economic Change. The Belknap Press of Harvard University Press, Cambridge, Massachussets; London, England.

Newcombe, M.A., Mccarthy, M.B., Cronin, J.M., Mccarthy, S.N., 2012. "Eat like a man". A social constructionist analysis of the role of food in men ' s lives q. Appetite 59, 391–398. doi:10.1016/j.appet.2012.05.031

Notarnicola, B., Tassielli, G., Renzulli, P.A., Castellani, V., Sala, S., 2017. Environmental impacts of food consumption in Europe. J. Clean. Prod. 140, 753–765. doi:10.1016/j.jclepro.2016.06.080

Ofgem, 2017. State of the Energy Market, 2017 Report. London.

Oosterveer, P., 2012. Restructuring food supply: Sustainability and supermarkets, in: Spaargaren, G., Oosterveer, P., Loeber, A. (Eds.), Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity. Routledge, New York, pp. 153–176.

Pearson, P., Watson, J., 2012. UK Energy Policy 1980-2010: A History and Lessons to be Learnt. London.

Penna, C.C.R., Geels, F.W., 2015. Climate change and the slow reorientation of the American car industry (1979 – 2012): An application and extension of the Dialectiv Issue LifeCycle (DILC) model. Res. Policy 44, 1029–1048. doi:10.1016/j.respol.2014.11.010

Perez, C., 2002. Technological Revolutions and Financial capital: The Dynamics of Bubbles and Golden Ages. Edward Elgar, Cheltenham.

Powell, W., DiMaggio, P. (Eds.), 1991. The New Institutionalism in Organizational Analysis. The University of Chicago Press, Chicago.

Princen, T., 2005. The Logic of Sufficiency. MIT Press, Cambridge, MA.

Raskin, P., 2016. Journey to Earthland: The Great Transition to Planetary Civilization. Tellus Institute, Boston.

Rip, A., Kemp, R., 1998. Technological Change, in: Rayner, S., Malone, L. (Eds.), Human Choice and Climate Change, Vol 2 Resources and Technology. Batelle Press, Washington, D.C., pp. 327–399.

Rycroft, R.W., Kash, D.E., 2002. Path dependence in the innovation of complex technologies. Technol. Anal. Strateg. Manag. 14, 21–35.

Self, J.D., 2017. Risk Managing Food Safety: Comparing the Enforcement of Food Safety Regulation in the UK and Germany. King's College London.

SGF, 2014. Smart Grid Vision and Roadmap. London.

Shove, E., 2003. Comfort, Cleanliness and Convenience: The Social Organization of Normality. Berg, Oxford.
Smith, A., 2007. Translating Sustainabilities between Green Niches and Socio-Technical Regimes. Technol. Anal. Strateg. Manag. 19, 427–50. doi:10.1080/09537320701403334
Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41, 1025–1036. doi:10.1016/j.respol.2011.12.012
Smith, P., Martino, D., Cai, Z., Al., E., 2007. Agriculture, in: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York.
Soil Association, 2018. Organic Market 2018.
Spaargaren, G., Loeber, A., Oosterveer, P., 2012a. Food futures in the making, in: Spaargaren, G., Oosterveer, P., Loeber, A. (Eds.), Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity. Routledge, New York, pp. 312–337.
Spaargaren, G., Oosterveer, P., Loeber, A., 2012b. Sustainability transitions in food consumption, retail and production, in: Spaargaren, G., Oosterveer, P., Loeber, A. (Eds.), Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity. pp. 1–31.
Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Hann., C., 2006. Livestock's long shadow. Rome.
Strachan, P.A., Cowell, R., Ellis, G., Sherry-Brennan, F., Toke, D., 2015. Promoting community renewable energy in a corporate energy world. Sustain. Dev. 23, 96–109.
Thelen, K., 1999. Historical institutionalism in comparative politics. Annu. Rev. Polit. Sci. 2, 369–404.
Tosun, J., 2017. Party support for post-exceptionalism in agri-food politics and policy: Germany and the United Kingdom compared. J. Eur. Public Policy 24, 1623–1640. doi:10.1080/13501763.2017.1334083
Trott, P., Simms, C., 2017. An examination of product innovation in low- and medium-technology industries : Cases from the UK packaged food sector. Res. Policy 46, 605–623. doi:10.1016/j.respol.2017.01.007
Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830. doi:10.1016/S0301-4215(01)00098-2
van Otterloo, A.H., 2012. Healthy, safe and sustainable: Consumers and the public debate on food in Europe and the Netherlands since 1945, in: Spaargaren, G., Oosterveer, P., Loeber, A. (Eds.), Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity. Routledge, New York, pp. 86–106.
van Otterloo, A.H., 2005. Fast food and slow food: The fastening food chain and recurrent countertrends in Europe and the Netherlands (1890-1990), in: Sarasúa, C., Scholliers, P., van Molle, L. (Eds.), Land, Shops and Kitchens: Technology and the Food Chains in Twentieth-Century Europe. Brepols Publishers, Turnhout, Belgium.
Vanloqueren, G., Baret, P. V., 2009. How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. Res. Policy 38, 971–983. doi:10.1016/j.respol.2009.02.008
von Oelreich, J., Milestad, R., 2017. Sustainability transformations in the balance: exploring Swedish initiatives challenging the corporate food regime. Eur. Plan. Stud. 25, 1129–1146. doi:10.1080/09654313.2016.1270908
Watson, J., Gross, R., Ketsopoulou, I., Winskel, M., 2014. UK Energy Strategies Under Uncertainty, UKERC report.
Woodman, B., Mitchell, C., 2011. Learning from experience? The development of the

Renewables Obligation in England and Wales 2002--2010. Energy Policy 39, 3914–3921.
WRAP, 2017. Household Food Waste in the UK 2015.