PATHWAYS project

Exploring transition pathways to sustainable, low carbon societies

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<u>Deliverable D2.3</u>: 'Integrated analysis of the feasibility of different transition pathways'

<u>Country report 2</u>: The UK electricity system

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Preface

This report is produced in the context of work package 2 (‘Dynamics of transition pathways’) of the FP-7 funded PATHWAYS project (‘Exploring transition pathways to sustainable, low carbon societies’). More precisely, this report provides the UK country study of the electricity regime for deliverable 2.3, ‘Integrated analysis of the feasibility of different transition pathways’.

The analysis in this report is based on a research template that is shared between the different contributors to WP2 to enable comparative analysis of findings between countries (UK, Netherlands, Sweden, Portugal, Germany) and empirical domains (electricity, heat, mobility, agro-food and land-use).

Contents

Executive summary

This report presents a combined analysis of findings from D2.1 and D2.2. It assesses the level of internal momentum for six niche-innovations in the UK electricity system and the extent to which these niche-innovations can take advantage of windows of opportunity provided by regime problems. It also assesses if, and to what degree, existing regimes are beginning to reorient themselves to address the focal environmental problems.

Internal niche momentum

Table 1 presents summary findings for the internal momentum of the six UK electricity niches, the extent to which the niches are aligned to existing regimes, future potential of the niche and whether the niche displays pathway A (mainly technology substitution) or B (deeper changes across several system dimensions) characteristics.

Niche-innovation	**Internal momentum**	**Strong or weak alignment with broader regime characteristics and developments**	**Likelihood of imminent breakthrough (and/or future potential)**	**Pathway A or B (or mixed)**
Onshore wind	Moderate	Strong: alignment with centralized, large-scale generation regime. Working with incumbents. Growing resistance from rural 'middle England'.	Further growth anticipated until 2020 (based on existing commitments). But, government support has been removed for new initiatives, so highly uncertain future.	A
Offshore wind	High	Strong: alignment with centralized, large-scale generation regime. Working with incumbents.	Further growth anticipated, with Government visions to 2030. Cost concerns could create legitimacy problems.	A
Biopower	Moderate	Strong: alignment with regime has grown, especially with coal-to-biomass conversion, which fits with preferences for centralized, large-scale generation. Working with incumbents.	Boom-and bust over the next 5-10 years. Long-term prospects low, especially if CCS does not become viable.	A
Solar-PV	Low	Weak: deployed by new entrants and based on decentralized generation.	Despite a recent burst of diffusion, solar-PV remains marginal. Recent downgrading of feed-in-tariff is likely to significantly decrease diffusion	B
Energy saving lighting	Very High	Strong: technology substitution keeps regime largely intact, despite early difficulties with consumer uptake.	Following major EU regulation, CFLs (and halogens) have substituted ILBs. Prospects for LED substitution uncertain; negligible government support.	A
Smart meters	High	Strong: alignment with existing regime, with significant benefits expected for energy companies and considerable support expressed by Government. More radical consequences for changing consumer practices remain highly uncertain.	Mandated targets point to rapid and full diffusion by 2020. But, implementation problems and escalating costs could jeopardise this.	A (but some alternative visions hope for B character-istics)

Table 1: Breakthrough analysis of niche-innovations in the electricity domain in the UK

Three RETs (onshore wind, offshore wind and biopower) have been displaying moderate or high internal momentum and have strong alignment with broader regime characteristics because they conform to the large scale, centralized generation preferences of the incumbent industry and government. Solar-PV has low momentum (despite a recent burst of diffusion from a low base) and is poorly aligned to the regime because it involves new entrants and is largely associated with smaller scale, decentralized generation. Recent policy announcements (November 2015) about the removal or reduction of support for new RET initiatives suggest that the recent period of rapid RET diffusion will soon finish; there are significant uncertainties about RET deployment beyond 2020, but in the absence of political support, the prospects do not look promising.

For electricity consumption, the only significant niche innovation, energy saving lighting has had very high momentum, especially since the EU ban on incandescent light-bulbs in 2012. This ban stimulated a very rapid diffusion rate for energy saving light-bulbs, which had struggled to gain consumer acceptance beforehand. Although diffusion rates are still quite low for smart meters, this niche is considered to have high momentum because it has strong support from the UK government and powerful energy companies; a full roll-out is mandated for 2020, although this might be jeopardized if there are implementation problem or increasing concerns about high costs as some critics predict.

Regime re-orientation

Table 2 presents a summary assessment of developments in the generation, network and consumption regimes that make up the UK's electricity system, assessing the strength of stabilizing forces, cracks and tensions in the regimes, the extent of re-orientation to environmental and the main socio-technical problems in relation to a low carbon transition.

	Lock-in, stabilizing forces	**Cracks, tensions, problems in regime**	**Orientation towards environmental problems**	**Main socio-technical regime problems**
Generation Regime	Strong	Weak / Moderate	Limited / Moderate – plans to phase out coal, but new commitments to (shale) gas and nuclear (while removing support for RETs)	Political commitment to energy security and cost containment dominates climate protection.
Network Regime	Strong	Weak/ Moderate	Limited - some incremental change to accommodate RETs and upgrade grid to reduce 'leakage'	Incumbent resistance to more radical smart grid possibilities
Consumption Regime	Strong	Weak	Moderate – incremental innovations have yielded significant efficiency improvements across a range of domestic appliances.	Persistent cultural expectations drive demand for more domestic appliances (which are often more energy intensive).

Table 2: Assessment of regime trends in the electricity domain in the UK

Despite strong stabilizing forces, the generation regime has been experiencing some re-orientation. Coal powered generation has been under pressure and in November, 2015, the UK government announced that coal will be phased out over the next 10-15 years. However, this was accompanied by announcements of new commitments to nuclear and (possibly shale) gas powered generation. Political support for regime technologies is associated with strong commitments for lowering electricity costs and ensuring energy security; as such, support for RETs has been significantly reduced with the Conservative government arguing that 2020 renewables targets will be met on the basis of existing plans.

The network regime has experienced very limited re-orientation. Incumbent actors (especially, Ofgem and the distribution network operators) remain resistant to change and innovation efforts are focused on incremental improvements to the grid to reduce leakage and to incorporate RETs in new locations. There are visions for a future ICT enabled "smart grid", but little progress towards its realization.

The consumption regime has experienced moderate re-orientation through a focus on incremental innovation to increase the energy efficiency of domestic appliances. This has been stimulated by EU legislation (the Ecodesign and Energy Labeling Directives), which stipulate minimum standards for the environmental performance of products that can be sold to consumers and comparable labels aimed at encouraging consumers to choose the most energy efficient products. Interantional appliance firms, UK retailers and trade associations (especially AMDEA in the UK) largely support the efficiency agenda, which helps the sector to avoid criticism for high electricity bills and emissions. Efficiency improvements, however, have been partly offset by ratcheting demand for increasing numbers of household appliances, which in many cases are more energy intensive (e.g. larger fridges and plasma TVs).

Wider Reflections

1. **Finance**: Financial estimates in various long-term (until 2023) scenarios suggest that the costs of the low-carbon transition range between £200 and £300 billion. While investments have increased markedly since 2010, the roll-out and system wide deployment of low-carbon options will require much greater expenditures in the next 15 years. The mobilization of this large amount of money is a major social and political challenge in the current climate of austerity and public cutbacks.
2. **Politics and governance:** The unfolding of the UK electricity transition is very dependent on supportive government policies, which are underpinned by the commitments in the 2008 Climate Change Act. This radical policy was followed by a raft of specific implementation plans and policies. This dependence, however, makes the UK transition very vulnerable to the fickleness and fluidity of UK politics. Announcements in November 2015 bear out these concerns, with major reductions in support for RETs and new commitments for gas and nuclear. UK political governance is characterized by a technocratic, top-down, bulldozer style, in which a coalition of big firms and policymakers push through concocted plans rather than consulting with citizens and societal actors. This could cause legitimacy problems, potential leading to public resistance and protests, and therefore problems for a UK transition over the coming years.
3. **Wider public:** There has been a decline in public attention for climate change in recent years, with attention shifting to concerns about jobs, competitiveness and energy prices since the financial-economic crisis. Civil society engagement in the

energy domain is also conspicuously weak. At a broader level, some analysis suggests that the wider public has become more passive in relation to public debates more generally. If this broader problem is accurate, it may be quite a challenge to gain public support for the further unfolding of the UK electricity transition.

1. Introduction

This report, Deliverable 2.3, presents an integrated analysis of the feasibility of different transition pathways for the UK electricity system. Its aim is to use the previous analyses of niche (Deliverable 2.1) and regime (Deliverable 2.2) developments in the recent past (last 10 years or so) to make an interpretive assessment of the feasibility (practicality, achievability) of sustainability transitions *in the present* for the UK electricity system.

The analysis addresses two questions:

- Do the analyses of recent developments in green niche-innovations (D2.1) and regime (in)stability (D2.2) suggest that a transition is beginning to (or about to) take place? If so, does this transition look more like pathway A or pathway B (see Table 1)?
- If niche-innovations are not about to break through more widely, what are the dominant system/regime trends in the UK electricity system (based on D2.2): a) are these trends continuing as Business as Usual (Pathway 0 in Table 1), with limited regime change to address environmental problems, or, b) are existing regime actors implementing incremental changes to address environmental problems.

	Pathway 0: Business as Usual	**Pathway A: Technical component substitution**	**Pathway B: Broader regime transformation**
Departure from existing system performance	Minor (no transition)	Substantial	Substantial
Lead actors	Incumbent actors (often established industry and policy actors)	Incumbent actors (often established industry and policy actors)	**New entrants, including new firms,** social movements, civil society actors.
Depth of change	Incremental change	Radical technical change (substitution), but leaving other system elements mostly intact	Radical transformative change in entire system (fundamentally new ways of doing, new system architectures, new technologies)
Scope of change	Dynamic stability across multiple dimensions	1-2 dimensions: technical component and/or market change, with socio-cultural and consumer practices unchanged	Multi-dimensional change (technical base, markets, organisational, policy, social, cultural, consumer preferences, user practices)

Table 3: Ideal-type transition pathways and their defining elements

The report is structured as follows:

Section 2 analyses the breakthrough potential of six niche-innovations in the electricity system. It uses the four phase model of the multi-level perspective (figure 1) which draws attention to the internal momentum of niche-innovations, the extent to which niches are aligned or not with existing regimes and whether or not the niche has or is about to break into the existing regime (stage 3 of the model).

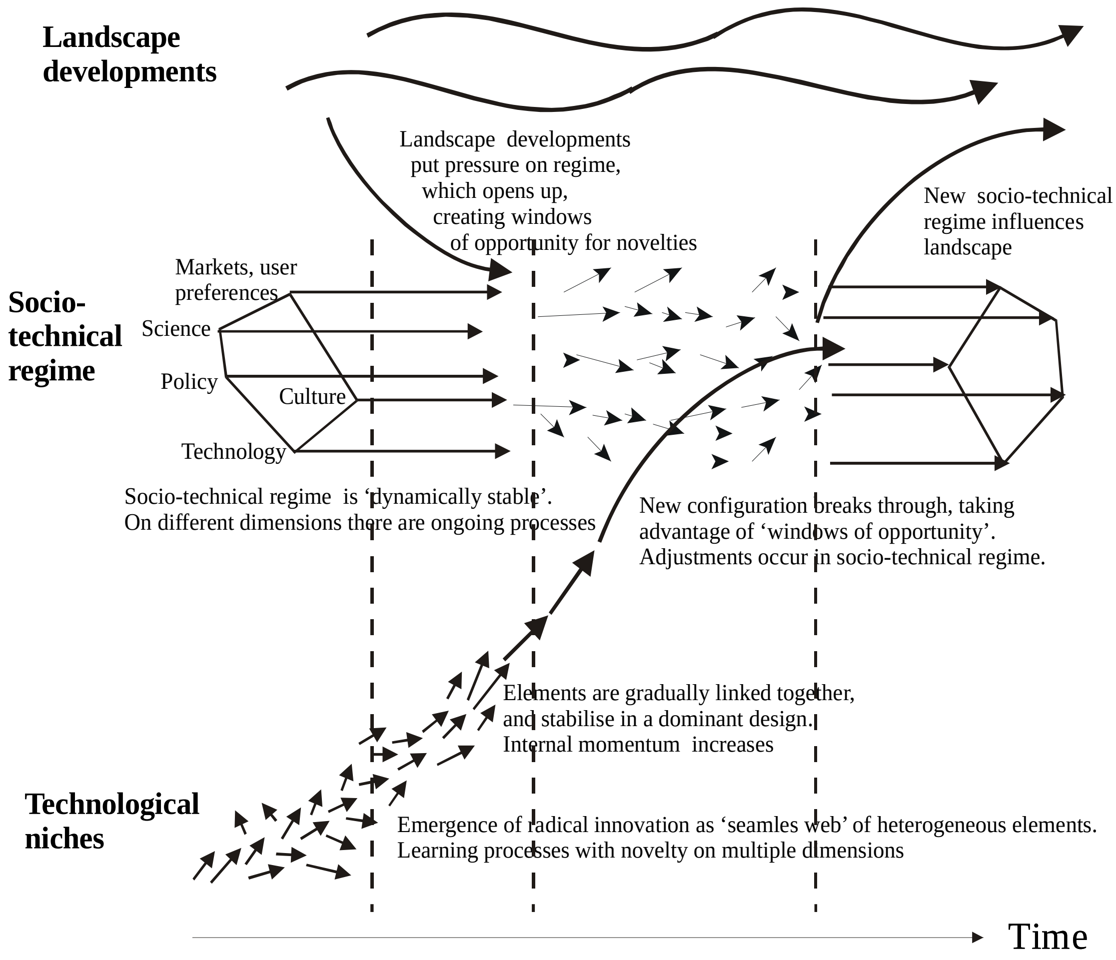

Figure 1: Four phases in multi-level perspective (Geels, 2006: 1006)

First, drawing on D2.1, internal momentum[1] is assessed as being very high, high, moderate, low, very low. Judgement of momentum is based on a combination of techno-economic, socio-cognitive and governance dimensions. Second, the niche is assessed in terms of the extent to which it aligns with existing regimes. The analysis looks at whether there positive alignments (e.g. windows of opportunity related to regime problems) that result in: a) more finance, investment, b) positive, widespread public debates, c) broader policy adjustments, and political will, to help the niche-innovation diffuse; or whether are there mainly mis-matches because existing regimes are still fairly stable? Finally, each niche is assessed in terms of whether it is about to break through more widely (i.e. enter phase 3)? If not, what is holding back the niche-innovation? Is it the lack of internal momentum (if so, which dimension)? Or the stability of the existing regime (and 'barriers' or mis-matches with the niche-innovation)?

[1] 'Momentum', which in physics is defined as the product of mass and velocity of an object, can be applied to socio-technical niche-innovations if we take diffusion rates (increasing market share) as indicator of 'velocity' and the size of social networks and commitment of actors (in terms of investments and converging strategies) as indicators of 'mass'.

Section 3, drawing on D2.2, assesses dominant system / regime trends for UK electricity. The analysis examines these trends in the three sub-systems that make up the overarching electricity system: generation, distribution and consumption. The assessment provides a judgement about whether trends are continuing as Business as Usual, with limited regime change to address environmental problems, or if existing regime actors are implementing incremental changes to address environmental problems? Key trends are identified: the dominant patterns of technology deployment and innovation; changes in political and institutional frameworks; financial and business interests; social movement pressures and changes in public discourse. Each of these is considered in terms of the extent to which regimes are stable and resistance to niche breakthrough, or weakening and therefore opening up opportunities for niches to grow and stabilize.

Section 4 concludes the report by providing a summary assessment of the extent to which the UK electricity system is undergoing a transition and, if so, the extent to which transition is following a Pathway A or B pattern. The final section discusses the scale of the transition challenge for UK electricity and some implications for policy, business interests and finance and civil society.

2. Assessment of breakthrough feasibility of the various niche-innovations

This section builds on PATHWAYS deliverable 2.1 to assess the breakthrough feasibility of six niche-innovations in the electricity domain: onshore wind, offshore wind, bio-power, solar-PV, energy saving lighting and smart meters.

Figure 2 compares the diffusion rates for the aggregate category of renewable energy generation.

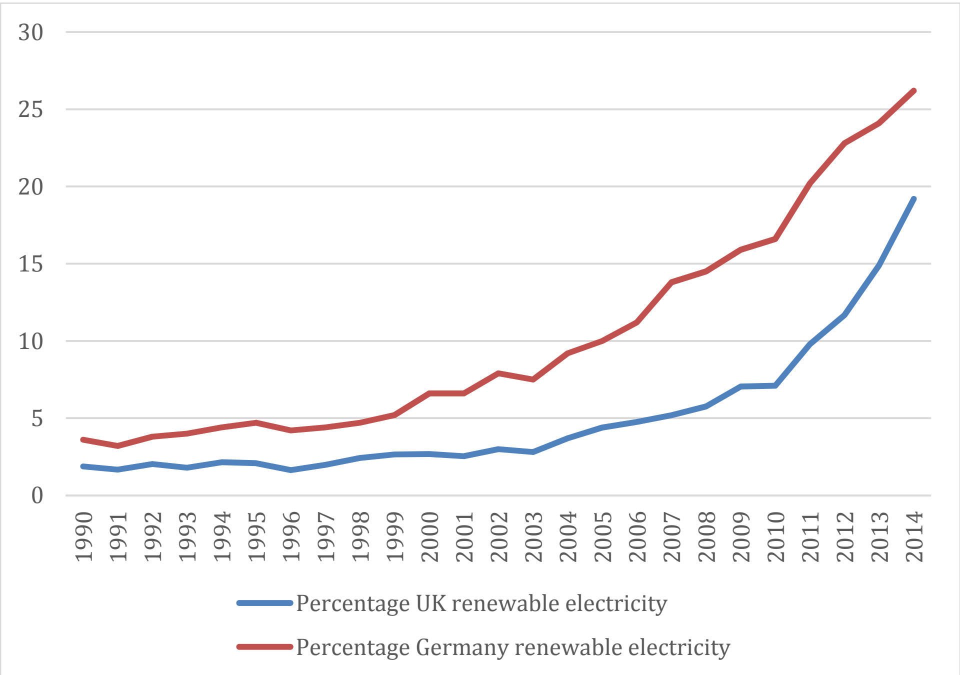

Figure 2: Percentage of UK and German renewable electricity, 1990-2014 (data from DUKES and AG Energiebilanzen (http://www.ag-energiebilanzen.de/, last accessed June 30, 2015)

It shows that the UK has recently accelerated RET deployment, reaching 19.2% of total generation by 2014 (up from 11.6% in 2012). In recent years, the growth rate of UK renewable electricity has been higher than for Germany. To some extent, the observed accelerations and decelerations are politically managed according to performance against targets and concerns over the costs of electricity.

Figure 3 provides a disaggregated account of diffusion rates for the main renewable energy technologies analysed in this report. Of the four most important niches in 2015, onshore wind started to diffuse earliest, followed by offshore wind. Bio-power, as a heterogeneous niche is now dominated by coal-to-biomass conversion, which has diffused very rapidly over the past 2-3 years. Finally, solar-PV has experienced much more recent quick burst of rapid diffusion.

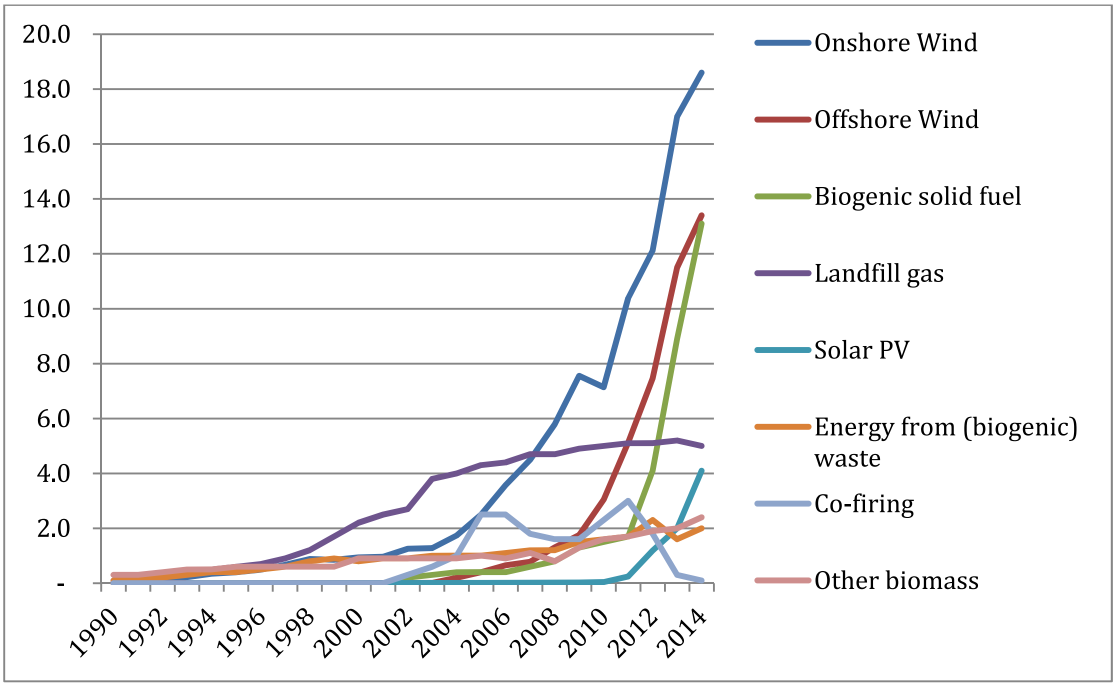

Figure 3: Power production from UK different renewable energy technologies, excluding hydro, in TWh, 1990-2014 (data from DUKES: Digest of UK Energy Statistics, https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes)[2]

Figure 4 shows changes in domestic electricity consumption according to the most important classes of domestic appliance. In terms of low carbon potential, lighting is significant because it has experienced one wave of full technology substitution (CFLs) and is potentially on the brink of a second wave transition (LEDs). The other significant low carbon trajectory is captured in the cold appliance class. These gains have been made on the basis of efficiency improvements and are dealt with in the regime analysis in the next section of the report.

The final niche to be analysed, smart meters, does not appear in these figures because the main phase of its diffusion has not yet started. It is included because of plans by government for a full transition to all households and SMEs by the end of

[2] 'Other biomass' includes biogas, sewage sludge, and animal biomass.

2020, and because some visions for the niche hope that smart meters will bring major gains for a lower carbon electricity system.

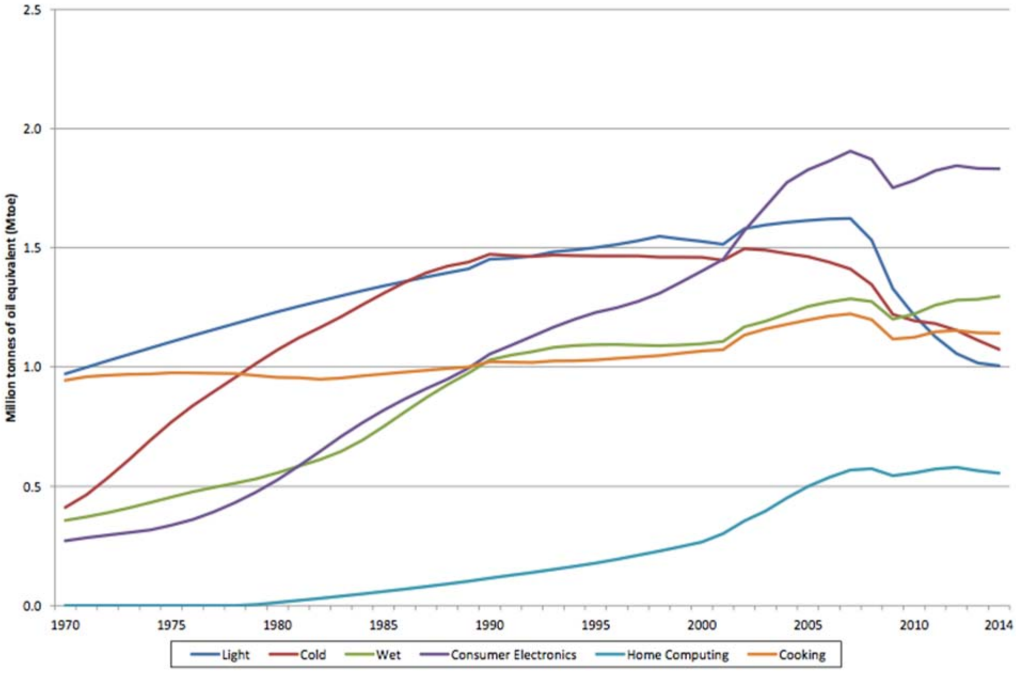

Figure 4: Electricity consumption by household domestic appliance, by broad type, UK (DECC, 2015, chapter 3, p. 7)

In the following subsections, each niche is assessed for its transition breakthrough potential following the analytical steps presented in section 1.

2.1 Onshore wind

Niche momentum

Techno-economic momentum: Onshore wind diffused quickly from 2002. It is the cheapest RET and is currently makes the largest contribution to electricity generation of all the RETs. Technical development in the last 10 years has focused on the up-scaling of wind turbines to greater heights (where propellers catch more wind) and more capacity and on improvements in rotor turbines, drive trains and material use. Wind forecasting models have also improved, leading to better turbine siting (Gross *et al*., 2013). However, onshore wind is now a mature technology and as such expectations for further significant learning curve effects are predicted to be significantly lower than for alternative generation technologies. Forecasts from DECC anticipate cost reductions from 75-127 £/MWh in 2010 to 71-122 £/MWh in 2020 (DECC, 2011)

Socio-cognitive momentum: UK onshore wind development is mainly a corporate economic activity (utilities, project developers, independent generators who sell electricity to utilities), which differs from Germany, Denmark, and the Netherlands, where cooperatives, farmers, and communities play a larger role (Toke *et al*., 2008). Whilst the involvement of large companies has been important in providing investment, onshore wind has been subject to mounting opposition and increasingly negative public opinion. The process for planning permission has played a significant role in this, with many proposals being rejected, largely because consultation activities were inadequate. Opposition has also been growing because: a) contrary to other countries, there are few environmental organizations in favour of wind turbines, b) very low levels of ownership by farmers, cooperatives, communities (which in other countries has led to much higher degrees of local acceptance and environmental NGO support, partly because local actors enjoy some benefits), c) strong cultural attachment to the countryside, which is part of the UK national identity. These concerns are voiced by powerful groups such as the Campaign to Protect Rural England and were voiced in an open letter (5 February 2012) by more than 100 Conservative MPs, who also demanded cuts in wind subsidies.

Governance and policy momentum: From 2002, the UK Government's Renewables Obligation (RO) policy significantly stimulated the diffusion of onshore wind. However, the Government's vision for onshore is now mixed. On the one hand, there is an aim to expand onshore wind to 10-13 GW installed capacity, which would generate 23-32 TWh electricity in 2020. Much of this additional capacity is already in the planning pipeline, with 1.9 GW of onshore wind under construction at the end of 2012, 4.4 GW onshore capacity having secured planning permission but awaiting construction, and about 9 GW awaiting approval and planning permission (CCC, 2013: 85). Given historic planning approval rates, this pipeline would bring onshore wind close to the envisaged government target for 2020. However, prospects beyond 2020 appear less certain. In the context of increasingly negative public opinion discussed above and government concerns about continuing subsidies for renewables, on April 5, 2014, the Conservative Party announced plans to introduce a manifesto for the 2015 election, which would introduce a moratorium on building more onshore wind farms after 2020. In November 2015, the Conservative government announced a withdrawal of subsidies for new onshore wind initiatives, arguing that prior commitments and projects in the implementation pipeline would meet targets without additional support[3]. So, while the current government vision to 2020 is very positive, the future beyond 2020 is uncertain, which is a major reason for attention shifting from onshore to offshore wind.

Alignments between niche and regime

The onshore wind niche has been able to grow quite quickly because the generation regime has a high degree of modularity vis-à-vis the wider electricity system architecture. As such, onshore wind deployment has grown without requiring any significant changes to the transmission / distribution system, beyond extensions to accommodate new sites. This may become more of a problem in the future, if the total proportion of RETs that have intermittency characteristics create pressures for the overall management (matching) of supply and demand. Growing onshore wind beyond this still to-be-determined threshold would require significant innovation in distribution networks and in demand side response (DSR) approaches.

In the UK, the deployment of onshore wind is well aligned with the incumbent model favouring large-scale, centralised generation operated by corporate economic actors, with significant involvement of utilities. This fit-and-conform of the niche to many aspects of the existing regime, in combination with government policies, has helped to provide investment and corporate support for onshore diffusion. However, smaller scale onshore wind projects operated by farmers, cooperatives and communities have experienced much less alignment with the existing regime because they deviate from the centralised, large scale model, and exclude incumbent energy

[3] https://www.gov.uk/government/speeches/statement-on-ending-subsidies-for-onshore-wind

companies. This partly accounts for the comparatively lower level of diffusion of decentralised onshore wind compared with the dominant centralized model and with other countries.

Increasingly negative public opinion may be partly attributable to the corporate, centralized model onshore wind deployment. The influence of long-standing UK cultural dispositions towards the countryside may also be surfacing in rural 'middle England', with Conservative Party policy following with the moratorium announcement and subsequent removal of further subsidies.

Status of the niche

As the largest RET in terms of capacity and current generation, onshore wind has broken into the generation regime. This momentum will potentially continue to 2020 with substantial installation still in the pipeline. However, further cost decreases appear unlikely, so while onshore remains the cheapest RET, its comparative cost advantage, compared to other RETs is likely to be eroded. This combined with negative public opinion and the Conservative government's withdrawal of subsidies means that historic and present momentum is likely to be short lived and may even lead to some pipeline projects being abandoned.

For these reasons, onshore wind is judged to have **moderate momentum** (high to 2020, but potentially decreasing rapidly afterwards). The trajectory of the onshore wind niche to date corresponds with PATHWAY A characteristics in the UK, because it is largely deployed and managed by incumbents and because it conforms to the large-scale, centralised model of generation characteristic of the incumbent regime; community level onshore wind (which would suggest some PATHWAY B characteristics) has negligible momentum.

2.2 Offshore wind

Niche momentum

Techno-economic momentum: After a period of government sponsored demonstration projects, installed capacity grew rapidly from 0.2 GW in 2008 to 1.2 GW in 2012, making the UK the world leader in offshore-wind. The size of wind farms continued to increase in the 2009-2012 period, ranging between 90 and 500 MW. Offshore-farms were also increasingly located further from shore (to reduce complaints about visibility) in deeper waters, requiring further technology development to deal with challenges (initially underestimated) of increasingly hostile marine environments. The *installation* of offshore-farms is also a major technical challenge, which requires specialized offshore capabilities and tools (e.g. docks, ships, platforms, cranes, drilling tools), creating a new market for UK offshore firms from the oil and gas sector. Despite some learning curve effects, offshore wind is likely to remain one of the more expensive RETs over the next decade.
Socio-cognitive momentum: While offshore wind is one of the most expensive RETs, Kern *et al*. (2014) suggest "that over time a highly networked coalition of powerful and resourceful actors emerged which boosted the credibility of and channelled resources into offshore wind. Formal networks centre around key public organisations as well as incumbent energy regime actors". It also benefits from some NGO support. This extended network of supporting actors has created high socio-political legitimacy and enthusiastic visions for future expansion. There are however some dissenting opinions (Toke, 2011): a) seaside residents criticized near-shore wind farms for spoiling views and damaging tourism, b) fishermen, shipping companies (lanes) and

the Ministry of Defense complained or had concerns that offshore wind hinders their operations (e.g. radar), c) some offshore wind-farm locations interfered with Natura-2000 sites (locations for nature conservation or bird habitat protection). But, perhaps more significantly, there have been some signs of erosion in legitimacy and support because of concerns over high costs, which have created uncertainty and affected investment decisions. Helm (2012), for example, criticized the government's recent emphasis on offshore wind, arguing that "as a major contributor to reducing emissions, offshore wind is a non-starter. (…) the implications for costs and standards of living would be radical, and politically, economically and socially not at all practical" (p. 87). Some planned installations have been abandoned because of cost and policy support uncertainty.

<u>Governance and policy momentum:</u> Government policy has strongly supported offshore wind, due to strong interest across many government departments with some very high projections for future expansion to 2020 and further towards 2030. Recent concerns about costs and the difficulties for innovation to realise cost reductions have dented these expectations. For example, in 2011, DECC envisaged expansion of OffSW to 11-18 GW installed capacity by 2020 with growth possibilities to 40 GW by 2030. By 2013, DECC started to lower expectations by stating that "10GW is achievable" and "this is not a target and actual deployment will depend on technology costs" (DECC, 2013b: 8). As a result of these cost concerns the government launched an Offshore Wind Cost Reduction Task Force in 2011 (with the aim of reducing costs to about 100£/MWh by 2020).

<u>Alignments between niche and regime</u>

Like onshore wind, offshore wind also benefits from modular characteristics of the generation system in terms of the opportunity for expansion without major impacts on system architecture. However, the challenge of integrating offshore wind into the electricity system is higher than for onshore wind because new transmission networks are required to connect new wind farms located in increasingly remote marine settings. This involves overcoming technical challenges of deep, hostile marine environments and also the investment required to link offshore farms to the terrestrial grid.

The offshore wind niche fits and conforms well with the incumbent regime. It is deployed and operated by major energy firms and fits with the model of large-scale, centralized electricity generation. To some extent, offshore wind has benefitted from the increasingly negative public and political discourse around onshore wind.

While there are some concerns expressed about the environmental impacts of offshore wind, these are much less pronounced than those directed towards onshore wind. Arguably, the shift to offshore represents a route to exploiting wind power without challenging deeply entrenched UK dispositions towards a protected countryside, whilst maintaining an opportunity to perpetuate the large scale, centralized, incumbent dominated logic of UK electricity generation.

<u>Status of the niche</u>

Offshore wind has broken into the electricity generation system. It has **high momentum**, because it is growing quickly but from a relatively low base; it is supported by a powerful network of actors, a generally supportive governance orientation and faces minimal organized opposition. Offshore wind is clearly following PATHWAY A because it is a substituting electricity generation technology, deployed by incumbent actors and because it largely fits and conforms with the existing regime. Longer-term government commitment remains (i.e. with visions beyond 2020, at least to 2030), although cost issues might eventually erode social and political legitimacy if productivity innovations remain elusive.

2.3 Bio-power

Niche momentum

Techno-economic momentum: Bio-power is a heterogeneous niche associated with a variety of feedstocks and conversion routes (official statistics struggle to keep up with different ways of representing the niche – the latest, as presented in figure 3 distinguishes biogenic solid fuel, energy-from-waste, co-firing, landfill and 'other'). Bio-power became technologically attractive because it provides a *predictable* and *continuous* source of power generation (in contrast to wind and solar, which are *intermittent*) and because many technologies were relatively mature. Figure 3 shows that the niche has become dominated, only in the last 4-5 years, by conversion of several large coal plants to biomass burning (e.g. Drax, Ironbridge), often based on imported wood chips or pellets. This has overtaken dedicated biomass as the bio-power trajectory with most future momentum. In terms of future innovations, the most tantalizing prospect involves linking bio-power to CCS (carbon capture and storage) to *reduce* carbon dioxide concentrations (because biomass absorbs it from the air when it grows). This is a still a far-future prospect, however, which first requires CCS-demonstration at scale. Without CCS, the Committee on Climate Change (2013b: 23) recommends that "long-term use of bioenergy in the power sector should be limited".

Socio-cognitive momentum. Because bio-power is a technologically heterogeneous niche, actor-networks are fragmented, with each sub-niche having distinctive principal actors and actor constellations: *landfill gas* is mainly enacted by professional landfill site operators; *anaerobic digestion* involves a variety of actors (farmers, food and drink processors, local communities) associated with alternative feedstocks; e*nergy-from-waste incineration* projects are enacted by project developers or waste companies; *dedicated biomass* plants (to date, relatively small at under 50 MW) are mostly operated by new entrants, with some exceptions (SSE and E.ON), although planned projects are progressively larger and with an increasing presence of incumbent energy firms; *biomass conversion* involves established coal plant owners converting coal to co-firing plant or 100% biomass. It is the latter that currently has most support from a coalition of coal plant owners and government.

Conversion was also attractive for coal plant operators because it provided a route for escaping or postponing the European Large Plant Combustion Directive, under which many UK coal plants have to close in 2015/2016 because they don't meet air pollution standards. This alignment between government and coal plant operators has generated opposition from developers of new-build dedicated biomass plants, who are left with stranded assets, which forced many to cancel future plans. More widely, social movement opposition has started to coalesce around some anti "big-biomass' campaigns that might grow in the future, perhaps drawing connections with controversies surrounding liquid biofuels for transport. Controversies about the sustainability of certain forms of biomass could therefore undermine socio-political legitimacy.

Governance momentum Government policy support has shifted unevenly and unpredictably across the sub-niches of bio-power. But, the 2012 *UK Bioenergy Strategy* substantially changed direction to the detriment of dedicated biomass and in favour of biomass conversion. One reason was that conversion became seen as more cost effective than new build dedicated biomass, indicating a preference for low cost over technical (and carbon) performance. A second reason was a change in long-term vision, with bio-power seen as fulfilling a "transitional role" (DECC, 2012: 43) with rapid expansion until 2020, followed by rapid decline in subsequent decades because of envisioned use of biomass in transport and heat domains, which are seen as having fewer alternatives for decarbonisation than the electricity domain. A third reason, is that this strategic change fits with the government's overall preference for working with incumbents on established large-scale technologies (such as co-firing and coal plant conversions) rather than new entrants (such as dedicated biomass) and smaller-scale solutions.

Alignments between niche and regime

Analysis of alignments between the bio-power niche and the incumbent generation regime are complicated by the heterogeneous and fragmented characteristics of the niche. At present, earlier innovation trajectories based on landfill, energy-to-waste and dedicated biomass appear to have very low momentum, with coal-to-biomass now dominating in terms of both deployment and support from powerful energy companies and government.

Coal-to-biomass conversion fits very well with the existing electricity regime, because it is easy for operators to switch from coal to biomass and because it can provide a reliable and constant level of electricity generation (compared with the intermittency problems with wind and solar). The appropriation of biomass by incumbent coal-powered generators has provided significant investment for this sub-niche, including decisive government support compared to other biomass alternatives.

Although opposition is yet to have any significant effect on the development of 'big biomass', some social movement activity has started to mobilise. This could pose problems for the niche, but irrespective of this, government plans currently view bio-power as a managed boom-and-bust transitional option for the next 5-10 years.

Status of the niche

Biopower has broken into the generation system and has been adopted by corporate actors central to the fossil fuel generation regime. The niche has **moderate momentum** because it is a mature technology (so, there are limited opportunities for technology improvements), where deployment in most sub-niches is plateauing or decreasing. The exception is coal-conversion which may grow significantly, but the boom-and-bust strategy suggests that biopower will play a limited role in electricity generation beyond 2020, especially if CCS does not become viable. Biopower follows PATHWAY A, although there may be further reconfigurations across domains with any rapid increases in land required for energy crops; this may lead to legitimacy problems in the context of international concerns about land-use change.

2.4 Solar PV

Niche momentum

Techno-economic momentum. From a very low base, UK diffusion of solar-PV was greatly accelerated by the 2010 Feed-in-Tariff (FiT), cost reductions and a positive discourse, resulting in 2.7 GW installed capacity by the end of 2013, generating over 2 TWh electricity. Decreasing PV-module costs were a major driver of solar-PV deployment, which dropped from nearly $40/W in the mid-1970s to approximately

$4/W in 2007 and $1.5/W in 2011. Within the overall solar-PV category, growth varied for different market niches. Small-scale solar-PV (<4 kW) on domestic rooftops grew fastest with over half a million homes now generating solar power. Mid-size building-mounted solar-PV (4-100 kW) on commercial and non-domestic properties has grown modestly (DECC, 2014b). Large, utility-scale solar farms (>5 MW), often ground-based in fields, has grown "stronger than anticipated" (DECC, 2014b:7). DECC (2014b:42) expects costs for solar PV "to fall much faster than for other key renewable energy technologies", but also notes that "the level of cost reduction that it feasible to achieve grid parity is still very uncertain" (DECC, 2013c: 17). There are prospects for major innovations in PV-modules in the future, but attention has also shifted to wider balance of system (BoS) costs, which include all other costs associated with installation and financing. BoS costs are unlikely to come down as fast as module prices, which may slow future diffusion.

Socio-cognitive momentum. Solar-PV has been supported by a strong network of actors, including NGOs (Friends of the Earth, Greenpeace), the construction industry, roofing contractors and the solar industry. The most decisive expression of this support was the highly visible public campaign in favour of the feed-in-tariff (FiT), which created pressure on policymakers. Introduction of the FiT in 2010 triggered much interest from households, consumers and local communities; also, commercial investors teamed up with farmers to develop large-scale solar farms, creating an unforeseen solar boom, which was unexpected by Government because solar was still the most expensive RET. The Government also underestimated the extent of household interest in adopting roof-top solar. Increasing visibility, confidence, and familiarity have stimulated *cultural articulation* processes (positive discourses and visions) and high public approval ratings. Rapidly decreasing prices have also given rise to wider cultural visions about the coming solar energy revolution and how it will transform energy systems towards decentralized production and active 'prosumers' (e.g. Barnham, 2014).

Governance and policy momentum. Government support was low until the introduction of the Feed-in-Tarriff in 2010 (the government struck a political deal with pro-renewables backbenchers to support the government bill for nuclear in return for the introduction of a FiT (Smith *et al*., 2014)). Following the unanticipated enthusiasm and diffusion of solar-PV, government support increased with the inclusion of solar-PV in government renewable energy plans from 2012 and dedicated solar-PV strategy documents in 2013 and 2014. There are hopes expressed in DECC's (2014b:44) *Solar PV Strategy* about a 'D3-agenda', in which solar-PV (with smart meters) can act as a stepping stone towards distributed generation, demand reduction, and demand response. However, this positive vision is arguably an exception within the dominant UK policy trajectory, with government recently announcing significant reductions in feed-in tariffs, which have created uncertainty about future deployment and government commitment.

Alignments between niche and regime

As a decentralized model of generation, solar-PV is poorly aligned to the incumbent regime, especially in the case of domestic rooftop solar. Furthermore, deployment of solar is undertaken by a range of new entrants to the generation sector. Future visions are even more radical, with some actor groups envisaging distributed solar generation coming with smart meters to stimulate domestic demand reduction, demand response and some interest in domestic electricity storage. The deviance of the decentralized solar niche from the incumbent regime perhaps explains why the rapid diffusion was unanticipated by government, because it did not fit with the established large-scale, centralized model. However, larger, utility-scale solar-pv does fit more with the incumbent regime and could grow more with support from utilities and government. Despite enthusiastic public discourse, the mismatch between decentralized solar-PV and the regime may make solar-pv vulnerable to shifts in government support, especially with energy security and costs concerns now dominating the energy policy agenda.

Status of the niche

Solar-PV has recently experienced a rapid burst of diffusion, but it only accounts for a marginal contribution to overall UK generation. The niche has **low momentum** (high velocity in terms of diffusion rates over the last few years, but low mass in terms of actual deployment and a committed social network) because it is vulnerable to rapid fluctuations across the three dimensions of momentum. While diffusion has grown significantly (and unexpectedly) over the last few years on the basis of a burst of strong socio-political legitimacy and the feed-in-tariff, it remains a high cost RET and policy support is exhibiting stop-start-stop characteristics. Without strong government support, price / performance improvement potential and positive public opinion may not be strong enough to grow momentum- the burst may be over. Solar-PV is most appropriately characterized as PATHWAY B in the UK because recent deployment and future visions have focused on decentralized power generation incorporating farmers for solar-farms and growing numbers of active and engaged 'prosumers' in the domestic roof-top sector.

2.5 Energy Saving Lighting

Niche momentum

Techno-economic momentum. Lighting is the only end-use category that has been subject to a niche technology substitution with major gains in terms of reducing electricity consumption. This has been achieved through product substitution of incandescent bulbs by CFLs (and to a much lesser extent, LEDs), which has led to an overall reduction in electricity consumption. After a long, slow start, rapid diffusion only occurred with give-aways, which energy companies did to meet their mandated energy use reduction obligations and ultimately through legislation, which established the phasing out of incandescent lightbulbs. Product innovations to deal with initial mis-matches with user expectations were also important. Consumers initially perceived CFLs as giving 'cold' light, being unattractively shaped, taking too long to achieve full brightness, being unsuitable for many fittings, being incompatible with dimmers and being unreliable (Wall and Crosbie, 2009). Several of these issues were addressed in subsequent technical developments that reduced flickering, re-engineered shapes, improved durability and included dimmable switches. Attention is now starting to shift to LED technologies, which are based on significantly different technical principles compared to existing bulbs. There are high expectations that ongoing innovation for LEDs can yield a further step change in the efficiency of lighting.

Socio-cognitive momentum. All international industry actors work on energy-efficient lighting, with European companies focusing on LEDs (since Chinese firms dominate the CFL market); retailers, utilities, NGOs and policymakers also work to stimulate adoption of energy-efficient lighting. With the transition to CFLs (and halogens) more or less complete, there are now very strong positive visions for a further wave of substitution based on LED technology, with expectations that this may be more radical than the diffusion of CFLs . Anticipated price reductions and improvements in efficiency are a major part of this, but perhaps more significant are visions for new and radically different 'smart lighting systems' (POSTnote, 2010). This might offer a step change in the ability for consumers to control all aspects of how their homes are illuminated, providing significant flexibility to alter lighting according to mood, changing interior designs and tailoring lighting to particular domestic practices. Manufacturers are also experimenting with flat surfaces of light that can be embedded in plastics, glass and other materials, producing illuminated curtains, wallpaper, etc., that offer potential shifts for interior design. Some future visions of LED highlight the potential of 'human centric lighting' which also addresses health and wellbeing benefits, stemming from positive effects of LED's white light on concentration, tiredness, prevention of depression and dementia (LightingEurope and ZVEI, 2013). Against these positive visions, there are also concerns about the precise timing of a shift towards LEDs, and whether or not this shift will be hindered by the long life spans of CFLs and halogens.

Governance momentum. Government support for the low energy lighting niche shifted considerably throughout the transition. Initially based on information campaigns and market incentives (which had very little effect), lighting then fell under the government's energy obligations, which mandated energy companies to stimulate the diffusion (via give-aways and massive price reductions). Finally, under the auspices of European legislation, ILBs were phased out, creating significant demand for CFLs and a trajectory towards full substitution. Currently, there are no comparable policies aiming at stimulating the second transition to LEDs.

Alignments between niche and regime

Regime resistance to the CFL niche principally came in the form of consumer reluctance to adopt the new technology. The more expensive up-front costs of CFLs were on factor in this, despite life-time costs being lower. Furthermore, early product versions clashed with existing consumer expectations, despite increasingly strong efforts by lighting companies, retailers and government to stimulate diffusion. It is also notable that over the same period the number of light-bulbs installed in houses more than doubled, which reduced the energy / carbon saving impact of the transition to some extent.

The future of lighting is not only influenced by price, lighting efficacy and policy stimulus, but also by cultural considerations. Lighting not only has instrumental qualities (e.g. seeing in the dark), but has increasingly taken on other meanings such as creating ambience, cosiness and moods. People appreciate different qualities of lighting for different household practices (e.g. home-working, watching television, cooking). Trends in lighting use have changed significantly, with most homes now having more light fittings than they did in 1970, especially in kitchens and bathrooms. Lighting use has also differentiated, with people using different kinds of light in different rooms. LEDs are a versatile technology, so different kinds of diodes can perhaps be combined in different packages (to create different light qualities) and/or linked with ICT to create 'smart lighting systems' that can be easily controlled to alter light characteristics.

Status of the niche

CFLs have largely substituted the pre-existing technology, becoming the dominant lighting technology since the EU ban of ILBs. This first wave of technology substitution is largely complete. But, a second wave, based on more radical LED technology has not yet taken off. CFLs have a long life-span which may temporarily slow down LED diffusion; and UK government support, at present, is largely non-existent for LEDs.

The first phase of the lighting transition can be considered to have **very high momentum** because incandescent bulbs have been phased out through legislation, facilitating the widespread diffusion of energy saving light-bulbs. However, momentum for LEDs is much lower. While there is positive momentum in terms of cost reduction and technology improvements for much greater efficiency, there are significant uncertainties about how LED lighting will be adopted into domestic spaces. Furthermore, it seems that government attention has shifted away from lighting after the success of CFLs. The first wave of the energy saving lighting niche, based on CFLs matches PATHWAY A characteristics, principally because it is driven by incumbent actors and technology substitution is the main focus; some future visions for domestic lighting anticipate LEDs as a more radical transformation, which might precipitate significant shifts in interior design and therefore suggest the possibility for some PATHWAY B characteristics.

2.6 Smart meters

Niche momentum

Techno-economic momentum. Smart meters can measure exact electricity usage by customers and send relevant information back to the energy supplier (using ICT devices such as a communications hub), without the need for someone to come and take the meter readings. Because smart meters enable two-way communication, customers can also receive information remotely (e.g. updates on tariff information or to switch payment mode). Furthermore, smart meters can be configured to include an In-Home Display (IHD), which can provide information to consumers about their energy use and alternative tariffs. Actual adoption levels are low (only 1% of the expected 53 million smart meters was implemented by 2014), but the growth rate is very high, starting from almost zero in 2012. Diffusion is expected to ramp up very quickly in the coming years, because the government has a mandated obligation for full adoption into all UK households by 2020. Development of technical standards (Smart Metering Equipment Technical Specifications (SMETS)) has been subject to considerable negotiation and some controversy regarding the use of IHDs and the ICT-based communication platform. The mandated roll-out anticipates very rapid and complete diffusion of smart meters by 2020; it is, however, quite possible that high costs and potential implementation problems could mean that the mandated time-frame becomes unfeasible.
Socio-cognitive momentum is high, with the creation of substantial social networks (mainly from the production domain) by the government and the articulation of positive visions about the benefits of smart meters, which largely crowd out some marginal dissenting voices. There are however, some concerns about whether benefits from smart metering are most likely to accrue to energy providers or consumers. DECC (2014c) anticipates that producers will benefit from £8.262billion of savings and consumers will benefit from a 2.8% reduction in electricity use, although it is unclear how this will be achieved. A new NGO, ‘Stop Smart Meters! (UK)’, was

established in 2012 and explicitly opposes smart meters, raising concerns about health risks, unwarranted privacy violations, and much higher bills. It also argues that: "In reality Smart Meters are a money-making solution to a very different challenge - namely, how profit-seeking corporations can continue to monetize further aspects of our lives" (http://stopsmartmeters.org.uk/). Positive visions for smart meters see potential for significant effects on domestic consumer behavior, through the use of IHDs in the government's preferred technical standard. "Smart meters make time-varying and other sophisticated types of tariffs possible (…). Such tariffs can incentivise demand-side response (DSR) or load-shifting, which can potentially bring significant benefits to the electricity system" (DECC, 2014c: 58). Controversy remains about the benefits of smart meters. It seems clear that energy utilities will benefit in tangible and well recognised ways; the extent to which consumers might benefit and how remains much less clear.
Governance momentum. In principal, governance momentum is very high because current UK policy still aims to complete the entire, population-wide roll-out by 2020. This is a major government programme, which may experience problems during the full implementation phase, as is often the case with major ICT programmes.

Alignments between niche and regime

Alignment between the niche and existing regime is strong, especially through the shared visions of government and because energy providers expect to enjoy significant benefits. There have been some technical controversies about the precise configuration of the technology, with some energy companies wanting cheaper versions (i.e. not using IHDs, which are expensive and do not offer significant supplier benefits). But, these controversies are largely resolved and the roll-out scheme is supported by the most central actors.

Apart from some opposition from academics and NGOs, there has been very little public debate about smart meters, so public opinion is largely neutral or non-existent. The extent to which this remains the case is likely to become apparent during the roll-out phase. It is plausible that the high costs, potential implementation problems and early evidence about where benefits are accruing could mobilise negative public opinion making connections to other major government ICT programmes and more generally in the context of debates about the costs of energy (as these costs are passed on to consumers through energy bills).

Status of the niche

Smart meters have only recently started to diffuse into the electricity system, but the ambitious government programme aims for full substitution of existing meters by the end of 2020. As such, the niche has **high momentum**, despite comparatively low current diffusion rates. This is because *anticipated* diffusion rates are extremely high based on strong socio-cognitive momentum and policy commitments for rapid deployment by 2020. This high momentum could drop significantly if implementation problems arise in the early phase (which are predicted by some critics). There are competing visions and expectations for the smart meter pathway: UK Government articulates broader expectations for sociotechnical changes associated with PATHWAY B, with smart meters triggering behavioural changes in electricity consumption and (less prominently) enhancing prospects for decentralized electricity generation. Critics expect these wider changes will not materialize and therefore anticipate smart meters following PATHWAY A, deployed by incumbents, with benefits largely accruing to incumbents.

2.7 Summary assessment of niche breakthrough feasibility

Table 1 presents summary findings for the internal momentum of the six UK electricity niches, the extent to which the niches are aligned to existing regimes, future potential of the niche and whether the niche displays pathway A (mainly technology substitution) or B (deeper changes across several system dimensions) characteristics.

Niche-innovation	**Internal momentum**	**Strong or weak alignment with broader regime characteristics and developments**	**Likelihood of imminent breakthrough (and/or future potential)**	**Pathway A or B (or mixed)**
Onshore wind	Moderate	Strong: alignment with centralized, large-scale generation regime. Working with incumbents. Growing resistance from rural ‘middle England’.	Further growth anticipated until 2020 (based on existing commitments). But, government support has been removed for new initiatives, so highly uncertain future.	A
Offshore wind	Moderate	Strong: alignment with centralized, large-scale generation regime. Working with incumbents.	Further growth anticipated, with Government visions to 2030. Cost concerns could create legitimacy problems.	A
Biopower	Moderate	Strong: alignment with regime has grown, especially with coal-to-biomass conversion, which fits with preferences for centralized, large-scale generation. Working with incumbents.	Boom-and bust over the next 5-10 years. Long-term prospects low, especially if CCS does not become viable.	A
Solar-PV	Low	Weak: deployed by new entrants and based on decentralized generation.	Despite a recent burst of diffusion, solar-PV remains marginal. Recent downgrading of feed-in-tariff is likely to significantly decrease diffusion	B
Energy saving lighting	Very High	Strong: technology substitution keeps regime largely intact, despite early difficulties with consumer uptake.	Following major EU regulation, CFLs (and halogens) have substituted ILBs. Prospects for LED substitution uncertain; negligible government support.	A
Smart meters	High	Strong: alignment with existing regime, with significant benefits expected for energy companies and considerable support expressed by Government. More radical consequences for changing consumer practices remain highly uncertain.	Mandated targets point to rapid and full diffusion by 2020. But, implementation problems and escalating costs could jeopardise this.	A (but some alternative visions hope for B character-istics)

Table 4: Breakthrough analysis of niche-innovations in the electricity domain in the UK

3. Assessment of regime reorientation

<u>Overall assessment</u>

Sub-report 2 of Deliverable 2.2 made a regime analysis of the UK electricity system. That report analytically divided the electricity system into three sub-regimes: electricity generation, electricity consumption, and electricity networks/infrastructures (see Figure 5). A characteristic of the electricity system is that the electricity networks acts as a 'buffer' between production and consumption, implying that developments in electricity generation don't necessarily influence demand.

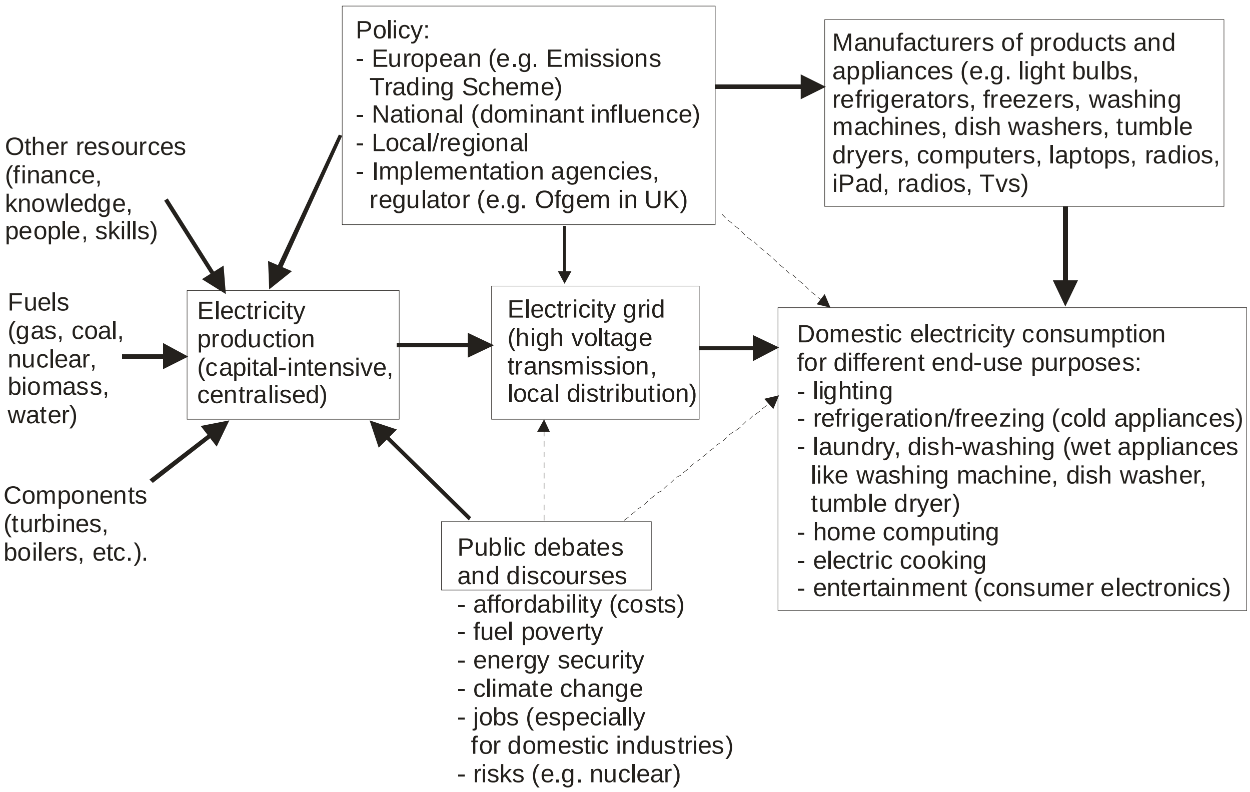

Figure 5: Schematic representation of socio-technical system in electricity[4]

Based on the findings in sub-report 2, our assessment is that:

- A low-carbon transition is beginning to unfold in electricity generation. However, this transition is not envisaged to be only driven by renewable electricity technologies (RETs), discussed above in chapter 2. At present, the government vision is to increase RETs to about 30% of electricity generation in 2020. But there are no commitments to further increase RETs beyond 2020. Instead, the government envisages to increase nuclear power and gas-fired power (possibly from shale gas) and deploy Carbon Capture and Storage (CCS), which could reduce carbon emissions from gas and coal-fired plants. Unabated coal-plants are planned to be phased out between 2016 and 2023.

[4] Electricity consumption occurs not only in households, but also in industry and services, which each account for about a third of overall consumption (see Figure 7 below). We have decided to focus our analysis on domestic consumption, however, because we want to provide a deeper analysis of the various user practices, cultural conventions and routines that shape electricity consumption in households.

- A transition is not yet happening in electricity consumption. Nevertheless, remarkable achievements have been made in the electricity consumption regime. Despite major increases in the number and size of appliances (e.g. TVs, computers, IPads, fridges), total electricity consumption peaked in the mid-2000s after decades of increases. Electricity use fell by 7% between 2008 and 2012 (CCC, 2014). One driver for this was the economic recession (which especially affected industrial use). Another driver, however, is energy efficiency improvements in most end-use sectors, driven by incremental innovations and (mostly) European regulations and standards. An exception is lighting, where the diffusion of *radical* niche-innovations (CFLs, LEDs) is reducing electricity demand (see the description above in section 2.5). So, the electricity consumption sub-regime is characterized by substantial (mostly) incremental regime improvement (energy efficiency innovation), which has resulted in some demand decrease despite major increases in electric appliances (‘running to stand still’). Many experts expect that *future* electricity consumption may increase if transitions towards electric vehicles and electric heat pumps occur in UK transport and heat systems. A qualitative shift in electricity consumption is expected to come from the diffusion of smart meters (discussed above in section 2.6), which may enable not only demand reduction, but also demand side response instruments (e.g. new tariffs that incentive consumers to reduce demand during peak times).
- A transition is not yet happening in electricity distribution and transmission networks. The networks are facing increasing pressures from new wind farms in remote locations, intermittency of wind and solar power, (some) increase of *distributed generation*. But these pressures have, so far, been met with incremental changes in transmission networks and, to a lesser extent, in distribution networks. There is substantial future potential for more transformative change (e.g. smart grids, a European super-grid, electricity storage, demand-side response options). This potential is not actively pursued, because the dominant regime actors (e.g. Distribution Network Operators, Ofgem) are characterized by reluctance, resistance and are subject to lock-in mechanisms.

We will further substantiate these conclusions with brief descriptions of the main characteristics of the three sub-regimes, based on findings in sub-report 2.

3.1. Electricity generation

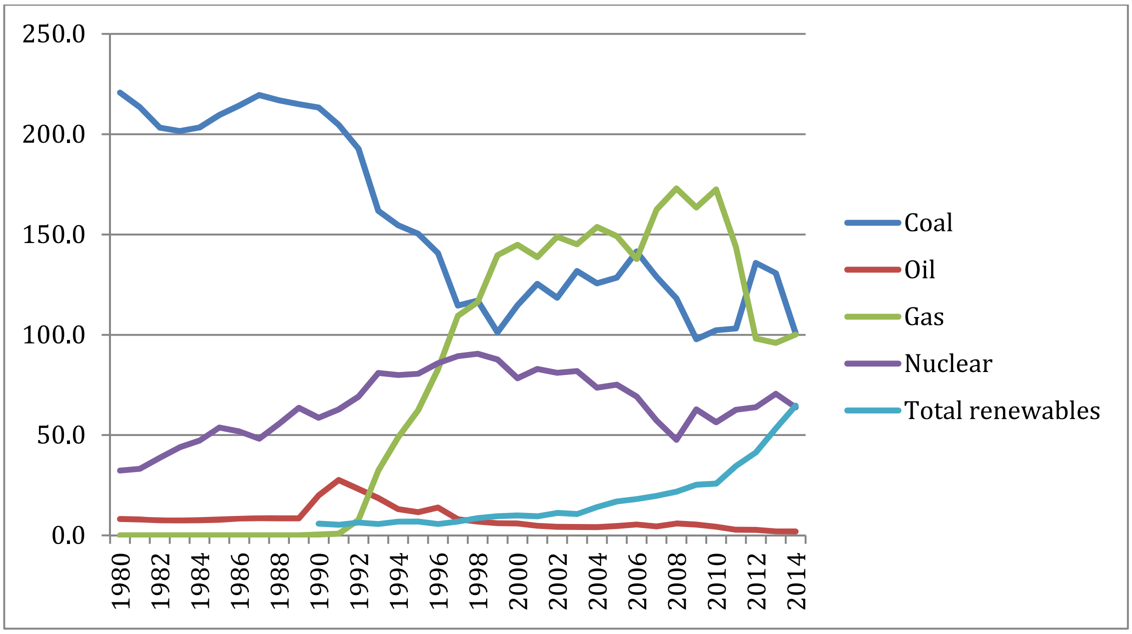

Figure 6: UK electricity generation by fuel type, 1980-2014, in TWh (data from DUKES)

Deployment of fuels and regime technologies

Figure 6 describes the fuel inputs for UK electricity generation. It shows that:

- Renewable electricity generation has been gradually increasing since the 1990s, with accelerated diffusion since 2010. As described above, most RETs are deployed by electric utilities and project developers. The prominence of new entrants in UK electricity generation has remained relatively limited, although their numbers have increased on the fringes (with small market shares).
- Coal seemed on its way out in the 1990s because of the 'dash for gas'. Since 2000, coal use has more or less stabilised. There are currently 72 coal-fired power plants in England, most of which were constructed in the 1970s and 1980s. Investments in new coal-fired power plants stalled since the 1990s. Utilities floated plans to construct new coal plants around 2008, but these were not built because of protests and procedural delays. Plans were put on the backburner in 2009, when the government announced that new coal plants would have to incorporate CCS technologies (carbon capture and sequestration). After 2010 coal use in *existing* plants increased substantially (Figure 6), especially in 2012 when coal use increased by 32% in one year, from 103.1 to 135.9 TWh (Figure 6). In recent years, (some) coal-fired power plants have been closed or converted to biomass (Table 2), because they reached the end of their life span or because of environmental legislation such as the European Large Combustion Plants Directive (LCPD).

	Status	Previous capacity	New capacity
Kingsnorth A	Closed in 2012	1940 MW	0
Cockenzie	Closed in 2013	1152 MW	0
Drax	Partially converted to biomass in 2013	3870 MW	3870 MW
Ironbridge	Converted in 2013	940 MW	360 MW
Tilbury B	Closed in 2013	750 MW	
Didcot A (coal/gas)	Closed in 2013	1036 MW	
Ferrybridge C	Partially closed in 2014	1960 MW	980 MW
Uskmouth	Closed in 2014	363 MW	

Table 5: Closed or converted coal-fired power plants between end-2010 and May 2014 (data from DUKES)

Coal use decreased substantially in 2013, when around 6 GW of coal-fired plants were closed under the European Large Combustion Plants Directive (LCPD) and air quality regulations. A further 2 GW were closed in 2014. The remaining 18 GW of coal capacity face further restrictions from 2016 and either need to close down by 2023 under the Industrial Emissions Directive or upgrade their equipment (e.g. fitting expensive NOx abatement devices) to meet stricter emission limits.

- Nuclear power seemed on its way out in the 1990s, because of privatization/liberalization. The newly created companies perceived nuclear power as too expensive and risky because of legacy costs and waste problems. Nuclear generation capacity has gradually diminished because no new plants have been built since the late 1980s and many have reached the end of their life-spans. Nuclear power made a come-back on the policy agenda in the mid-2000s, because of energy security concerns and low-carbon emissions. Since 2005, UK governments have called for a 'nuclear renaissance' to replace decommissioned plants and contribute to low-carbon electricity supply. This call included plans to build 8 new nuclear plants by 2030, delivering 16 GW new capacity. However, the plan for the first new plant (Hinkley C) is already delayed 5 years, with the opening date pushed back from 2018 to 2023. Negotiations for two more nuclear plants are under way, but not yet concluded. Discussions about the other five plants have not yet started. These nuclear plants, which may be built in the 2020s, will require large investments. The new Hinkley C nuclear power plant alone is estimated to cost £16 billion; its start-up date has been pushed back from early 2018 to 2023, because of delays, but received fresh impetus in Novemebr 2015 with the announcement that the Chinese state will make a significant financial contribution. Two other plants, Wylfa and Moorside, are estimated to cost £20 billion and £10 billion respectively.
- Gas use increased rapidly in the 1990s, alternating since around 2000 with coal, based on changes in relative prices. Gas use decreased in 2004 when prices increased, went up again in 2006 when gas prices decreased. In the last few years, shale gas (based on fracking of shale rock to extract gas) has revolutionized international gas supply. Inspired by the US 'shale gas revolution', the UK government lifted restrictions on fracking in 2012. Dozens of potential shale gas sites have since been identified across the country. In 2013, the government also expressed desires for a substantial expansion of up to 40 new gas-fired power stations, delivering 16-25 GW by 2030. These power stations are not expected to

use CCS, which led the Committee on Climate Change (CCC) to warn that such an expansion would be incompatible with climate change targets.

This discussion suggests that the UK government hopes to reduce a large part of future carbon emissions through a ‘modal shift’ or a *change in the relative size of existing regime technologies*: increasing nuclear power and gas, decreasing unabated coal use.

<u>CCS as more radical regime innovation and potential capacity problems</u>

Another plank of the government’s climate strategy is the future deployment of carbon capture and storage (CCS), which is a moderately radical innovation (in the sense that it requires the acquisition of new technical capabilities and construction of new infrastructures) that could be added to existing regimes (coal, gas) to reduce their carbon emissions. But although CCS is technical feasible, there is much uncertainty about commercially viability. Utilities are not keen to deploy the technology and look for government support and hand-outs. Most of the corporate activity on CCS has therefore “been focused on basic scientific research and lobbying governments for subsidies and support rather than investments needed to deploy the technology on a commercial scale” (Bowen, 2011:2256). In 2008, four consortia (Peel Energy, BP, E.ON, Scottish Power) showed interest in the subsidized (£1billion) demonstration programme. The 2010 government coalition agreement included the ambition of supporting four CCS-demonstration projects. By late 2010, however, firms began withdrawing their interest in participation in these projects. The last consortium (Scottish Power) dissipated in October 2011, creating serious problems for the government’s energy strategy (which assumed widespread future use of CCS).

In 2012, the government tried to revive interests aiming for operational demonstration projects between 2016-2020. Four plants were shortlisted in 2013, with two preferred bidders identified: White Rose project in Yorkshire and Peterhead in Scotland. Front End Engineering and Design (FEED) studies for both plants started in late 2013. The White Rose consortium, comprising Drax (the UK biggest power plant), Alstom, Bank of China and National Grid, was awarded €300 million under the EU New Entrant Reserve mechanism[5]. The Peterhead consortium, comprising Shell and SSE (an electric utility), plans to use an existing pipeline and power plant and may therefore be operational sooner. The Committee on Climate Change (2014) is negative about the government’s handling of CCS, highlighting “slow progress” and “little sign of urgency” (p. 127). The CCC hopes that the first two plants may be operational by 2020. Final investment decisions are not due until late 2015, however, which means that there is still much uncertainty about the future of CCS.

The delays and problems in realizing the nuclear power and CCS plans point to a potential future problem, namely lack of generating capacity. If the government sticks to climate change targets and the current phase-out policy of unabated coal, then the electricity-generation regime will face serious capacity problems (because CCS is not currently deployed and new nuclear power does not come on-stream until the mid-2020s). If the government wants to address the capacity problems by building new coal-fired plants *without* CCS, then it is unlikely to meet its climate change targets. One should not ignore the (devious) possibility that the second option is actually the government’s strategy (i.e. using capacity problems as an argument to build new coal-fired plants, thereby forcing a debate about dropping or weakening the climate change targets of the 2008 Climate Change Act (see also Lockwood, 2013).

[5] Drax withdrew funding and support for the White Rose project in September 2015.

Decreasing political will
Another potential problem for the electricity generation transition is the tension between climate *policy* and recent *political* counter-trends. A crucial driver of the UK transition are the European 20-20-20 targets[6], which the UK government accepted in 2007, and the target of 80% GHG reduction by 2050 and 34 % reduction by 2020, which is embedded in the 2008 Climate Change Act, which was a radical policy change (Carter and Jacobs, 2014). The translation of these high-level goals into more specific targets and plans created a *policy* delivery momentum and new policy instruments, e.g. the UK Low Carbon Transition Plan (2009), the amended Renewables Obligation (2009), the UK Renewable Energy Strategy (2009), the Carbon Plan (2011), the Energy Bill (2012) and the Electricity Market Reform (2013). The various policies represented a move from a hands-off approach to higher degrees of interventionism (Lockwood, 2013; Kern *et al*., 2014b).

While *policy* momentum increased, the transition began facing *political* counter-trends, which gathered pace after the financial-economic crisis and the election of a new Conservative-Liberal Democrat government in 2010. First, public attention to climate change diminished, leading politicians to realize that they were ahead of their voters (Lockwood, 2013). Especially the right-wing of the Conservative party became more vocal, criticizing subsidies for onshore wind and questioning climate change science. Second, the financial-economic crisis enhanced concerns about jobs, competitiveness and energy prices. The Treasury used these concerns to regain influence over climate policy (Carter and Jacobs, 2014), issuing warnings that green policies should not hinder the economy. In 2013, cost concerns escalated into a full-scale political row over rising energy bills, which led the government to scrap, delay or water down various green policies. Third, the government refused to commit to long-term renewable electricity targets beyond 2020, despite repeated recommendations from the Committee on Climate Change. In July 2015, these political counter-trends culminated in decisions by the newly elected Conservative government to slash support for onshore wind, solar-PV (especially 1-5 MW installations), and biomass plants. The UK is likely to meet the 2020 renewable electricity target (30%), because much political capital has been invested and because of deployment momentum. But the recent downscaling of RET-support is likely to substantially slow down RET diffusion in the 2020s.

Regime stability
The refusal of the UK government to commit to post-2020 renewable electricity targets suggests that policymakers and industry remain committed to existing large-scale regime technologies, although in different degrees. Decentralised energy generation technologies (community wind-farms and rooftop solar) represents a distinctive vision, but has so far failed to scale-up much. Social networks in the electricity generation regime have remained relatively stable, especially the alliance between policymakers and utilities, which consult and negotiate in many ways. The UK governance style can therefore be characterized as ‘working with incumbents’ (Geels *et al*., 2014). In sum, there are not yet major cracks in the existing regime. Instead, core regime actors (utilities and policymakers) are gradually reorienting themselves by adjusting their beliefs and strategies. So, the unfolding pattern is a negotiated and controlled transformation of the existing regime, tailored to incumbent interests rather than to meeting long-term climate change targets. There are currently

[6] These targets include a 20% share of renewables in *energy* consumption by 2020.

limited signs of 'opening up' of the regime, except maybe the phase-out of coal, which creates some space for other generation options. Future tensions may, however, arise from capacity problems resulting from slow nuclear expansion, phase-out of unabated coal, and slow progress of CCS-and-coal.

3.2 Electricity consumption

Total consumption trends

Our assessment is that a transition is not yet happening in the electricity consumption sub-regime. Nevertheless, interesting incremental regime developments have occurred in the last 10 years. Overall electricity consumption peaked in the mid-2000s after decades of increases across the industrial, services and domestic end-use domains (Figure 7). Electricity use fell by 7% between 2008 and 2012, mostly because of the economic recession (which especially affected industrial use), but also because of efficiency innovations in appliances (which are further discussed below).

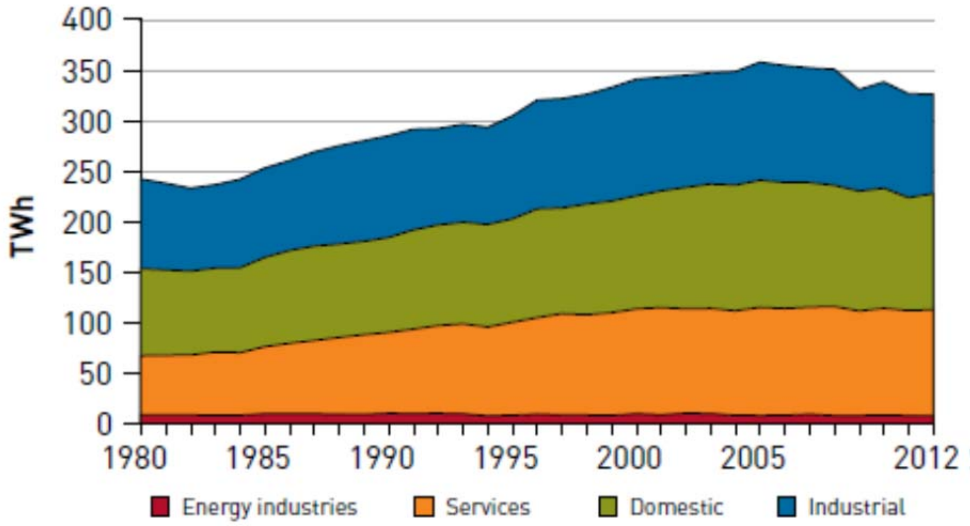

Figure 7: UK electricity consumption, 1980-2012 (DECC, 2013a: 29)

Within the aggregate demand category, there has been significant flux in the electricity intensity of specific domestic practices and appliances (Figure 4), reflecting contrasting diffusion patterns and different innovation trajectories, including efficiency oriented innovation.

The main trends in end-use domains and appliances are:

- The rise of consumer electronics home computing
- Electricity use by wet appliances (washing machine, dishwasher, tumble dryer, washer-dryer) increased since the 2000s after plateauing in the 1990s.
- Electric cooking remained largely stable.
- Electricity use decreased in lighting, because of the technological shift from incandescent light bulbs to CFLs and LED (discussed in section 2.5).
- Electricity use also decreased in cold appliances (refrigerators, freezers), due to energy efficiency improvements.

Long-term electricity use is expected to increase (Figure 8) because of ongoing household electrification (driven by consumer electronics and ICT) and because of a possible electrification of transport (electric vehicles) and heat (e.g. electric heat pumps). Growing electricity use will require expansion of electricity production and grid improvement (e.g.-directional flows, smart meters, smart grids).

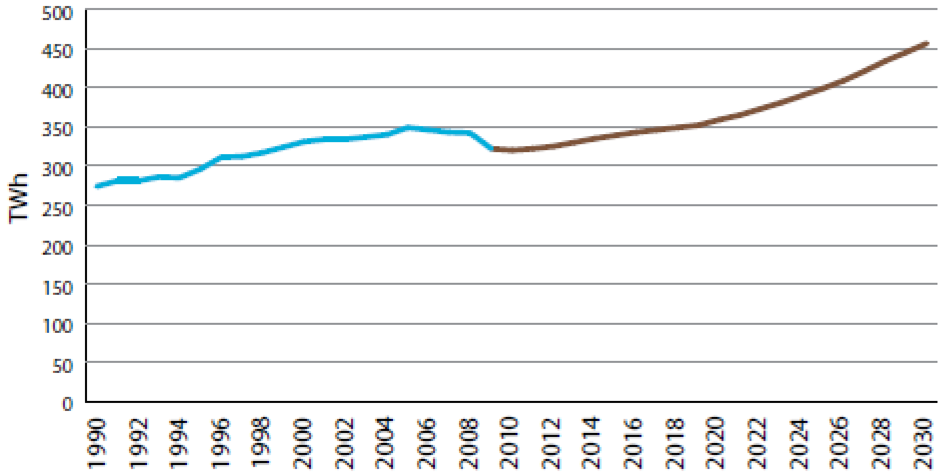

Figure 8: Past and projected UK electricity demand (CCC, 2011: 44)

Regime stability

The electricity consumption regime (which is composed of a set of more specific regimes around end-use functions such as lighting, cooling, consumer electronics, washing) is characterized by substantial stability.

One stabilizing force is the landscape development towards an ICT-based information society and the further electrification of the household, which provides economic opportunities for international firms to proliferate innovations in the context of domestic practices.

Another stabilizing force comes from persistent cultural conventions for convenience, cleanliness, freshness, and expectations for ever-increasing standards of entertainment and connectivity, which drive demand for domestic appliances. These cultural conventions drive the following specific trends:

- The increase in the variety of types of appliance adopted by households (e.g. new consumer products such as coffee makers, juicers, games consoles etc.).
- The continued spread of established consumer electronic appliances throughout the population (e.g. dishwashers, microwaves).
- The addition of extra functions to existing technologies (e.g. ice-makers for fridges, photocopiers and scanners for printers).
- The trend towards larger appliances (e.g. TV and PC screens, fridges).
- The trend towards multiple ownership within single households of appliances in specific categories (e.g. fridges, TVs, computers).
- An overall decrease in manufacturing costs for electrical appliances (through learning mechanisms), leading to price reductions and therefore increased affordability for consumers.

Thirdly, the dominant beliefs and guiding principles of industry actors and appliance manufacturers are oriented towards developing better and cheaper products with more functionalities on the basis of which they compete in the market place. The rules of the game for commercial actors have maintained a focus on persistent innovation in domestic appliances for firms to maintain or improve their competitive standing. Climate change and energy efficiency have been added as *additional* principles in the last decade, but arguably do not form the various appliance industries' main concerns. So, we argue that the efficiency agenda has been *layered* into the electricity consumption sub-regime, without displacing long-standing cultural expectations and institutional logics that shape innovation life-cycles of the sector.

Incremental energy efficiency innovation in existing regimes

Nevertheless, incremental energy efficiency improvements have been impressive in the last decade, leading to a plateauing of consumer electricity consumption (Figure 8). Without efficiency innovation, electricity demand would probably have continued to rise significantly. One example of impressive efficiency innovations is washing machines. Since the mid-1980s electricity consumed by washing machines has declined substantially from 268 kilowatt hours to 166 kilowatt hours, (Zimmerman *et al,* 2012). Another example are cold appliances, where energy efficiency has also been substantially improved (Table 3). Sub-report 2, on which we draw here, provided more examples.

Electrical appliances	**Efficiency improvements from 1990 to 2012**
Chest freezer	66%
Fridge freezer	50%
Refrigerator	56%
Upright freezer	56%

Table 6: Efficiency gains in new cold appliances bought in the UK, 1990 to 2012 (DECC 2013a)

Firms in the domestic electricity consumption regime have incorporated the efficiency agenda as an *additional* regime dimension, which has led to some re-orientation of industry strategies and beliefs towards efficiency innovation, and therefore some tangible gains in terms of reductions in electricity use. The pattern of energy efficiency improvement has, however, been very uneven across appliance categories. Efficiency has been a significant driver for innovation in cold appliances, but has been almost absent in consumer electronics and home computing until very recently. More generally the gains from energy efficiency improvements have often been offset by countervailing tendencies associated with longer standing regime characteristics, discussed above. So, the overall pattern can perhaps be characterized as 'running fast, but standing still'.

Energy efficiency policy and public debate

The efficiency agenda has been largely driven by European policy, enacted domestically through the UK Government's Market Transformation Programme (MTP). In 2010, EU policy was consolidated through revisions to the two main energy efficiency directives: 1) the Ecodesign Directive, which stipulates minimum standards for the environmental performance of products available on the market (i.e. banning those that do not meet those standards), 2) the Energy Labelling Directive, which mandates the provision of comparable energy performance ratings to be provided by manufacturers to encourage consumers to choose more energy efficient products. Therefore, the governance approach mixes market and control measures, which, in the context of a stable sub-regime, represents a fairly high degree of intervention.

In the early 1990s, international appliance manufacturers, UK retailers and trade associations (especially AMDEA in the UK) were resistant to government intervention around the efficiency agenda during. This changed in the mid-1990s when supply side actors became increasingly compliant and less resistant (i.e. a reduction in lobbying). Moreover, by 2014, the UK's appliance trade association AMDEA had started to call for *more* policy attention to the efficiency agenda in order to prevent a potential backlash against the electricity regime as decarbonisation in electricity generation puts upward pressure on consumer electricity prices. As such, the efficiency agenda now has *pro*-active support from regime actors, presumably as a strategy for regime protection and reproduction.

Political and public debate around the efficiency agenda has been fairly muted. The policy process is dominated by technocratic debates about specifying the minimum level for environmental performance and the most appropriate layout of labels to communicate information to consumers. NGOs and social movements are largely supportive of the efficiency agenda, but apart from the Green Alliance most groups are fairly silent. Within this context of strong regime actor alignment, there are occasional bursts of opposition when new appliances become subject to the EU directives (e.g. vacuum cleaners), but this opposition is typically short-lived.

Maybe a stronger public debate, supported by social movements and policymakers, could enhance future energy efficiency improvements? Such a debate would, however, probably have to address some of the deeper cultural conventions, discussed above, which may prove difficult (but maybe not impossible).

3.3 Electricity networks

Increasing pressures on the grid

Our assessment is that a transition is not yet happening in the electricity network sub-regime. So far, this regime has remained relatively stable, despite various pressures stemming from increasing electricity production from renewable sources:

- The creation of new wind farms in remote locations (e.g. Scottish islands, Welch coast, offshore) requires the creation of new transmission networks, both onshore and offshore, to connect them to the grid.
- Increasing electricity flows from Scotland and Wales (where most wind parks are situated) to England (where most electricity is used) requires upgrading, extension and intensification of the onshore transmission grid.
- The intermittency of wind and solar power creates problems for matching supply and demand, and requires changes in the electricity networks to better manage and direct electricity flows.
- The gradual increase of *distributed generation* (e.g. roof-top solar PV, community energy, small dedicated biomass plants) needs to be connected to (local) electricity distribution grids and requires two-way flows instead of traditional one-directional flows (from generators to users).

Incremental regime changes

These pressures have, so far, been met with *incremental changes* in the high-voltage *transmission* networks:

- Extensions of *onshore* power lines and cables to remote locations; new *onshore* connections between Scotland and England.
- The creation of a new *offshore* grid.
- The building of *inter-connectors* that link the UK to other countries. Current interconnectors are to France, Netherlands, Ireland. Future plans exist for sub-sea connection cables to Iceland, Norway and Denmark (Figure 9).

These infrastructure changes do not substantially change the transmission architecture, but are very costly: about £17 billion between 2010-2013, and much greater investments up to 2020, up to £35 billion (DECC, 2014).

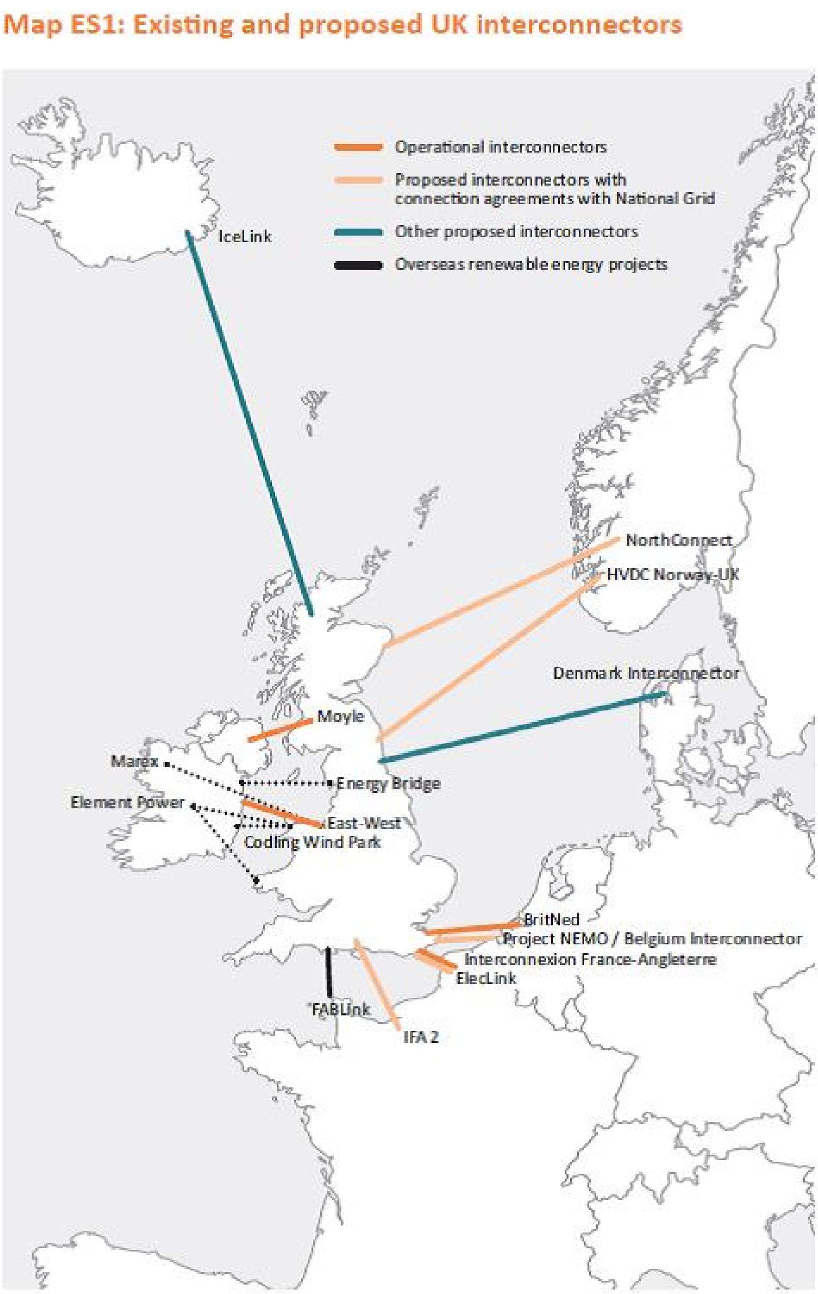

Figure 9: Existing and proposed UK inter-connectors (Moore and Newey, 2014: 7)

<u>Potential radical innovations</u>

A range of more radical innovations is being discussed for the low-voltage *distribution* network, which delivers power from sub-stations to end-users. These potential innovations entail:

- Creation of a smart grid (by introducing information and communication technologies into the grid) that would better measure, monitor and manage electricity flows.

- Electricity storage with batteries, which grid managers can draw on when intermittent supply falls short.
- The introduction of demand-side response (DSR) options, which would enable demand to be adjusted to supply-side fluctuations.

Slow implementation because of regime stability and lock-in mechanisms

The implementation of these innovations in the distribution network has been rather slow, because of reluctance, resistance and lock-in mechanisms, especially with regard to Ofgem (the independent regulator) and the DNOs (Distribution Network Operators). Some of the main lock-in mechanisms are:

- Ofgem, which is dominated by economists and engineers, has been reluctant to accommodate climate change and sustainability as an additional criterion besides its traditional focus on competition and low costs.
- The independence of the regulator Ofgem provides substantial shelter from (increasing) criticisms and demands from policymakers and politicians, enabling it to stick to its core regulatory principles.
- The DNOs are risk averse, because their traditional focus was cost reduction and efficiency instead of innovation.
- Despite various policies (which aimed to stimulate R&D and innovativeness),
- DNOs have lost technical capabilities, have limited future planning skills, and are constrained by business models that focus on efficiency and cost reduction. They are therefore reluctant to engage with the various radical innovations.

More generally, the actors in the electricity network regime form a closed-knit network, operating a form of ‘club governance’, which means that they share mindsets and take each other’s interests into account when negotiating future plans and policies. So far, these actors have mainly implemented incremental innovations that keep the regime relatively stable. There are some pressures from policymakers (who worry that electricity networks need to be adjusted quicker in low-carbon directions) and local communities (who protest against new power lines), but these are not (yet) causing major regime tensions. We therefore conclude that a transition is not yet happening in the electricity network sub-regime.

3.4 Summary assessment of regime re-orientation

Table 2 presents a summary assessment of developments in the generation, network and consumption regimes that make up the UK's electricity system, assessing the strength of stabilizing forces, cracks and tensions in the regimes, the extent of re-orientation to environmental and the main socio-technical problems in relation to a low carbon transition.

	Lock-in, stabilizing forces	**Cracks, tensions, problems in regime**	**Orientation towards environmental problems**	**Main socio-technical regime problems**
Generation Regime	Strong	Weak / Moderate	Limited / Moderate – plans to phase out coal, but new commitments to (shale) gas and nuclear (while removing support for RETs)	Political commitment to energy security and cost containment dominates climate protection.
Network Regime	Strong	Weak/ Moderate	Limited - some incremental change to accommodate RETs and upgrade grid to reduce 'leakage'	Incumbent resistance to more radical smart grid possibilities
Consumption Regime	Strong	Weak	Moderate – incremental innovations have yielded significant efficiency improvements across a range of domestic appliances.	Persistent cultural expectations drive demand for more domestic appliances (which are often more energy intensive).

Table 6: Assessment of regime trends in the electricity domain in the UK

4. Conclusions and wider discussion

4.1. Conclusions

Breakthrough of niche-innovations

Renewable electricity generation has increased rapidly since 2010, generating 19.1% of total electricity in 2014. The three niche-innovations that are particularly making inroads into the electricity-generation system are:

- Onshore wind, which generated 18.6 TWh in 2014.
- Offshore wind, which generated 13.4 TWh in 2014.
- Bio-power (particularly the conversion of coal plants to biomass combustion), which generated 13.1 TWh in 2014.

All three niche-innovations are primarily operated by incumbent regime actors (utilities, project developers), which have diversified into these large-scale RETS (operated mainly as wind *parks*). Some onshore wind turbines are operated by community energy groups, but these represent a relatively small fraction (<5%). Solar-PV has grown fast since the introduction of a Feed-in-Tariff in 2010, but is still relatively small, generating 4.1 TWh in 2014.

We therefore conclude that a low-carbon transition is beginning to unfold in electricity generation, following the characteristics of transition pathway A (large-scale technologies, operated by incumbent actors). So, the UK transition can be characterized as a 'working with incumbents' pattern.

Regime developments

The three large-scale RETs have strong alignments with the existing regime, in the sense that most UK RETs are operated by incumbent regime actors, which diversify to RETs because of attractive financial incentives created by the government (e.g. via the Renewables Obligation and Contracts-for-Difference).

Furthermore, the UK transition is not only driven by renewable electricity technologies (RETs). At present, the government vision is to increase RETs to about 30% of electricity generation in 2020. There are presently no commitments to further increase RETs beyond 2020. Instead, the government envisages to expand certain technologies such as nuclear power and gas-fired power (possibly from shale gas) and deploy Carbon Capture and Storage (CCS), which could reduce carbon emissions from gas and coal-fired plants. Unabated coal-plants are planned to be phased out between 2016 and 2023. So, the envisaged UK low-carbon transition is a hybrid mix of new RETs and the expansion of old regimes (nuclear, coal, gas), with CCS bolted on.

In electricity consumption, we conclude that a transition is not yet happening. Nevertheless, incremental energy efficiency improvements in existing regimes (cooling, washing, consumer electronics) have largely offset the major increases in the number and size of appliances (e.g. TVs, computers, IPads, fridges), leading to a plateauing of domestic electricity demand since the mid-2000s. An exception is lighting, where the diffusion of *radical* niche-innovations (CFLs, LEDs) is reducing electricity demand. The diffusion of another radical niche-innovation (smart meters) could lead to qualitative changes in electricity demand (e.g. peak-shifting, demand side response), which enable a shift from the current functional principle in which 'supply follows demand' (e.g. switching on gas turbines if demand increases) to 'demand follow supply' (reducing demand when intermittent electricity production drops).

In electricity distribution and transmission networks, we also conclude that a transition is not yet happening. Although the networks are facing increasing pressures, these have, so far, been met with incremental changes. There is substantial future potential for more transformative change (e.g. smart grids, a European super-grid, electricity storage, demand-side response), but this is hindered by various lock-in mechanisms of dominant regime actors (Distribution Network Operators, Ofgem).

4.2. Wider discussion

Reflections on transition pathways

Our empirical findings and assessments stimulate some reflection on our current typology of transition pathways, which includes two ideal-type transition pathways A and B (Table 1), and Pathway 0, which represents Business-as-Usual.

Pathway A and B both emphasize that transitions arise from the breakthrough radical niche-innovations, which are mainly technical in pathway A and more multi-dimensional in pathway B (business models, social innovation etc.). There is also an implicit assumption that existing regimes only do insignificant incremental innovation (BAU). This view on transition pathways has two mis-matches with our empirical assessments:

1) The UK low-carbon transition is likely to only partly consist of the breakthrough of radical niche-innovations (such as RETS). The expansion of certain regime technologies (nuclear, gas) is envisaged to also play a substantial part. So, the transition is likely to have a more mixed or 'hybrid' character (new combinations between old and new, which may lead to *reconfigurations* in overall systems), which is not accommodated in the pathways typology.

2) Existing regimes are more dynamic and innovative than the current typology accommodates. The deployment of CCS, for example, can be seen as a substantial modification and improvement of existing coal and gas-fired technologies. Also in the electricity consumption sub-regime there have been very substantial incremental improvements that substantially improved energy efficiency performance. This possibility of substantial incremental *regime transformation* is not really accommodated in the pathways typology.

So, perhaps we need to revisit and broaden our view on transition pathways. Geels and Schot (2007), for instance, also distinguish regime transformation and reconfiguration as potential transition pathways.

Finance

An important challenge for the future unfolding of the UK electricity transition is the availability of finance. Between 2010-2013, total investments were around £50 billion, largely in renewables generation and transmission grids (Table 4). Investments up to 2020 are estimated to be about £100 billion (DECC, 2014), again largely in renewables and transmission grids. Table 1 somewhat mis-represents future investments in nuclear power, which will accelerate after 2020. The new Hinkley C nuclear power plant alone is estimated to cost £16 billion; its start-up date has been pushed back from early 2018 to 2023, because of delays. Two other plants, Wylfa and Moorside (£10 bn), are estimated to cost £20 billion and £10 billion respectively.

	Past investments (2010-2013)	Future investments (2014-2020)
Renewables	£28.9 bn	£40-50 bn
Nuclear	£2 bn	£ 10-12 bn
Gas	£2.5 bn	$4.1 – 4.7 bn
Transmission grid (onshore, offshore)	£16 bn	£35 bn
Interconnectors	£1 bn	£2.4 bn
Subsidy for CCS demonstration projects		£1 bn
Total	£50.4 bn	£92.5- 105.1 bn

Table 7: Estimated investments in new electricity generation and transmission (based on data from DECC, 2014)

Financial estimates in various long-term (until 2023) scenarios suggest that the costs of the low-carbon transition range between £200 and £300 billion.[7] Figure 10 also shows that investments in the low-carbon transition have only just begun. While investments have increased markedly since 2010, the roll-out and system wide deployment of low-carbon options will require much greater expenditures in the next 15 years. The mobilization of this large amount of money is a major social and political challenge in the current climate of austerity and public cutbacks.

[7] These scenarios are from the following organisations:
1) Ofgem (2010), which distinguishes four scenarios: Green Transition (GT), Green Stimulus (GS), Dash for Energy (DE), Slow Growth (SG)
2) National Grid (2013), which has two scenarios: Slow Progression (SG), Gone Green (CG)
3) DECC (2012), which has a central scenario besides four others
4) The Crown Estate (2012), which offers four scenarios for offshore wind: story 1 (Slow Progression), story 2 (Technology Acceleration), story 3 (Supply Chain Efficiency) and story 4 (Rapid Growth)
5) Ernst & Young (2009), which has one scenario for 2025 of £234 billion investment
6) Committee on Climate Change (2013c), which has four scenarios: Ambitious Nuclear (AN), Ambitious Renewables (AR), Ambitious CCS (ACCS), and Ambitious Energy Efficiency (AEE),
7) LSE (2012), which has three scenarios: Hitting the Target (HtT), Gas is Key (GK), Austerity Reigns (AR).

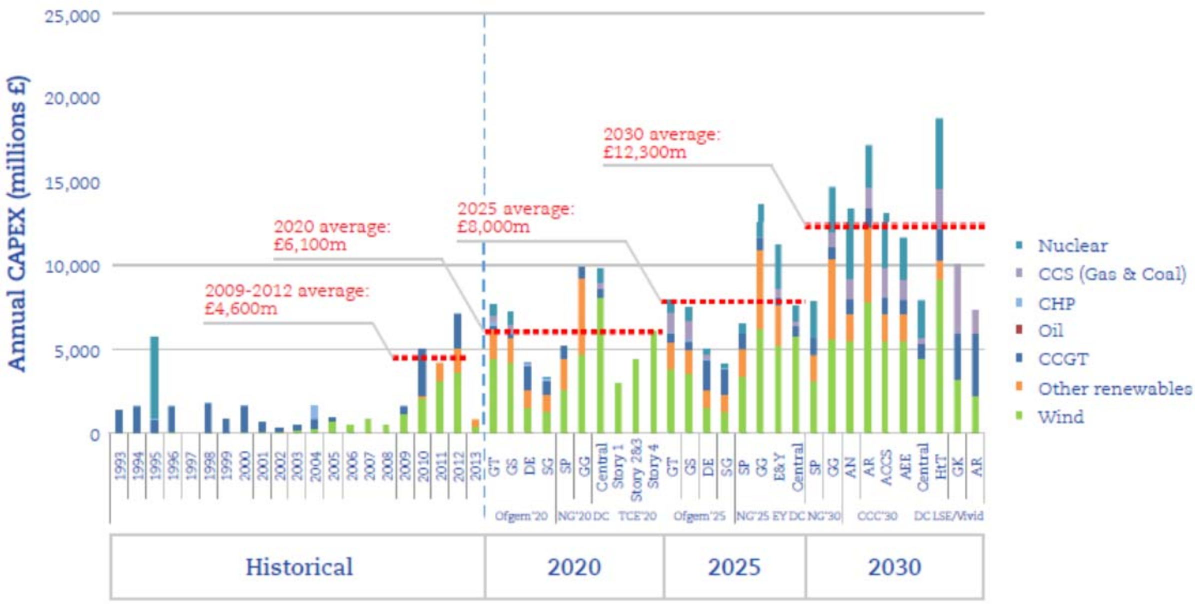

Figure 10: Financial resources required to decarbonize the UK electricity sector (Watson et al., 2014: 14)

Politics and governance

The unfolding of the UK electricity transition is very dependent on supportive government policies, which are underpinned by the commitments in the 2008 Climate Change Act. This radical policy was followed by a raft of specific implementation plans and policies. This dependence, however, makes the UK transition very vulnerable to the fickleness and fluidity of UK politics. UK energy policy has a long history of frequent policy changes (Woodman and Mitchell, 2011), which create substantial investor uncertainties. In the last few years, the UK transition has started facing *political* counter-trends, which gathered pace after the election of a new Conservative-Liberal Democrat government in 2010. Concerns about subsidies and rising electricity costs escalated into a full-scale political row in 2013, which led the government to scrap, delay or water down various green policies. In 2015, the newly elected Conservative government further slashed support for onshore wind, solar-PV (especially 1-5 MW installations), and biomass plants, which are likely to substantially slow down RET diffusion in the 2020s. Meanwhile, the new government has confirmed its commitments to nuclear power and shale gas. These political counter-trends provide a major threat for the future of the UK electricity.

An additional risk is the UK governance style, which can be characterized as a technocratic, top-down, bulldozer style, in which a coalition of big firms and policymakers push through concocted plans rather than consulting with citizens and societal actors. This style has created substantial problems for onshore wind farms (where increasing local protests hinder deployment), fracking and shale gas (where local protests have disrupted permit procedures), and bio-power (where NGOs have criticized the sustainability of imported biomass). Public resistance and protests may delegitimize and hinder aspects of the UK transition in the coming years.

Wider public

Another challenge for the UK electricity transition is to secure public support and socio-cultural legitimacy. One problem in this respect is the decline in public attention for climate change in recent years (Figure 11). Since the financial-economic crisis, public attention has shifted from climate change to concerns about jobs, competitiveness and energy prices.

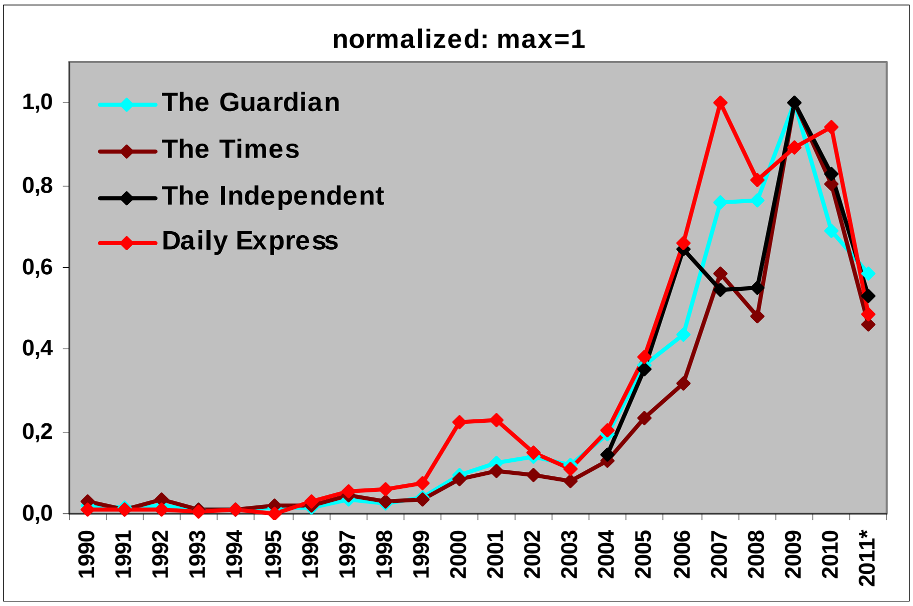

Figure 11: Yearly number of articles in UK national newspapers containing the word 'climate change'

A second problem is that civil society in the UK has weakened since the 1980s (Marquand, 2004), as a result of which there are no strong public spokespersons. Although civil society engagement is vocal in some areas (e.g. animal welfare), it has been muted in the energy domain where "the level of grassroots activity has been very weak" (Toke, 2005: 373). A third, more general problem is that the wider public has become relatively passive with regard to engagement in public debates. Crouch (2004: 2-3) characterized the UK as a post-democratic country characterized by "little interest in widespread citizen involvement or the role of organizations outside the business sector. (…) The mass of citizens plays a passive, quiescent, even apathetic part, responding only to the signals given them. Behind the spectacle of the electoral game, politics is really shaped in private by interaction between elected governments and elites that overwhelmingly represent business interests". If Crouch is correct, it may be quite a challenge to gain public support for the further unfolding of the electricity transition.

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