The importance of regional scenarios for low carbon transitions: the case of Wales

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Abstract: This paper examines the complexities of modelling a regional energy system in the context of Wales, and in the process, examines the role of regions in low carbon transitions. Despite a wealth of studies at national level, it can be challenging to derive insights into the regional potential of different technologies and transition pathways. The Welsh Government has set ambitious energy policy targets; viewed against the background of limited devolved powers – decisions on large-scale power generation lie with central UK Government – and an integrated power network in which Wales is a net power exporter, these present an interesting modelling problem. We discuss the need for 'regional' scale integrated energy modelling assessments, to improve the evidence base on the contributions of different technologies against the existing infrastructure and potential. We also discuss the need for appropriate indicators based on region-specific data in order to inform progress against policy goals.

Keywords: low carbon; resources and infrastructure; regional policy; scenario modelling; renewable energy; Wales.

1 Introduction

Despite a wealth of studies at national level, it can be challenging to derive insights into the regional scope of the different low carbon technologies and transition pathways. Much of the energy policy research treats the UK as a homogenous space and there is little analysis on the different options and the strengths and weaknesses of various approaches towards energy policy targets at the regional level. However, as technologies that tackle energy supply and demand at a distributed level become both available and necessary in order to achieve energy efficiency and emission reduction targets, much of the responsibility for their deployment is increasingly passed to regional and local governments. This transfer of responsibility in itself may not be enough to lead to effective implementation if not combined with additional support at the appropriate level. Having played a leading role in the global emergence of a carbon economy, as a major coal exporter and centre of heavy industry from the mid-19th through much of the twentieth centuries, Wales has now made a very strong commitment to a low carbon future. Following a process of political devolution and the recent establishment of a regional government with a statutory duty to promote sustainable development, Wales is pursuing ambitious targets for emissions reductions and renewable energy generation. These goals are supported by the belief that Wales has an advantage in the abundance of renewable natural resources in its disposition, but may come into question in the context of the limited powers devolved to the Welsh Government in key areas such as the energy sector. In this paper, we discuss the need for better evidence to support the deployment of low carbon technologies and policy making at a regional level, taking into account the availability of natural resources and infrastructure, and debate approaches that could provide this insight using the case of Wales as an example.

The ambitious targets for both carbon emission reductions and renewable power generation capacity set by the Welsh Government, viewed against the background of limited devolved powers – large-scale power generation decisions still lie with central UK Government – and an integrated power network in which Wales is a net power exporter, present an interesting modelling problem. The inherent complexities of isolating the Welsh energy system, introduce a number of difficulties in terms of defining system boundaries, while at the same time raise questions about the level of intervention possible under various policy scenarios. At the same time, it is becoming evident that in order to ensure the effectiveness of policies at a regional level their deployment needs to account for the differences between areas of implementation. Using Wales as a case study, we discuss the importance of 'regional' scale integrated energy modelling and assessment, in order to improve the evidence base on the potential contributions of different technologies against common background techno-economic scenarios. We highlight the need for appropriate indicators and metrics to monitor progress against policy objectives based on region-specific data. This discussion does not deal with the complex policy and institutional landscapes associated with regional politics and multiple levels of governance as such, although research on these topics with regards to Wales is ongoing (Stevenson and Richardson, 2003; Wang and Eames, 2010). Rather, we look into the practical difficulties these boundaries introduce in modelling the implementation and impacts of low carbon policies and technologies and the importance of delivering the necessary knowledge and tools to stakeholders at the appropriate level in order to facilitate the transition to a low carbon future for the region.

This paper is structured as follows. First, we briefly consider the use of scenario modelling for policy support at the UK level. Secondly, drawing from the literature on innovation and regional studies, we highlight the potential importance of the regional level in low carbon transitions. Studying the case of Wales, key points of the Welsh energy system, Welsh Government policies and targets are described to review the current evidence base and discuss the need for improvement. A case is made on the importance of accounting for regional differences at a more disaggregated level in scenarios and models to improve the evidence base.

2 Scenario modelling in support of evidence-based policy

There is a considerable amount of work on energy and low carbon scenarios and models at the UK level, summarised in part in reviews such as the ones published by the Energy Research Partnership (ERP, 2010), the Tyndall Centre (Mander et al., 2008) and the Transition Pathways to a Low Carbon Economy Consortium (Hughes and Strachan, 2010) as part of their ongoing work in the field. These reviews provide an overview of existing work and identify areas of consensus, divergences, interdependencies and uncertainties in the existing views on how the energy system could evolve. They classify modelling work based on approach as prospective (or forecasting) versus backcasting; qualitative versus quantitative; normative versus descriptive; expert versus participatory; entire energy system versus sector specific. Further grouping is based on key assumptions, messages and outputs, and the strengths and weaknesses of the approach. In practice, most will not conform to the given typologies but rather use a combination of methods in their approach. A collective criticism expressed by the reviews is that in general there is no attempt to integrate societal and techno-economic issues and consider political dynamics. These tend to be treated as discrete entities or external factors, which give little information about the reasoning behind assumptions or the relationship between the actions of stakeholders and the resulting change. Most scenarios take a prospective approach projecting the result of certain drivers to an end point in the future without explicitly considering the transition to a decarbonised energy system. The twin axis typology (BIS, http://www.bis.gov.uk/foresight), which has been popular for scenario development, may be problematic in examining the pathways to a low carbon economy, since often the axes used are a combination of more than one factor and the values chosen are not mutually exclusive.

Increasing responsibility to achieve renewable energy targets and reductions in both energy consumption and GHG emissions has been transferred down to regional authorities and local administrations. On the one hand, it has been suggested that regional and local governments may be in a better position to promote sustainable development (Smith, 2007), and setting and achieving regional and local emission reduction targets is emerging as a key point in fulfilling policy commitments at European and national levels (Wolkinger et al., 2012). On the other, a broad range of responsibility for climate change policy action resides on regional governments as often they are responsible for policy areas such as transport, housing, environment and economic development (Galarraga et al., 2011).

A number of efforts to model energy transitions at a smaller scale exist but are very data intensive and often do not address the entire system, while their complexity may not provide a user-friendly, open access interface. Research such as the Greenhouse Gas Regional Inventory Protocol (GRIP) (Carney and Shackley, 2009), targeting emission mitigation or the Low Carbon City Region (Gouldson et al., 2012) require expert user support and collaboration in order to perform and present an analysis for a given region, which not all regional authorities are able to undertake, even though much of the information required is in the public domain.

These renewed concerns with regions resonate with the interest in the region as a scale of economic organisation and political intervention that occurred over the past two decades or so in the field of economic geography, regional development studies and innovation. The next section briefly summarises these contributions, and drawing from the geographers community, highlights the importance of the resources and infrastructure in low carbon innovation.

3 Regions in low carbon transition

The notion of region highlights an important level of governance and coordination of economic processes between the national level and the level of the industrial cluster or firm (Asheim and Gertler, 2005). The meaning of region is to be understood in a much broader sense than its geographical/administrative connotations. The definition of a region often comprises an administrative dimension (Cooke and Schienstock 2000), a sub-national level of governance (Cooke and Leydesdorff, 2006) and a cultural dimension (see for instance the case of the

Welsh language in Wales, (De Laurentis, 2006). Economic geographers, regional and innovation theorists have argued that regions are an ideal territorial scale for the institutional, learning and innovation processes (Morgan, 1997; Storper, 1997; Cooke and Morgan, 1998). Innovation and technological trajectories are based on 'sticky' knowledge and localised learning processes that are bounded within the region and the regional spatial level is increasingly the level at which innovation is produced through regional networks of innovators, local clusters and the cross fertilising effects of research institutions (Cooke, 1992; Braczyk et al., 1998; Asheim, 2003; Gertler, 2003; Asheim and Coenen, 2005). It is argued that it is often the institutional embeddedness of technological development processes and the regional institutional infrastructure within a particular region that explain different innovation paths. Regional institutions and organisations are therefore deemed to play an important role in nurturing and enhancing innovation (Cooke et al., 2007) and, in turn, regions have been considered critical for delivering economic competitiveness (Bristow, 2010, 2012).

However, the literature identifies two shortcomings in these contributions. Firstly, some critics have argued that regional development trajectories have too often focussed on a narrow discourse of competitiveness and economic metrics vis-à-vis regional productivity performance (Smith et al., 2003; Morgan, 2004; Bristow, 2005, 2010). Thus, scholars are increasingly focussing their attention to the ways in which the conventional context of innovation and economic development – perceived too narrow to address the challenges of climate change – can be expanded to contribute to the pressing need of more sustainable forms of economic growth and development (see for instance, Healy and Morgan, 2012). This highlights that the region is increasingly being articulated as a key strategic space for the management of economy-environment tensions and, in some instances, regional governments are helping to facilitate this debate by devising more socially progressive, sustainable and redistributive policies (Bristow, 2012; De Laurentis et al., 2012).

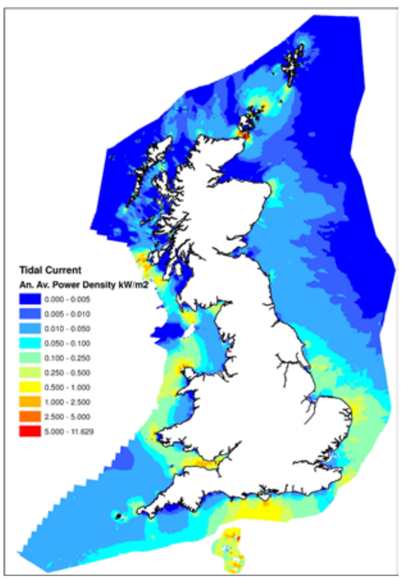
Secondly, innovation studies have, conventionally, tended to concentrate on high technology or knowledge intensive industries, since the surge of interest in the knowledge economy and the increasing role and significance of knowledge as an input to economic processes (Smith, 2000). One of the key components, it is argued, within the knowledge economy, is that there is a greater reliance on intellectual capabilities and that the role of knowledge (as compared with natural recourse) has become more important (OECD, 1999). However, taking sustainability and a low-carbon economy as a *meta-narrative* (Healy and Morgan, 2012) implies that the materiality and physical geography of particular territories, such as regions, needs to be considered. On the one hand, low carbon energy innovation based on renewable sources needs to be understood as a combination of natural-resource-based activities with knowledge intensive-assets. On the other, within policy discourses, there are often explicit links between the natural environment and resources, the built environment and existing infrastructure, with both regional competitiveness/comparative advantage and past and prospective energy transitions, as highlighted in the quotes below:

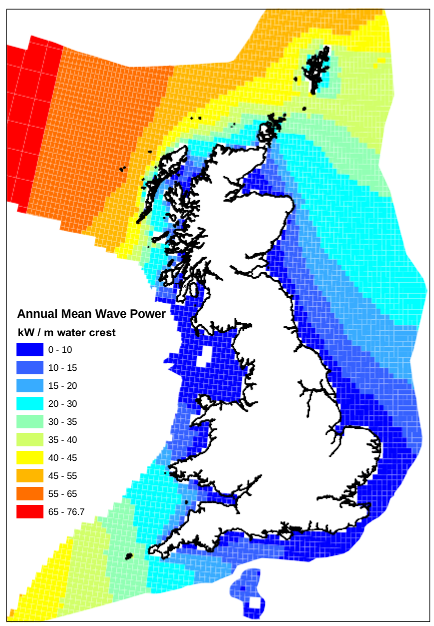
"We possess 10 per cent of Europe's wave power resources and 25 per cent of its offshore wind and tidal resources. Scotland's extraordinary natural marine energy resources and leading position in the development of wave and tidal energy technologies provide a unique platform to establish a world leading position in this vitally important sector. Scotland is becoming the Silicon Valley of marine energy worldwide." (Salmond, 2012)

"Wales has significant assets in virtually every energy source – we have significant wind resources, both onshore and offshore; significant wave and tidal energy potential; one of the best solar resources in the UK; scope for more biomass and hydro; and existing nuclear sites and expertise in the nuclear industry. We also posses the key infrastructure to make the most of the energy opportunity in terms of our roads; railways; deep ports and electrical and gas grids." (WG, 2012)

Further to this, within the geographers' community, it is argued that geography is central to understanding and addressing current energy discourses. Although many energy-related issues have not yet received much attention in the economic geography or the geography traditions (Jiusto, 2009), many aspects of energy display strong spatial dimensions (Pasqualetti, 2011). Hence, the resource systems of energy are entwined as social-environmental interactions occur across multiple-scales (Zimmerer, 2011) and energy production, distribution and consumption are grounded to the natural environment in which they occur. The geography of resource occurrence becomes increasingly important in this context.

Figure 1 Annual averages for tidal current power density (a) and wave





power (b) for the UK

(a) (b)

Note: Based on data sourced from the Atlas of UK Marine Renewable Energy Resources.

Source: ABPmer (2008)

For example, there has been a growing appreciation of the scale of offshore wind (Jay, 2011); marine and tidal (ABPmer, 2008) energy sources available to the UK, due to the availability of relatively shallow windy waters, wave and tidal currents with centres of high demand close to the coast. This is coupled with the availability of a well-developed grid system and ports infrastructures, which are deemed to be important characteristics for the commercial success of offshore renewables (Murphy et al., 2011).

Figure 1 shows two indicative maps of tidal and wave power density for the UK, displaying the different spatial distribution of natural resources around the coast. In addition to the quality of the natural resource, grid and port infrastructure, local weather conditions and local geography (e.g., accessible onshore areas suitable for assembly and maintenance) will determine the priority and extent to which these resources will be utilised.

It follows that physical geography could play an important role in helping to understand processes of low carbon innovations and transition. The case of Wales which is examined in the next sections provides an example of a regional government pursuing ambitious energy and emission policies, based on the abundance of natural resources at its disposal. In this context, regions are seen as major nodes in wider networks of actors that may simultaneously develop their local resources and access and influence resources at different spatial scales to trigger sustainable socio-technical change (De Laurentis et al., 2011; Eames and De Laurentis, 2012). However, the lack of evidence, knowledge and tools at the appropriate spatial level may hamper this process.

4 Wales as a prospective low carbon region

Wales is a relatively small country, with a population of just under three million, located on the western periphery of the UK (the UK is comprised of the nine regions of England, Scotland, Wales and Northern Ireland. Wales, Scotland and Northern Ireland have devolved administration and elected assemblies). Devolution in Wales took place after the 1997 Welsh Devolution Referendum with the first National Assembly for Wales (NAW) elected in 1999.

Reviewing historic patterns of economic and industrial development and decline in the Welsh economy (Wang and Eames 2010) describe these as largely driven by external interventions and demands, rather than internal processes of technological innovation and growth within the region. In contrast, Wales now aims to be at the forefront of the transition to a low carbon economy by actively supporting the research, development and deployment of key technologies. in priority areas such as hydrogen; large-scale power generation; marine energy; solar photovoltaic; low carbon built environment; also focusing on cross cutting themes and energy sector training.

4.1 *The particulars of the Welsh energy system*

Devolution has given the Welsh Government control on decisions over 20 areas of devolved responsibility for which direct law-making power were also transferred after a further referendum in March 2011. Crucially, however, energy policy still remains largely controlled by the central UK Government, with requests to devolve planning authority over large energy projects (> 50 MW) situated in the region rejected this far. Wales bears a considerable share of the emissions from production in the UK due to:

- a large industry sector compared to its size and population
- harder to treat residential housing stock (ard to treat properties have solid walls and are

off the gas network – solid wall properties account for 37% of the total in Wales and 27% in England while the proportion of properties off the gas network is 37% in Wales against 15% in England (Baker and Preston, 2006))

- and the fact that it is a net exporter of electricity (see Figure 2) and energy services.

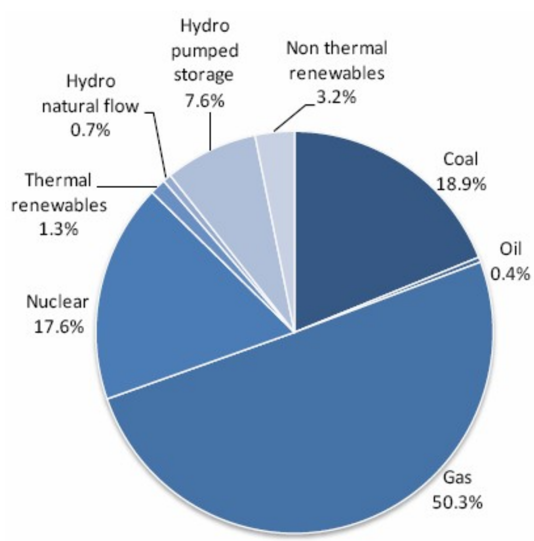
At 16.6 tonnes, it has the 6th highest per capita greenhouse gas (GHG) emissions between the EU-27, the UN Framework Convention on Climate Change Annex 1 Parties and the UK devolved administrations. To date it has also made slower, and rather inconsistent, progress towards emission reduction than the rest of the UK (NAW, 2011). Over 60% of Wales' emissions originate from power generation, business and combustion in heavy industry and fall under European Union Emissions Trading Scheme (EU ETS), Carbon Reduction Commitments, or Climate Change Agreements and thus outside Welsh Government competence. The energy intensive structure of the Welsh industry, a large dependence on private car compared to the rest of the UK and a high (and increasing) level of fuel poverty also leaves Wales more vulnerable to fossil fuel price hikes or a potential energy crisis (Jones, 2010).

The Welsh Government has declared a strong commitment to achieve annual carbon equivalent emissions reductions of 3% per year in areas of devolved competence (WAG, 2010a) and work with industry to reduce emissions in non-devolved sectors towards an overall CO_2 equivalent emission reduction of 40% by 2020 compared to the 1990 baseline, aiming to reach 80% in 2050. The target of 3% reduction per year, relates to all direct GHG emissions in Wales except those covered by the EUETS. In addition, recognising the importance of reducing electricity consumption, power generation emissions (for the most part covered by EU ETS) are also included in the 3% target, by assigning them to the end- user in each of the non-traded sectors. By this definition, the residential and transport sectors become key targets for reductions as they represent 30% and 36% of the emissions within Welsh Government competence (WAG, 2008).

Welsh Government aspirations also include reducing the use of carbon-based energy by 80% to 90%, making all new buildings zero carbon buildings and at least matching electricity consumption in Wales with power generated from renewable sources by 2025 (WAG, 2009). This last target would translate to more than 30 TWh of renewable electricity and 3 TWh of renewable heat per year. More ambitious plans hope to generate twice as much renewable electricity annually in 2025 as presently consumed in Wales, with a view to expand this to cover all local energy needs by low carbon electricity by 2050 (WAG, 2010b).

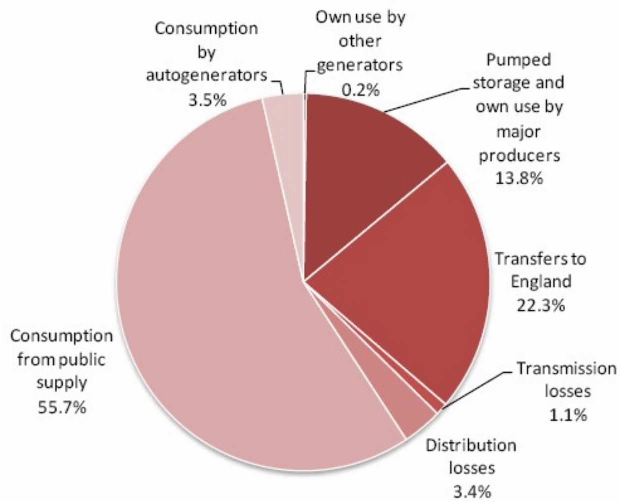
Figure 2 shows current electricity generation in Wales with regards to the type of fuel and the generation and supply figures, which demonstrates both the magnitude of the task involved in achieving the policy targets described above and the extent of Wales' importance as a power exporter. Renewable power generation in Wales presently accounts for just over 5% of the total (1.6 Twh) and almost a quarter of generation is exported to England.

Figure 2 Percentage share of electricity generation by fuel (a) and



(a)

electricity supply (b) in Wales for the year 2010



(b)

Source: Data source (DECC, 2011)

4.2 *A low carbon transition for Wales: the current evidence base*

Reviewing current scenarios and energy models to examine their utility in a Welsh context reveals considerable expertise and a range of well established tools available for integrated energy system modelling and assessment at UK level (Mander et al., 2008; ERP, 2010; Hughes and Strachan, 2010). However, despite this wealth in UK-scale research, the capacity to undertake detailed regional scale integrated modelling is much less advanced. As a result, it is challenging to derive insights into the regional scope of the different technologies and transition pathways, as most studies do not address UK regions and devolved administrations separately, although some do offer disaggregated figures (CCC, 2008).

Whilst a number of partial assessments have been undertaken on the potential contribution of different technologies and policy measures, there is currently no integrated energy system model for Wales. Forster and Levy (2008) set a baseline for emissions under a business as usual scenario and list policy options for GHG reductions as set out in Welsh Government policy. The different options are ranked in terms of cost, and priority policy interventions per sector are highlighted. A short comparison across sectors was attempted, but no aggregate results were derived since the interactions between the different measures across sectors were not taken into account. Calverley et al. (2009) examined the pathways and implications of achieving emission reductions beyond the 3% already pledged in policy documents. The analysis focuses mainly on the devolved sectors, while assuming successful implementation of the Welsh Government renewable energy targets, i.e., electricity demand being fulfilled by zero-carbon generation by 2025, even though it is acknowledged that this target will require considerable effort to achieve. Turner et al. (2011) examine the usefulness of consumption accounting measures (such as carbon footprints) and final consumption as the main driver of regional emissions generation. This approach offers a different viewpoint, given Wales' position as a net exporter of energy and heavy industry services, but is highly data-intensive and may not offer the desired insight in terms of the technologies under examination.

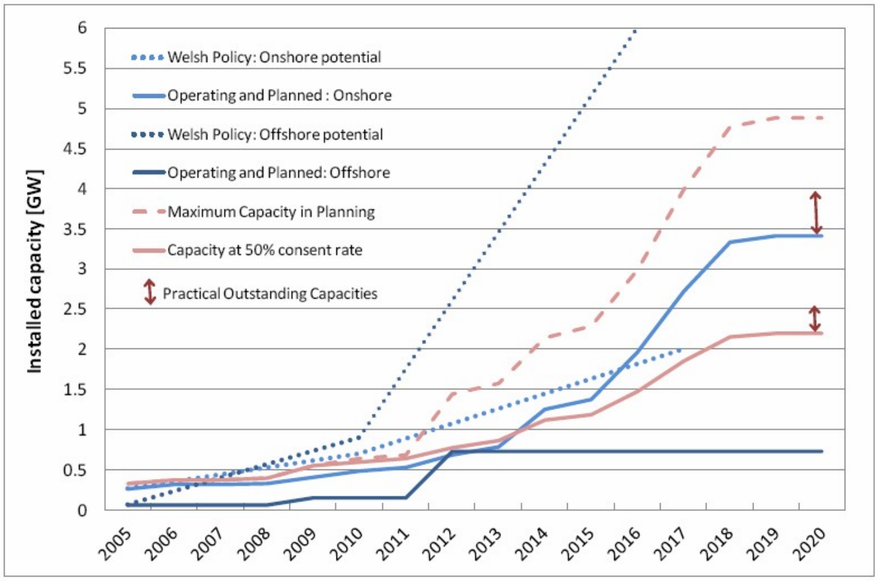
These studies are a useful starting point for setting emission baselines and scoping out the potential contribution of certain technologies in the transition to a low carbon Wales. However, for the most part, especially in sector specific studies, the potential for energy and emission savings of emerging technology options is explored de-coupled from other developments that may be taking place at the same time, and not accounting for the diversity in materiality and physical geography of the areas they address. Regional stakeholders thus struggle to derive insights from the research as it does not reflect the needs, potential, opportunities and constraints specific to their area of jurisdiction or responsibility. The next section provides a few examples and arguments stressing the need for a modelling framework that accounts for regional diversity in the context of Wales.

5 Scenario modelling framework for a low carbon Wales: some key issues

The abundance of renewable energy potential and declared intention to exploit it, does not necessarily translate into capacity being deployed at the desired rate or time frame. It is important to maintain an open and realistic, forward view on the prospects of emerging technologies to contribute to a low carbon future and be able to continuously re-evaluate their potential contribution under different economic and regulatory frameworks. Moreover, defining and monitoring appropriate indicators at the regional level is critical, in order to set feasible targets, promote efficient use of resources, and protect against unrealistic expectations (Wolkinger et al., 2012). Figure 3 highlights the potential shortfall from policy targets in wind power capacity based on current projects in operation and planning (DECC, 2012; REF, 2012) as well an assessment of the limitations on further expansion (WAG, 2010d). Offshore wind deployment in particular is very much behind the desired targets and a similar situation could arise with marine power where the quoted potential of 12.5 GW by 2025 seems difficult to achieve in view of a modest 17.5 MW currently in the planning process.

According to Welsh Government policy, for the purpose of monitoring progress against the 3% reduction target, a UK-wide carbon intensity factor will be used to convert electricity at the end-user level into CO_2 equivalents. This factor was chosen in order to reflect the integration of the electricity network across England and Wales and to avoid fluctuations caused by change in operation of power stations in Wales (WAG, 2010a). Investigating electricity consumption at end-user level is essential in order to influence demand and optimise supply. However, using a UK-wide emission factor will not reflect progress on renewable generation, for which indicators such as a “CO_2 efficiency of electricity production in Wales” have been suggested (WAG, 2008).

Figure 3 Wind capacity in operation and planning in Wales, against potential quoted in



policy (see online version for colours)

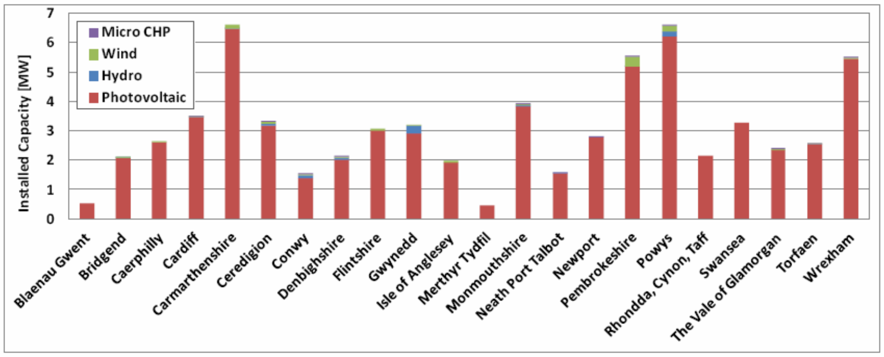
The effectiveness of energy saving measures in terms of carbon emission reductions from power generation is dependent on the marginal emission factor of the large-scale power generator at the time they come into effect, both in terms of the point in the pathway at which they may be ready for implementation and the actual time of operation and influence they have on the daily or seasonal supply/demand curve (Bettle et al., 2006; Hawkes, 2010). There is inherent complexity in distinguishing the Welsh energy system from that of the UK, however it may be essential to adopt the 'island' approach (Calverley et al., 2009) in order to gain insight about the effect of devolved policy decisions. In doing so, care should be taken to account for displaced impacts. For example, there is a finite supply of sustainable biomass, which means that the various bioenergy applications may have to compete for resources which can also have knock-on effects on the food supply chain, land use and agriculture sectors. Similarly, in the case of scenarios not treating the entire system, when emission reduction potential is quoted, it is important to clarify whether this represents avoided emissions or part of the effect comes from displacing the burden to a different sector, or region, which may or may not be included in the scope of the study. Further research is required to establish appropriate and effective metrics and indicators for monitoring progress against the twin policy objectives of achieving emission reductions at end user level and promoting renewable power generation.

While there is ongoing debate about the planning and authorisation of large energy schemes, inevitably, as more and more technologies that tackle energy supply and demand at a distributed level become both available and necessary in order to achieve energy efficiency and emission reduction targets, the responsibility for their implementation is passed down the administrative level. Local authorities in Wales have been charged with tasks such as improving and maintaining building stock conditions to achieve certain levels of sustainability (NAW, 2001), and identifying and deploying sustainable and financially viable renewable energy schemes (WAG, 2010c). Regional and local administrations have displayed varying levels of readiness in responding to these challenges, which can be attributed to a gap in knowledge and capacity in what effectively is deployment of state-of-the art technology at a local level. It has been argued that the transfer of responsibility has not been combined with the level of support required (Wolkinger et al., 2012), and the resulting lack in expertise can mean that local authorities are hesitant in taking decisions on cutting edge or contentious projects (Stevenson and Richardson, 2003). This is compounded by the fact that information and analysis at regional or sub-regional level on areas such as renewable energy potential or targets is not readily accessible.

The residential sector is a good example of the challenges faced by local administrations. It has been identified as one of the critical areas of intervention in order to achieve the emission reduction targets set out in policy, and as previously mentioned, in Wales the sector has a larger share of hard to treat properties compared to the rest of the UK. Therefore, the potential for energy efficiency improvement of the housing stock is higher, albeit at a higher associated marginal cost (Baker and Preston, 2006). However, at the time of writing there is no representative residential stock model for Wales, and previous work (Hinnells et al., 2007) approximates the region using data from elsewhere in the UK, which is less than representative or useful for the local authorities that need to act on the problem. It is essential to work towards an accurate portrayal of the sector that will allow stakeholders to address residential stock-specific constraints and opportunities in Wales, disaggregated appropriate level.

Figure 4 shows that the deployment of small scale renewable generators across the Welsh local authorities displays a great degree of variability, not entirely consistent with the size of the regions in question (Figure 5) which is yet to be evaluated against regional technical and socio-economic factors. The availability of natural resources, as well as the underlying socio-economic structure are dictating the extent and speed of deployment for specific technologies out of the choices available. Small hydro resources are extensive in certain areas but require substantial investments. Photovoltaics have been very popular, but the deployment seems on first examination to be prevalent in more affluent areas (targeted by developers) and may be constrained in certain localities by the Welsh topography (e.g., buildings in shadow-cast areas). Accounting for the potential in each area as well as the drivers behind implementation is a key step in allowing regional stakeholders to make informed decisions. It is therefore important that any research undertaken is disaggregated, as a minimum, down to the level of the authority responsible for the deployment of the measures concerned, and that provisions have been made for dissemination and use at that level.

Figure 4 Small scale renewable generators subsidised by the feed in tariff scheme by local



authority in Wales (see online version for colours)

Source: Data source (REF, 2012)

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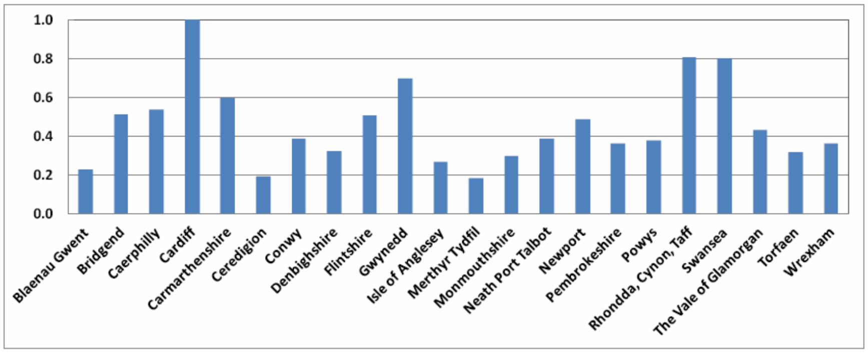
Figure 5 Size index of Welsh local authorities relative to Cardiff in terms of household



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Part of the existing scenario and modelling work mentioned previously, uses a single set of future fuel and carbon price projections as the basis for comparing the competitiveness and effectiveness of different options. While this offers a consistent comparison of new technologies, the fact is that when put in to practice, these options will all have to compete with existing counterparts which in their majority are fossil fuel based. Fossil fuel costs and the level of carbon constraints imposed will also have an impact and are both factors that should be explored. Carbon constraints translated into real costs, and the relative rather than absolute price of oil, coal and gas, set the level of competitiveness that has to be achieved by emerging technologies, so as to be contenders for a role in the energy market (Hughes and Strachan, 2010; Tzimas and Georgakaki, 2010). Furthermore, the implications of fuel or technology switching to competitiveness, security of energy supply, and fuel poverty for the system should be part of the research brief, as much as the focus on achieving the emission reduction milestones set out by policy.

We have already mentioned Wales' vulnerability to disruptions in the global energy market. This could be both a driver to adopt efficiency measures and renewable technologies, and a hindrance with regards to the scale of the change required. A number of choices may be available for each sector, offering different advantages and disadvantages in terms of feasibility, cost, resources, maturity, time and scale of deployment. In addition, a number of these choices might be mutually dependent or exclusive, have to compete for resources or have knock-on effects on other sectors. Technologies may have a very limited time window in which to capture the readily accessible share of the market, and their commercial readiness against that of competing solutions, along with the economic climate may reduce deployment potential and impact, especially if technologies are targeted at the same sector. For these reasons, the potential for energy and emission savings of emerging technology options cannot be explored de-coupled from concurrent technical and socio-economic developments.

6 Concluding remarks

Models, scenarios and transition pathways are increasingly used to inform policy decision making at different spatial and governance levels. However, the output and assumptions made in these often do not take into account regional differences in for example physical geography, natural resource occurrence and socio-economic background. This paper has presented a discussion on the need for integrated energy modelling assessments to be performed at a more disaggregated level, to improve the evidence base taking into account existing infrastructure and resource potential at an appropriate scale.

Other disciplines reflect quite extensively on the role that regions play in economic terms and in managing the economy-environment tensions. This paper argued that regional governments have increased responsibility to achieve renewable energy targets and reductions in both energy consumption and GHG emissions, however, the lack of evidence, knowledge and tools at the appropriate spatial level may hamper this process. Wales provides an example of a regional government pursuing ambitious energy and emission policies, based on the abundance of natural resources at its disposal. Looking at the case of Wales, there is a clear need to improve the evidence base and capacity to undertake integrated energy modelling and assessments at the regional (Welsh) level, in order to support effective implementation of the Welsh Government progressive carbon reduction policy aspirations. The potential contributions of different technologies need to be assessed in parallel and against common background techno-economic scenarios.

This paper has highlighted that natural resource occurrence of energy, and renewable energy in particular, are important elements that are increasingly rising to the attention of policy discourses and strategies. Nevertheless, there are further elements that have an impact upon resource utilisation and technology deployment such as differences in the built environment (e.g., infrastructure availability and housing stock) and underlying socio-economic structures. Therefore, models that do not take into account such differences are not best placed to offer a good evidence base to stakeholders. The lack of information at the appropriate level is often seen as a barrier to action at local governance level.

Drawing from the example of Wales, further research is required to re-assess and allocate the potential of different technologies, based on region-specific data in sectors where notable differences exist between the national and regional dimension. Regional scale integrated modelling could also provide indicators for monitoring progress against the twin policy objectives of achieving emission reductions at end user levels and promoting renewable power generation. The approach will have to take into account stakeholders at different levels of governance and reconcile the need to isolate the regional Welsh energy system with the interactions that arise from the fact of its physical and regulatory integration with the rest of the UK.

More research is needed on the emerging technologies and pathways to low carbon futures, especially when it comes to enabling or disruptive factors, system interactions and the relevance of the availability of resources at the regional level.

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