Pen-y-Cymoedd wind farm photo credit Vattenfall

Swansea Bay City Region : A Renewable Energy Future

Energy system vision for 2035

April 2018

Report and analysis produced by Regen for the Institute of Welsh Affairs

The IWA Re-energising Wales project is kindly supported by the Hodge Foundation, the Friends Provident Charitable Foundation and the Polden-Puckham Charitable Foundation.

About the Institute of Welsh Affairs (IWA)

The IWA is Wales' leading independent think tank, working to make Wales better. Our role is to act as a catalyst to generate intelligent debate about Wales' future. We are an independent charity with a broad membership base across the country. We bring people together so that ideas can collide and solutions can be forged.

The Re-energising Wales project, which is being led by the IWA, is a three year programme of work that will provide evidence to supporting the project's goals of showing how Wales could meet its future energy demands from renewable sources by 2035. This evidence will be used to support policy makers in Wales to achieve an overall objective to reduce energy-related greenhouse gas (GHG) emissions by 80% by 2035 based on 1990 emission figures .

About Regen

Regen is an independent not-for-profit that uses our expertise to work with industry, communities and the public sector to revolutionise the way we generate, supply and use energy.

Regen passionately believes that sustainable energy has a vital role at the heart of a successful economy and thriving local communities. We are ambitious on the scale of our impact and aim to be the leading national experts in how to enable radical change in the energy system at a regional and local level.

With thanks :

The Re-energising Wales project is supported by the Hodge Foundation, the Friends Provident Charitable Foundation and the Polden-Puckham Charitable Foundation. Further information on the project is available on the IWA website.

Thanks also to the Re-energising Wales steering group, local authorities and other organisations that have contributed to and shaped the development of the Swansea Bay City Region energy vision.

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	Johnny Gowdy, Director, Regen

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1 Executive summary

1.1 Re-energising Wales project

The IWA's **Re-energising Wales** project has brought together representatives from industry, regional stakeholders and academia that have an interest in the future development and transformation of the energy system in Wales. The overall objective of the project is to provide practical plan by which Wales could achieve its ambition to maximise its use of renewable energy resources by 2035, resulting in an 80% reduction in energy-related greenhouse gas (GHG) emissions.

As part of the Re-energising Wales project, Regen has been asked to conduct an analysis of the future energy demands and potential sources of energy generation and, working with the Re-energising Wales steering group, to create a low carbon energy system vision for the Swansea Bay City Region (SBCR) in the time period to 2035.

"The purpose of developing an energy system vision for a Welsh city region has been to present a case study of the targets, challenges and actions that would be needed to achieve a radical transformation of an energy system at a local level. These insights could then be applied to other Welsh regions and at a national level."

Shea Buckland-Jones IWA
Re-energising Wales Project Coordinator

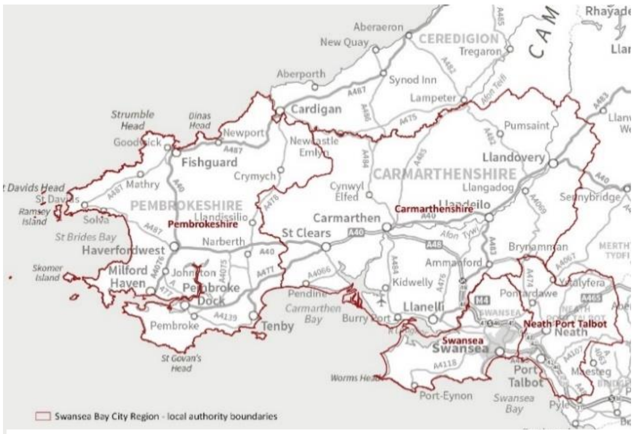


Figure 1: The geography of the Swansea Bay City Region includes Pembrokeshire, Carmarthenshire, Swansea and Neath Port Talbot.

The case study is <u>not intended to be prescriptive.</u> There are a number of potential pathways to achieve energy transformation, and new opportunities that will emerge as energy systems develop. The case study therefore presents a potential development scenario which is intended to highlight the scale of the challenge and opportunities that exist, and to explore some of the enabling actions through which a new energy system might be developed.

The choice of the SBCR as a case study recognises the ambition that has been shown by the region's leaders and stakeholders, and the city region's good mix between urban and rural communities, social diversity and range of potential renewable energy resources including wind, solar and marine energy. The city region is already progressing a number of energy innovation projects including the "Homes as Power Stations" programme and the Pembrokeshire Wave Demonstration Zone.

1.2 Energy system vision and objectives

A key objective and challenge for the study has been to develop a credible future energy system vision for the SBCR in 2035 that would :

1. Maximise the region's contribution to reaching or exceeding Wales' decarbonisation targets
2. Make best use of local generation and renewable energy resources and assets to meet the energy demands within SBCR for electrical power, heat and transport
3. Enable the transition of Wales to an energy efficient, smart and clean energy system by accelerating the adoption of new technology and flexible business models

Working with stakeholders and partners the project has developed an overall vision, and defined a set of objectives and targets, for different aspects of the future energy system as set out in Table 1.

Energy vision for the Swansea Bay City Region 2035	
Key objectives and outcomes (with targets)	
Step change Energy efficiency	Deliver a step change in domestic and commercial and industrial energy efficiency represented by at least a 20% reduction in heat and electricity demand, with a 30% energy efficiency stretch target.
Renewable energy generation:100% of consumption	Maximise use of regional energy resources to achieve a target of renewable electricity generation equivalent to 100% of electricity consumption on an annual basis. Deliver an overall carbon intensity < 50g CO_2e/kWh from local renewable generation and imported (or backup) electricity.
Decarbonisation of heat	40% of heat supply from decarbonised heat supply sources – through electrification, gas decarbonisation and use of renewable energy sources. Reduce the overall carbon emissions from supply of heat (including energy efficiency) by at least 40% compared to 2017.
A transport revolution	Become a leading region for the reduction of vehicle emissions through: • the electrification of transport with 80% of new cars, and over 30% of all cars electric by 2035 • growth and decarbonisation of public transport with 100% Ultra Low Emission Vehicles by 2035.
Local energy generation and ownership	Maximise use of local energy resources to minimise the need for imported electricity with a target of less than 15% electricity imports over the year. Support Wales' ambition that all renewable energy schemes should have an element of local ownership as a basis for another workstream within the Re-energising Wales project.
Flexibility and smart energy	Use flexibility through energy storage, time of use tariffs, smart charging and appliances, and demand side response, to minimise energy system imbalance, grid impacts and imports.

Table 1: 2035 SBCR energy system vision with targets and objectives

The energy system vision objectives and targets[1] are recognised by the steering group as being extremely challenging. The vision is intended to put Wales on track to achieve at least an 80% reduction in emission by 2050 (Environment (Wales) Act 2016 target) and to be in a position to achieve a more ambitious target of zero-net carbon emissions consistent with Wales', and the UK's, overall ambition to transition to a low carbon economy and to meet the commitments made under the Paris agreement to combat climate change. It is hoped that the analysis in this report will give the

[1] Note the regional vision targets and objectives were developed before the Committee on Climate Change published its own advice to the Welsh Government on interim carbon targets (Dec 2017) https://www.theccc.org.uk/publication/building-low-carbon-economy-wales-setting-welsh-carbon-targets/

Welsh Government a good evidence base and case study to assist in the setting of interim carbon targets.

Although the ambition set out in the vision will be difficult and challenging, radical change also brings opportunity and, as this report highlights, the transformation of our energy system will bring myriad opportunities for innovation and investment, for energy consumers, businesses and for Welsh communities.

1.3 Delivering the vision – 2035 energy system highlights

The future energy system described in this paper achieves the targets and objectives set out in the 2035 energy system vision. The summary analysis presented in this executive summary is explained in more detail in the main sections of the report which include the relevant data sources and references.

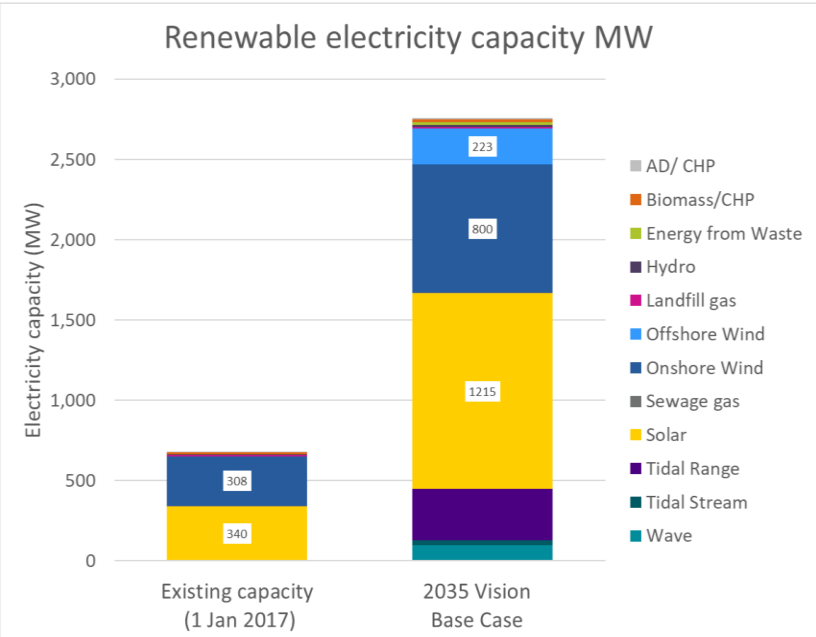
1.3.1 Energy efficiency and demand reduction

A step change in energy efficiency, to achieve a 20% energy demand reduction, is delivered by a comprehensive programme of efficiency measures to domestic and commercial properties.

Over 200,000 domestic properties (60% of households in the SBCR) are improved by at least one Energy Performance Certificate (EPC) band rating, reducing the region's energy demand by 790 GWh, whilst saving householders between £350 and £420 on their annual combined energy bill.

1.3.2 Renewable energy generation (electricity)

A mix of renewable energy technologies would be deployed comprising over 2.7 GW capacity, enough to generate 5.2 TWh of electricity, equivalent to the annual consumption of 4.9 TWh of electricity within the SBCR (plus network losses). The overall carbon intensity of electricity (including imported energy) would be reduced to circa 44g CO_2e/kWh, below the 50g CO_2e/kWh vision target.



The base case scenario includes onshore and offshore wind, solar PV, the Swansea Bay Tidal Lagoon and new technologies such as wave and tidal stream energy.

Alternative scenarios have also been modelled with less solar and without a tidal lagoon, which would require additional wind energy.

Figure 2: SBCR Energy Vision 2035 - Base case renewable electricity capacity mix

1.3.3 Decarbonisation of heat

The most challenging and difficult aspect of the energy vision is to decarbonise the source of heat supply for domestic households and businesses. To achieve the energy system vision of 40% of heat supply from decarbonised sources, and a 40% carbon emission reduction (based on a 2017 estimate), will require the implementation of a number of heat decarbonisation strategies described in Table 2.

Heat decarbonisation strategies	
Strategy	**Description**
1. Energy efficiency	Demand and energy efficiency with a 20% reduction target
2. Electrification of heat	With a principle focus on the deployment of heat pump and hybrid heat pump system technology, although other technologies could be considered
3. Decarbonisation of gas	Through injection into the mains network of "green gases" such as biomethane and hydrogen
4. Renewable heat	Direct delivery of renewable heat energy from sources such as biogas and biomass
5. District heat networks	Delivery of heat through district heat networks which could then in turn be decarbonised

Table 2 Heat decarbonisation strategies

In 2035 the mains gas network would continue to deliver over 65% of total heat demand (directly or via heat networks) but would be decarbonised through the use of green gas, biomethane and hydrogen, to provide 20% of mains delivered energy. Air source, ground source and hybrid heat pumps would deliver 12% of total heat (backup sources for hybrid heat pumps would delivery 2%). District heat networks would deliver 11% of heat while other renewable energy heat sources, such as biomass and biogas, would deliver a further 11%.

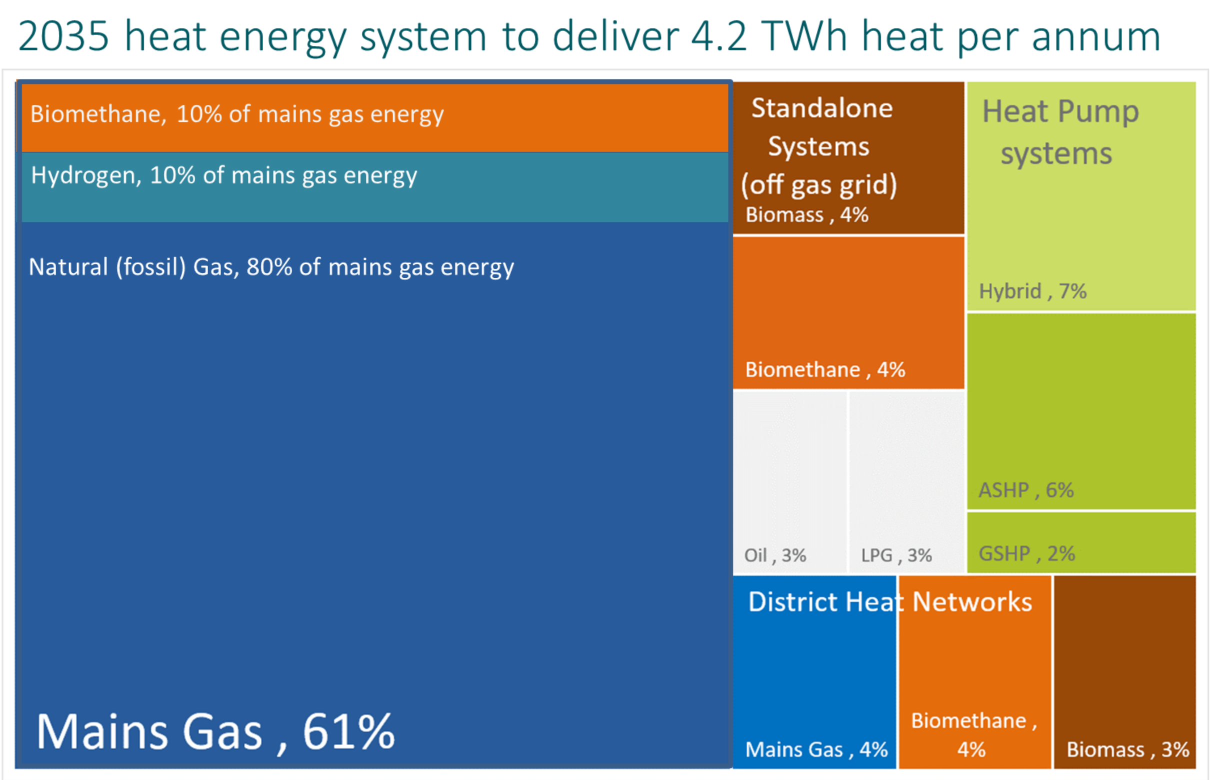
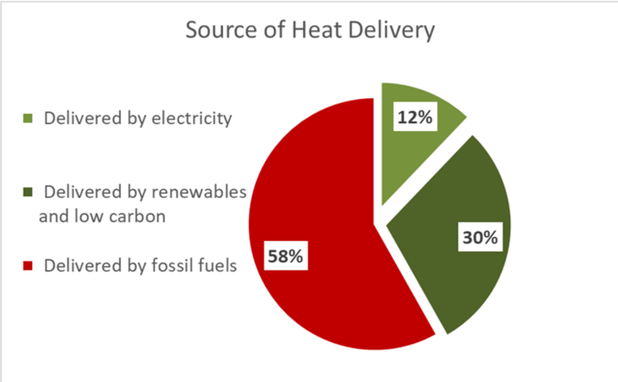


Figure 3: Portfolio of technologies and channels to deliver heat in 2035

The net result is a future energy system with over 42% of heat delivered from decarbonised sources (including electricity and the decarbonised element of mains gas) with an overall carbon emission saving of 41%.

Meeting the 2035 energy system vision for heat

Over 40% of heat delivered from decarbonised sources



Over 40% of carbon saving compared to current emissions

Heat Carbon Savings		
Carbon	**CO2e tonne**	**Carbon Intensity**
	Tonne	**gCO2e/kWh**
Current emissions	940,768	178
2035 Energy System	557,341	133
Carbon saving	383,427	45
Percentage saving	41%	

Figure 4: Meeting the energy system vision for heat

1.3.4 A transport revolution

The future energy vision requires a transport revolution that will deliver an exponential growth in Ultra Low Emission Vehicles (ULEVs), and an increased use of public transport systems. Road transport will be decarbonised with a rapid uptake of electric vehicles for private and light goods vehicles, while hydrogen and biogas vehicles will also play a key role for HGVs and public transport.

By 2035 the number of electric vehicles in the SBCR will have reached over 131,000 vehicles, including 110,000 cars comprising around 34% of the cars registered within the city region.

Overall, electric vehicles (cars, LGV, HGV and public transport) deliver a carbon saving of 324,000 Mt CO_2, equivalent to 30% of today's road fuel emissions.

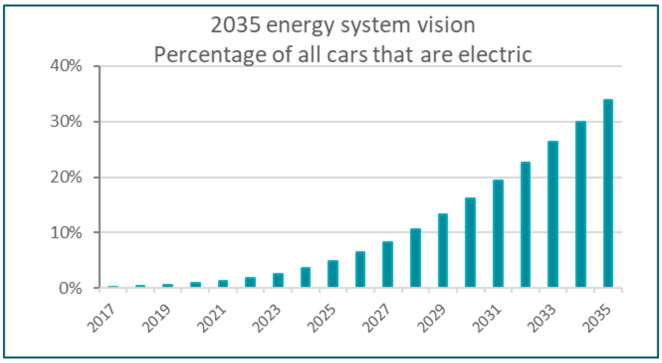


Figure 5 Percentage of cars that are electric vehicles (EVs)

Together with other ULEV technology, such as biogas and hydrogen, increased use of public transport and active travel and conventional fuel efficiencies, SBCR would be on track to achieve the 44% transport carbon reduction that the Committee on Climate Change have identified as needed to meet the Fifth Carbon Budget.

1.3.5 Local energy in a smart and flexible energy system

The energy vision is predicated on the adoption of new technology and the development of new business models, that will generate additional value for energy customers while at the same time improving energy system balancing and security. Smart flexibility will come from a variety of sources including energy storage, local supply markets, demand side response and optimised smart energy solutions which will encourage greater local ownership of energy.

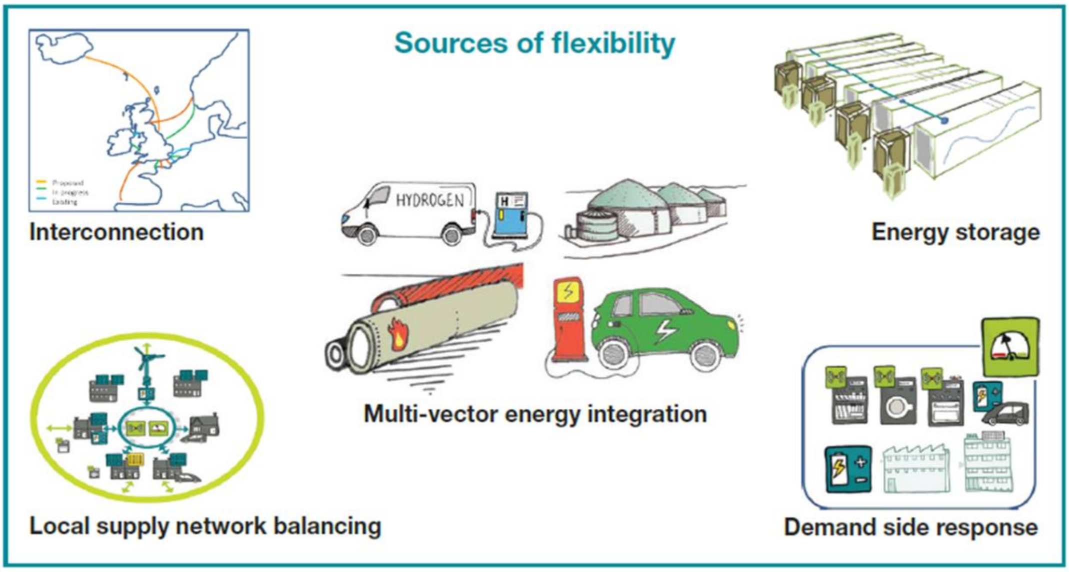


Figure 6 Sources of flexibility

Flexibility will enable best use of variable energy resources, harnessing energy to the maximum extent possible when the sun shines and the wind blows, and will allow system operators to balance the energy system to ensure security of supply at a national and local constraint level. The addition of "smart" technology and business models to the paradigm will also enable the future energy system to be energy customer led, allowing them to take advantage of lower energy costs and the value of their demand flexibility.

Local generation coupled with local flexibility solutions will reduce electricity imports to less than 15% of annual consumption. Already a number of new technologies and business models are beginning to emerge including energy storage, whose market potential has grown significantly on the back of falling costs, and a variety of local supply models[2] including local energy clubs[3], local generation tariffs and private wire systems.

1.4 Big challenges and big opportunities

While the energy system vision demonstrates the potential of what could be achieved it is understood that delivering the vision presents very significant challenges. These challenges can only be met by Welsh regions working together, within an overall supportive policy framework and in partnership with industry.

The challenge of deploying more renewable electricity is perhaps the least difficult to achieve in the sense that the main barriers, which are largely commercial viability and planning, are ultimately within

[2] Regen – Local Supply Models 3rd edition https://www.regensw.co.uk/Handlers/Download.ashx?IDMF=a2053ab5-f5c3-4ed9-a413-2f9861ba1a27

[3] For example Bethesda Energy Club in North Wales see http://www.energylocal.co.uk/

the control of policy makers. Across the UK over 25 GW of renewable electricity generation capacity has been deployed since 2010, in Wales over 3 GW has been deployed. So there is no technical or practical reason why these high growth rates cannot be repeated, and surpassed, provided a positive and stable policy environment to support grid and energy infrastructure investment is in place.

The most difficult challenges are those involving the mass uptake of new technology and energy efficiency measures by consumers and businesses. Highlights within the energy vision include the challenge to install energy efficiency measures in 200,000 domestic properties and over 50,000 heat pumps, equivalent to one heat pump in every seven buildings. Securing active support from Welsh consumers and industry will therefore be critical, and any future energy strategy must be underpinned by public support and a large degree of public and local ownership.

SBCR Energy Vision 2035
Big challenges and big opportunities

		Energy prize (MWh)	Carbon Saving p.a. mT CO_2e	Prime opprtunity for Wales
Energy efficiency	Shift circa 30% of properties from EPC bands D-G to bands A-C, and deploy energy efficiency measures across circa 200k (60%) SBCR properties	788,597	102,863	
		Electricity		
Electricity generation	Is it possible to more than double on-shore wind capacity to 800 MW?	1,159,681	218,020	
	Will the Swansea Bay Tidal Lagoon be built?	504,854	94,913	
	Will a new offshore wind farm be built off the south Wales coast?	759,548	142,795	
	Can tidal stream and wave energy reach maturity?	398,275	74,876	
		Heat		
Heat	Is it realistic to deploy over 50,000 heat pumps (circa 14% of properties)	508,007	84,642	
	Could 10% of buildings be served by a district heat network	468,299	83,518	
	Will sufficient biomethane and/or hydrogen be available - do we have the resources and will they be commercially viable?	623,940	111,320	
		Electricity		
Transport	Will drivers embrace the EV revolution, will we see exponential growth such that a third cars in the SBCR are EV's by 2035?	398,674	324,282	
Flexibility	Is there a business model that would justify investment in over 350 MW and 1500 MWh of energy storage capacity?			
	Will business and domestic consumers embrace smart systems and flexibility - Time of Use Tariffs, optimised and managed smart appliances including heating and EV charging, demand side response -to enable 10-15% of demand to be deferred during peak imbalance periods?			

Table 3 Challenges and opportunities for Wales

The areas of challenge also represent the greatest areas of opportunity both in terms of carbon reduction and the opportunity for the SBCR, and Wales, to demonstrate leadership and seize the commercial, societal and economic benefits that will come from the transformation of energy systems and transition to a low carbon economy.

There are a myriad of individual opportunities contained within the 2035 energy system vision, too many to summarise here. The top five opportunity highlights would include:

i. Creation of a Welsh building power-house
ii. Harnessing offshore wind and marine energy
iii. Maximise the commercial potential of bioenergy
iv. Smart, flexible and local energy
v. Leading the transport revolution

1.4.1 Net zero carbon homes (and commercial buildings) as power stations

A massive uptake of energy efficiency measures, combined with heat-pump technology and on-site generation through roof-top and integrated building PV, offers the opportunity to for Wales to lead in the area of building efficiency and local power generation.

The SBCR energy vision includes:

- Over 200,000 properties with improved energy efficiency measures (66% of properties)
- 50,000 properties with a heat pump (14% of properties)
- 75,000 properties with rooftop or building integrated solar PV (totalling 375 MW capacity)
- Accelerated uptake of electric vehicles and battery

Taken together these measures would radically transform domestic and commercial properties into super-efficient power stations.

As well as enabling Wales to achieve its low carbon targets, increase local and community ownership and drive down energy bills, innovation and supply chain development would create a new low carbon construction and building industry.

1.4.2 Harnessing offshore wind and marine energy

Wales has some of the first offshore wind farms deployed in the UK and has developed a significant offshore service sector based in North Wales and around the Port of Mostyn. Wales could potentially develop a similar industry based around the ports of south Wales including Pembroke, Swansea and Port Talbot. As costs continue to fall, offshore wind is expected to play a pivotal role to enable the UK to deliver its decarbonisation targets with perhaps another 20 GW of offshore wind deployed in the coming decade. It is essential therefore that Wales builds a pipeline of future offshore wind projects, off North Wales, and also in the Bristol Channel and Celtic sea. Floating wind technology offers a significant opportunity for innovation for which the Pembroke demonstration zone and the deeper waters of the outer Bristol Channel and Celtic Sea are prime sites for deployment.

The Swansea Bay Tidal Lagoon project is a strategic project which could create a new tidal energy industry. The synergy between offshore wind, wave energy, tidal stream and tidal range (lagoons) should be exploited. Already new technologies are being attracted to Wales and their commercial development will position Wales as a leading nation for the development of offshore energy.

1.4.3 Maximise the commercial potential of bioenergy

Heat is the biggest challenge, but the decarbonisation of heat will also create opportunities for Wales to develop new capabilities and accelerate its transition to a thriving low carbon economy. Hybrid heat pumps, district heat networks and hydrogen production offer exciting opportunities.

The commercial exploitation of bioenergy – biomethane, bioSNG and biomass – perhaps offers the greatest overall opportunity. Sustainable bioenergy production would enable Wales to create a world class circular economy that fully utilises of waste and residual resources from industry, agriculture and domestic households – potential delivering up to 9 TWh of heat energy via mains gas injection, district heat networks and combined heat and power (CHP) plants. As well as energy benefits, sustainable bioenergy would also create value for the rural economy including through the use of agricultural waste, energy crops and a massive increase in the tree planting that would sustain forestry industries.

1.4.4 Smart, flexible and local energy

Section 8 of the report highlights the critical role that smart technology and flexibility will play in the future energy system. Technological innovation is now intense – encompassing energy storage, digital media, new trading and aggregation platforms, communications, smart meters, smart appliances blockchain and the internet-of-things. All these enabling technologies will create new commercial and business opportunities to create value by optimising energy usage, reducing energy costs and monetarising flexibility services.

Wales should be in the vanguard of the technology and business transformation that will accompany the drive towards smarter energy. In particular, building on the strength of the Welsh community energy sector and schemes like the Bethesda energy club, Wales could become a world leader in the development of local energy supply markets including energy clubs, local generation tariffs and peer-to-peer trading.

1.4.5 Leading the transport revolution

Transport is about to undergo a revolution. The twin drivers of climate change and air pollution, plus the congestion that plagues modern cities, makes it inevitable that the transport systems of the future will be very different to what we see today.

Electric vehicles (EVs) are likely to be the most common form of vehicles, although hydrogen and biogas vehicles will also play a key role. While electrification of transport will bring challenges for energy supply, these are largely surmountable. The uptake and public acceptance of EVs is therefore critical and Wales could do more to support this through the rapid deployment of smart chargers.

Wales could take a leadership position in the adoption of Low Carbon Emission Zones (Clean Air Zones) and measures to radically increase the use of public transport, cycling and walking in order to improve health and wellbeing which should be a priority for future clean air and emission control legislation.

EV charging provides a great opportunity to make best use of energy resources, an integrated transport and energy strategy is therefore needed at a city and regional level as well as nationally. Smart transport systems; using low emission technology, integrating transport modes, harnessing data and communications, will provide the means to transform the way people and businesses utilise mobility services.

1.5 Making it happen

The top five opportunity areas identified above are just the tip of the iceberg. This report shows that the Swansea Bay City Region is in a prime position to exploit its energy resources and generate local value for businesses and communities. Similar analysis, if conducted for other Welsh city regions and rural areas, would show the breadth of opportunity that exists across Wales and highlight the potential for Wales to position itself in the vanguard of the low carbon energy transformation.

Many of the foundations to enable change to happen are already in place. Wales has made a number of significant policy commitments and has gone further than the UK government in setting out its targets and ambitions; notably through the recent Welsh National Marine Plan; Environment (Wales) Act, and the Well-being of future generations (Wales) Act. The National Resources Policy launched in autumn 2017, reaffirms Wales' commitment to achieve an 80% reduction in carbon emissions by 2050 (against a 1990 baseline) and to set interim targets and five-yearly carbon budgets against which progress can be measured.

The high level policy framework and ambition is therefore in place. The priority now should be to turn those overarching goals into targets and shorter-term objectives that can be actioned at a local and regional level. Targets that will act as a call to action for the many individuals, communities, businesses and other organisations that will be needed to deliver a new low carbon economy for Wales.

Progress is being made. Last year's announcement by the Welsh Government which set new targets for renewable energy technology to generate the equivalent of 70% of electricity consumption and for 1 GW of renewable energy capacity to be locally owned by 2030, and for all new renewable energy projects to have at least an element of local ownership by 2020, was a very positive step. At a local level, regions like the SBCR are rising to the challenge with a range of local initiatives to target energy efficiency, fuel poverty and to promote community owned renewable generation.

1.5.1 Taking ownership and control

The commitment to encourage local ownership and community benefit is vital to ensure that there is momentum and support behind the energy transformation. Welsh communities are leading the way and it is significant that Wales is already seen by many renewable energy developers and investors as a good place to develop community based projects. There are many new and exciting local ownership and energy supply models emerging, many of which could be enabled by new technology and digital platforms.

Building on this grassroots momentum, and empowering communities to seize the opportunity that will be created by new technology should be a priority for Welsh energy and environmental policy. This topic is being explored in more detail in another workstream of the Re-energising Wales project.

Taking ownership and control also applies at a Welsh national level. It is notable that the growth of renewable energy projects in Wales are still dependent, to a large extent, on the energy strategies and policies that are developed in Westminster. The recent cuts to subsidies, which has had a direct impact on the rate of renewable energy deployment in Wales, has highlighted this issue, as has the delay and uncertainty regarding major projects such as the Swansea Bay Tidal Lagoon.

The Wales Act 2017[4], does transfer some new powers to Wales in the area of planning for generating stations less than 350 MW, for example, but does not go far enough to enable Wales to determine and achieve its low carbon energy ambitions. As an example Wales could, as Scotland has done, have a greater say and influence over the strategy to develop offshore wind and marine energy technology, as well as setting subsidy levels and priorities for supporting community energy and energy efficiency schemes.

1.5.2 Action at a national and regional level

Very few of the challenges and opportunities identified in this report can be fully realised by Welsh regions working in isolation or without a very strong degree of national policy support. Likewise Wales' energy ambition and decarbonisation targets, cannot be achieved without the support and active engagement of Welsh regions.

As this report shows, greater ambition is needed, and could be achieved, with greater granularity and focus to cascade policy targets down to a regional and local level. Engagement with local communities and stakeholders (and industry) is therefore crucial both to garner support and also to ensure that decarbonisation strategies make best use of local resources to deliver the maximum benefit to Welsh

[4] Wales Act 2017 http://www.legislation.gov.uk/ukpga/2017/4/contents/enacted

communities. It is essential therefore that the interim decarbonisation targets that are about to be defined are accompanied by a practical implementation plan that can be adopted and actioned at a local level.

Understanding what can be done is crucial, as well as acknowledging the challenges that must be overcome and recognising the opportunities that could be harnessed. It is hoped that this report offers useful insight by presenting a case study model of an energy system vision for the SBCR and that it will promote discussion, debate and argument about the best pathway to a low carbon energy future, as well as how the transformation that is needed to achieve this is best governed and implemented.

2 Introduction and approach

The Re-energising Wales project has brought together representatives from industry, regional stakeholders and academia that have an interest in the future development and transformation of energy in Wales. The overall objective of the project is to provide an ambitious and practical plan by which Wales could maximise its use of renewable energy resources by 2035, resulting in an 80% reduction in energy-related greenhouse gas (GHG) emissions.

The 3-year project, running from April 2016 until April 2019, will develop a practical blueprint to use Wales' natural resources to decarbonise the Welsh economy whilst delivering co-benefits in the areas of economic and community resilience, the widening of energy ownership models, and in energy demand management and efficiency. Re-energising Wales aims to provide the evidence to convince policy makers in Wales to adopt a new and ambitious programme to transform Welsh energy and set an example within the UK and internationally.

Within the programme there are six workstreams which cover different aspects of the Welsh energy landscape, from demand management and energy efficiency, energy costs and policy challenges through to the community and societal aspects of a new energy system. This report documents the the outcome of workstream 2, which is to develop an energy portfolio/vision as a case study for a Welsh region.

Work stream	Re-energising Wales programme
1	**Maximising energy efficiency and demand management** Energy demand in Wales – an assessment and detailed data mapping
2 This paper	**Developing an energy portfolio/systems vision** Developing a case study of a future energy system for a Welsh region (SBCR)
3	**Setting the economic parameters** Socio- economic assessment including assessment of energy costs
4	**Social and community issues** Focus on delivering co-benefits in the areas of community resilience when considering the widening of energy ownership models
5	**Regulatory and political challenges** Focuses on devolution and the powers needed in Wales to meet the overall vision
6	**Turning fantasy into reality** Bringing together the overall programme to present an overall analysis and policy recommendations

Figure 7 Re-energising Wales workstreams

The project is supported by the Hodge Foundation, the Friends Provident Charitable Foundation and the Polden-Puckham Charitable Foundation. Further information on the work packages is available on the IWA website.

2.1 Developing an energy portfolio/system vision

The objective of the second workstream of the Re-energising Wales project has been to conduct an analysis of the future energy demands and potential sources of energy generation, and also to create a holistic low carbon energy system vision for the Swansea Bay City Region (SBCR).

The geography of the region includes Pembrokeshire, Carmarthenshire, Swansea and Neath Port Talbot – see Figure 8 Swansea Bay City Region.

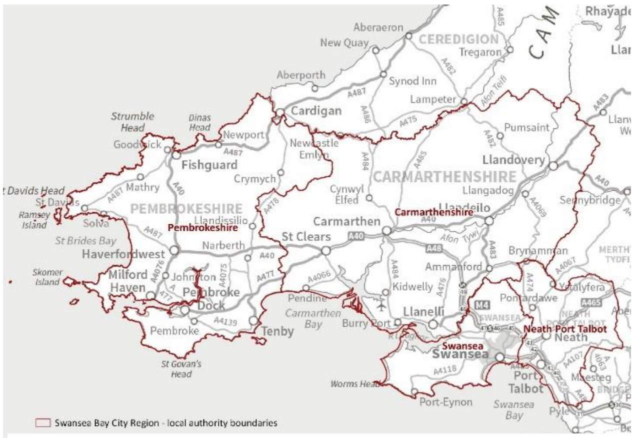


Figure 8 Swansea Bay City Region

This workstream has been divided into two phases. The phase 1 report, which was published in December 2017, set out the level of ambition, objectives, key assumptions, scope and modelling approach for the SBCR energy vision which was agreed with input from the Re-energising Wales steering group and stakeholders. This phase 2 report has taken those assumptions and vision objectives to create a future energy model for the region.

While the intention is that the energy vision for the SBCR should be ambitious, the aim of the study has been to identify local and regional opportunities that are achievable within the timeframe to 2035. The study has therefore been guided by a balance between ambition and realism and there has been a strong direction from the steering group to consider options that could be delivered in the timeframe and resources that are "developable".

The definition of "developable resource" has varied depending on the resource/technology under consideration but as a general definition, the term is intended to include resource which is:

- **technically viable** within the constraints of current technology and/or technology that is likely to be available within the study timeframe to 2035
- **commercially viable** assuming that there is a positive market environment for renewable energy including on-going cost reduction and appropriate levels of market support
- **socially acceptable** assuming that there is a positive planning environment and support for low carbon technology to combat climate change but accepting that there will continue to be planning constraints including, for example, avoidance of designated landscape areas and proximity restrictions.

2.2 Interim scoping, vision and approach report (Dec 2017)

The phase 1 scoping and approach report, set out the key assumptions, definition of scope and modelling approach that was agreed with the Re-energising Wales steering group.

A significant amount of work during phase 1 was spent collating and analysing the current energy generation and demand mix in the SBCR including, for example, the current renewable generation mix for electricity (see Figure 9), domestic and commercial demand for gas and heat and an analysis of existing housing stock.

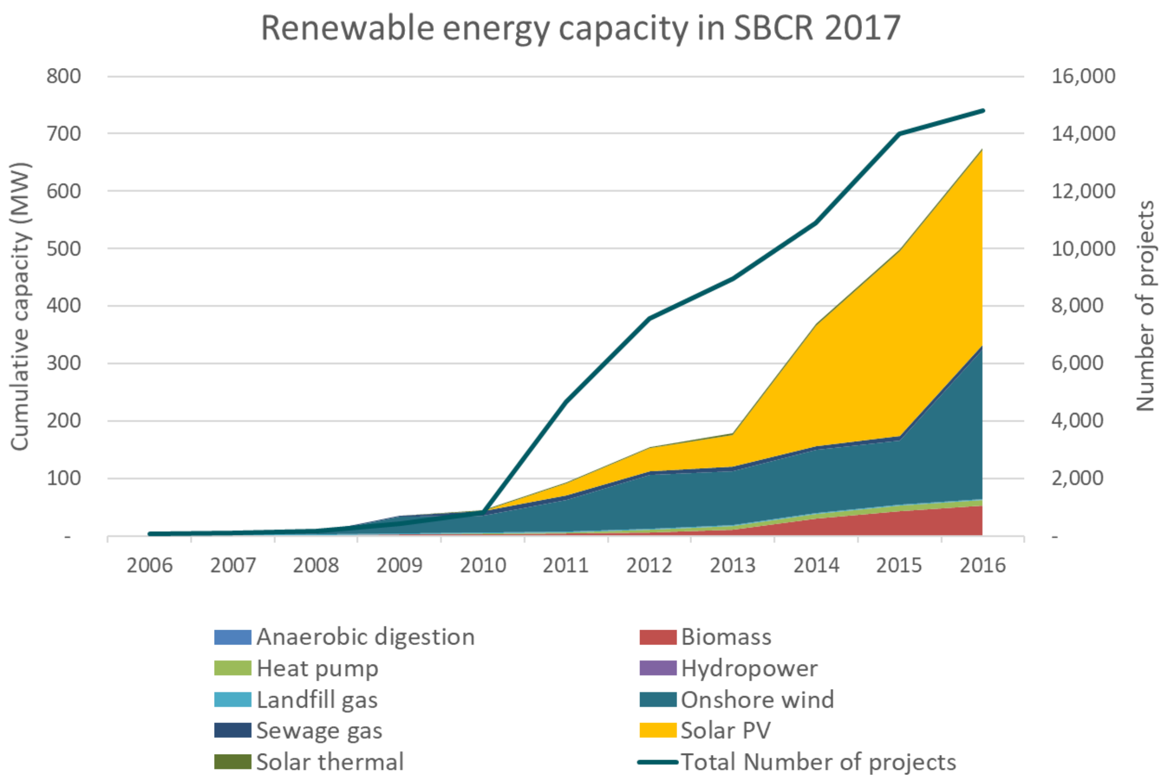


Figure 9: Renewable energy capacity by technology in the SBCR (as of Jan 2017)

The phase 1 report also presents an analysis of the potential resource and growth of key renewable energy technologies including onshore wind, solar PV, tidal range, marine energy, hydro, anaerobic digestion and biomass. The resource potential for onshore wind, for example, looked at available land space, wind speeds and planning constraints, as well as the history and pattern of onshore wind farm development in the SBCR. This bottom-up analysis was used to assess and estimate the development potential of different renewable energy technologies in the period to 2035.

2.3 Modelling and analysis approach – an integrated energy model

A key objective of the project has been to look at the holistic energy demand and supply for a city region including electricity, heat and transport. This analysis therefore required an integrated energy approach, which would consider how demand for heat and transport would have a direct and indirect impact on the demand for electricity (via heat pump electrification, for example).

The modelling also needed to consider not just the overall or aggregate energy flows but also how energy supply and demand could be balanced within daily and hourly time periods. The energy model has therefore profiled energy demand and supply in hourly periods over 365 days.

The core of the model is an energy supply balancing model (which has been adapted from a version of the Wales & West Utilities energy simulator pathfinder model). To this core model Regen has integrated a number of sub-models to model heat demand, transport, storage and flexibility, energy generation technologies and energy efficiency, to create an overall energy supply balance.

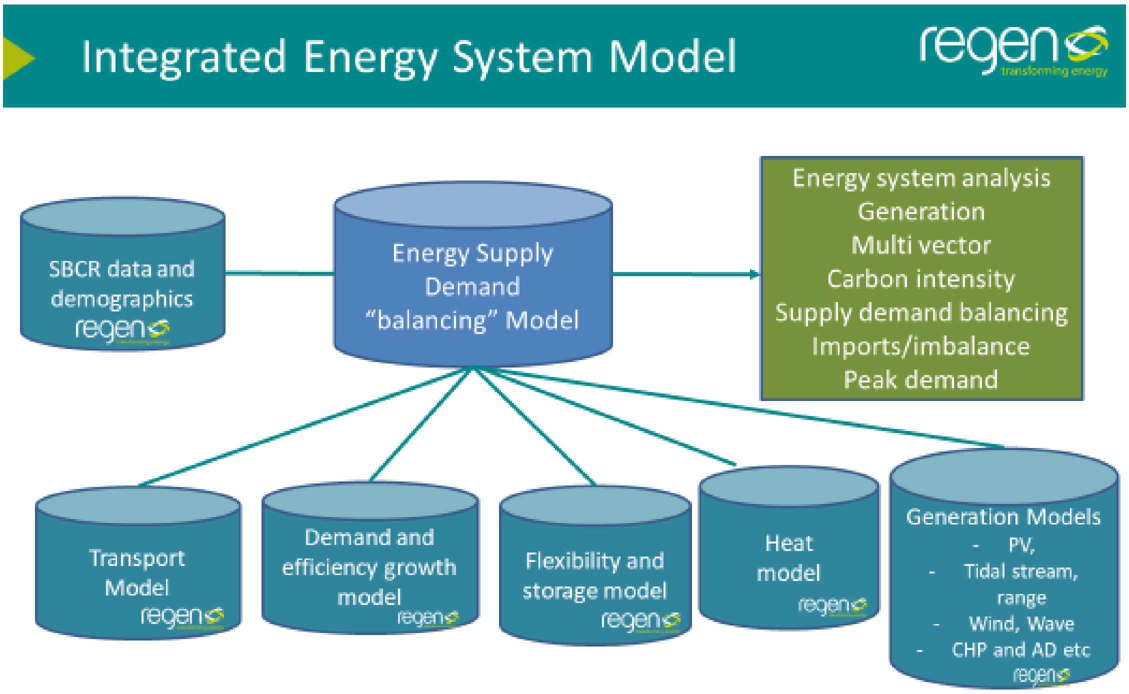


Figure 10: Integrated energy system model and sub-models

2.4 Energy system and investment costs

This report does not include a detailed analysis of energy system costs or the capital investment that would be incurred. A parallel workstream of the project, "Setting the economic parameters", is looking more closely at the economic and costs impacts of the future energy system and vision.

There is however an important overlap and interface between the development of a future energy vision for SBCR and understanding what that future energy system will cost, and how it might impact on consumer bills, system costs and fuel poverty.

Although the future energy system vision is primarily about maximising the use of renewable resources to achieve decarbonisation, it is important to consider the likely impact on energy costs as the vision is developed. To do this, we have used the Levelised Cost of Energy (LCoE) as part of the energy system analysis and adopted a merit order approach to ensure the resources/technologies with the lowest LCoE are utilised first. Using the BEIS 2015 Electricity Generation Cost analysis, for example, would suggest deploying onshore wind and ground-mounted solar PV first, before moving to other technologies such as offshore wind, smaller scale solar and tidal energy.

As an exception to the LCoE merit order approach, wave and tidal energy has been included within the SBCR energy vision because they offer a significant opportunity for technology development from which the SBCR can create jobs, investment and new capabilities.

As well as the LCoE, there is also a case to consider the wider energy system costs of different energy generation portfolios. However, there is insufficient time and budget within workstream 2 to do this justice and so the analysis of energy system costs will be considered in workstream 3.

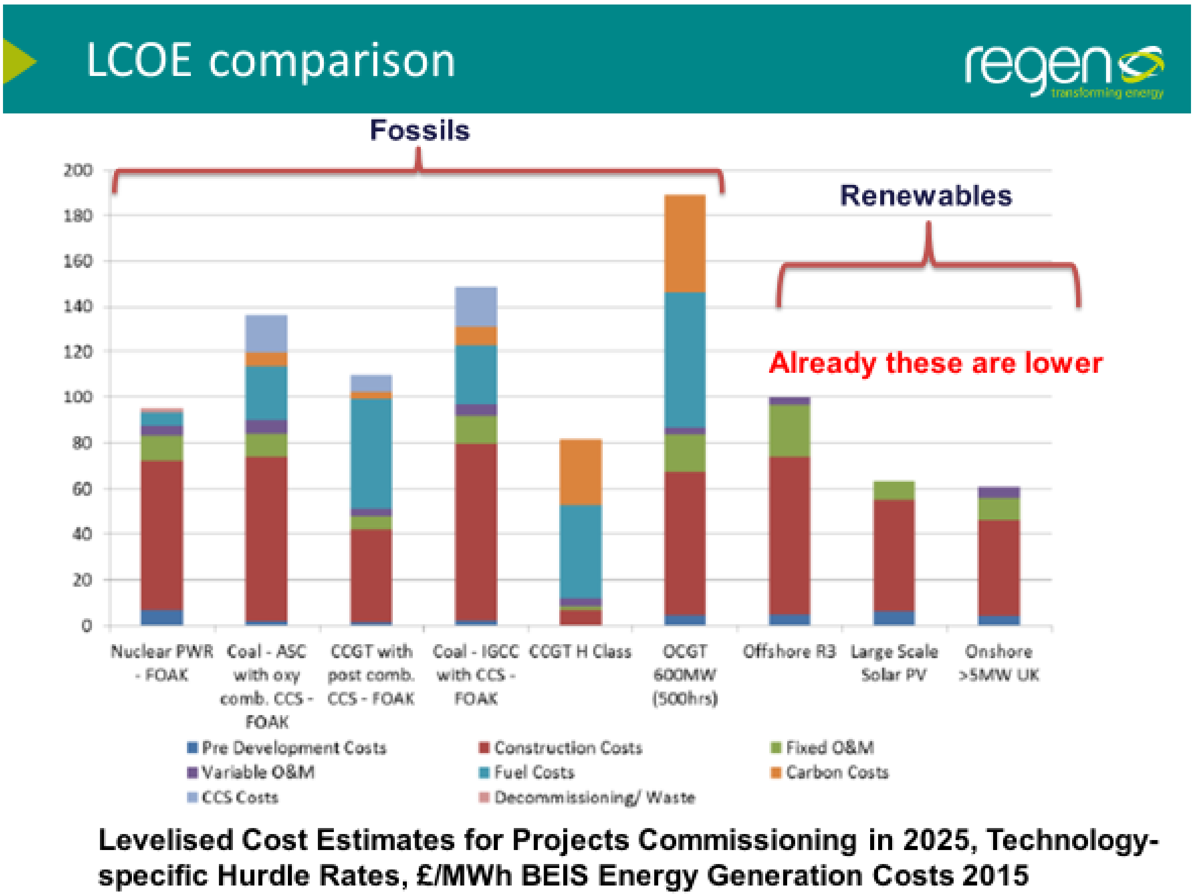


Figure 11: LCOE comparison BEIS Generation Costs 2015

The remainder of this report presents the final results of the analysis and modelling of the SBCR energy vision together with the policy initiatives and roadmap which would be needed to deliver the vision. The report also highlights some of the sensitivities, and challenges, that must be overcome to make the future energy vision a reality.

3 Energy system vision for the SBCR in 2035

To develop this overall objective, work package 2 of the Re-energising Wales project has developed a future energy vision and energy case study for the SBCR, that will make best use of the renewable energy resource and assets within the region to:

1. Maximise the region's contribution to reaching or exceeding Wales' and the UK's decarbonisation targets
2. Make best use of local generation and renewable energy resources to meet the energy demands within SBCR for power (electrical), heat (electrical and non-electrical) and transport
3. Enable the transition of Welsh energy to an energy efficient, smart and clean energy system by accelerating the adoption of new technology and business models

Energy Vision for the Swansea Bay City Region 2035	
Key objectives and outcomes (with targets)	
Step change Energy efficiency	Deliver a step change in domestic and commercial and industrial energy efficiency represented by at least a 20% reduction in heat and electricity demand, with a 30% energy efficiency stretch target.
Renewable energy generation:100% of consumption	Maximise use of regional energy resources to achieve a target of renewable electricity generation equivalent to 100% of electricity consumption on an annual basis. Deliver an overall carbon intensity < 50g CO_2e/kWh from local renewable generation and imported (or backup) electricity.
Decarbonisation of heat	40% of heat supply from decarbonised heat supply sources – through electrification, gas decarbonisation and use of renewable energy sources. Reduce the overall carbon emissions from supply of heat (including energy efficiency) by at least 40% compared to 2017.
A transport revolution	Become a leading region for the reduction of vehicle emissions through: • the electrification of transport with 80% of new cars, and over 30% of all cars electric 2035 • growth and decarbonisation of public transport with 100% Ultra Low Emission Vehicles by 2035.
Local energy generation and ownership	Maximise use of local energy resources to minimise the need for imported electricity with a target of less than 15% electricity imports over the year. Support Wales' ambition that all renewable energy schemes should have an element of local ownership as a basis for another workstream within the Re-energising Wales project.
Flexibility and smart energy	Use flexibility through energy storage, Time of Use Tariffs, smart charging and appliances, and demand side response, to minimise energy system imbalance, grid impacts and imports.

Table 4: SBCR energy vision targets and objectives for 2035

While the vision should be ambitious and challenging, the steering group also wanted to ensure that any targets and goals set could be achievable within the 2035 timeframe. It was therefore agreed that the case study should:

- Be ambitious and transformational enough to challenge decision makers, drive the development of energy policy and create a pathfinder case study of what could be achieved at a regional level
- Be realistic and achievable within the 2035 timeframe of the analysis, so as not to undermine the case for change and action
- Be developed around the specific environment and geography of SBCR, and energy opportunities within the region, whilst demonstrating concepts and ideas that could be replicable across other Welsh and UK regions, and relevant to the wider debate about future Welsh and UK energy strategy
- Utilise emerging technology and business models, including new generation technologies such as marine and floating wind, and flexibility technologies such as energy storage and “smart” technologies capable of supporting demand side response, local supply models, and dynamic time of use charging.

4 Energy demand and efficiency

2035 Energy System Vision

A step change in domestic and commercial and industrial energy efficiency represented by at least a 20% reduction in heat and electricity demand, with a 30% stretch target.

4.1 Existing energy demand in SBCR

Figure 12 and Table 5 show the current breakdown of energy consumption in SBCR by fuel type and sector. The sectoral breakdown highlights the dominance of commercial and industrial consumption for electricity and the domestic consumption for gas.

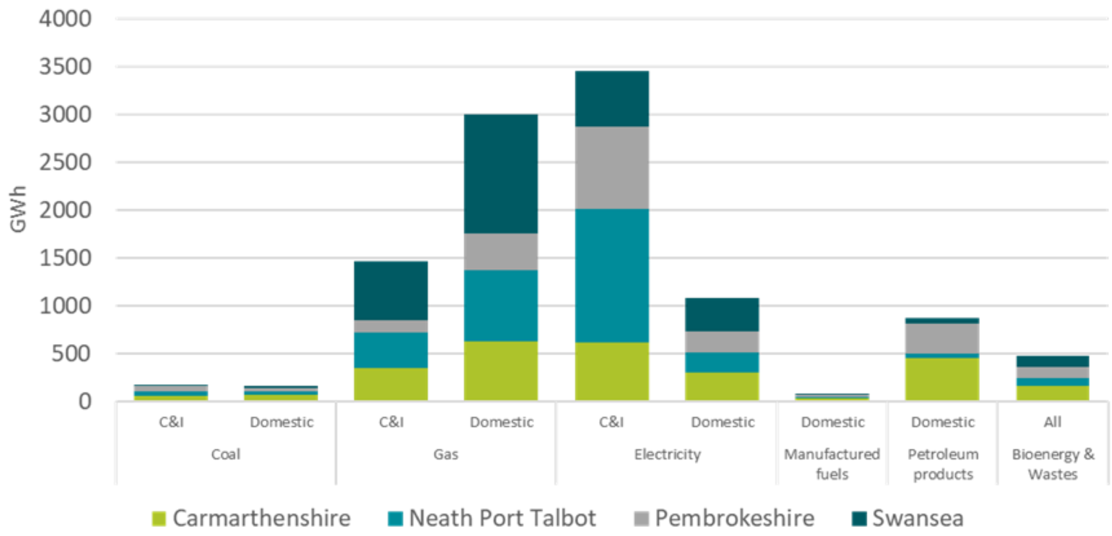


Figure 12: energy consumption in SBCR by local authority, fuel and sector (2015)

		Carmarthenshire (GWh)	NPT (GWh)	Pembrokeshire (GWh)	Swansea (GWh)	SBCR (GWh)
Coal	C&I	58	51	53	10	172
	Domestic	75	31	32	27	165
Gas (mainly heat)	C&I	351	369	133	612	1,465
	Domestic	630	740	383	1,245	2,998
Electricity	C&I	618	1,401	852	589	3,460
	Domestic	303	204	227	352	1,086
Manufactured fuels*	Industrial	35	15	17	15	81
Petroleum products*	Industrial	455	48	310	66	878
Bioenergy and Wastes	All	167	72	125	115	479
Total		**2,691**	**2,931**	**2,131**	**3,031**	**10,784**

Table 5: Energy consumption by fuel type in SBCR[5] by local authority, fuel and sector (2015)

***Note: For the purpose of future energy scenario modelling the demand for manufactured fuels (mainly coke used in steel manufacturing and feedstocks used in refining and chemical plants) have been excluded.**

[5] BEIS https://www.gov.uk/government/collections/total-final-energy-consumption-at-sub-national-level

4.1.1 Current electricity demand

Based on 2015 BEIS sub-national statistics electricity demand for domestic and commercial and industrial consumption within the SBCR totalled approximately 4.5 TWh.

SBCR Electricity demand (2015)	Electricity Demand (GWh)		
	Industrial & Commercial	Domestic	Total
Pembrokeshire	851.9	227.2	**1,079.1**
Carmarthenshire	617.9	303.6	**921.5**
Swansea	588.7	351.8	**940.5**
Neath Port Talbot	1,401.5	204.1	**1,605.6**
Total	3460	1086.7	**4,546.7**

Table 6: Electricity Demand based on BEIS sub-national figures 2015

4.1.2 Current heat energy demand

Based on 2015 BEIS sub-national statistics demand for gas, used for domestic and commercial and industrial heating, totalled 4.4 TWh per annum.

SBCR Gas demand (2015)	Demand (GWh)		
	Industrial & Commercial	Domestic	Total
Pembrokeshire	132.7	383.4	**516.1**
Carmarthenshire	351.2	630.1	**981.3**
Swansea	612.2	1,245.4	**1,857.6**
Neath Port Talbot	368.5	739.8	**1,108.2**
Total	1464.7	2998.7	**4,463.2**

Table 7: Gas demand in SBCR used for domestic and C&I heating (not electricity generation)

Conversion of mains gas demand into heat demand gives an estimated 4.2 TWh of heat demand. Extrapolation[6] to include non-gas connected properties and commercial and industrial use of non-mains gas heating fuels (e.g. coal, oil, LPG etc) suggests an estimated current total heat requirement within the SBCR of circa 4.9 TWh.

[6] Based on gas consumption the average heat requirement for an on-gas domestic property in SBCR is 11 MWh of heat energy per annum. This demand figure has also been used for non-gas grid properties.

4.1.3 Households in the Swansea Bay City Region

	Carmarthenshire	NPT	Pembrokeshire	Swansea	SBCR Total
Existing number of houses[7]	86,867	65,265	61,811	110,892	324,835
2035 number of household projections[8]	91,172	67,956	64,045	125,123	348,296
Number and percentage of off gas households (2015)[9]	35,450 41%	4,607 7%	27,224 44%	10,421 9%	77,702 24%
Number of on gas households (2015)[6]	51,417	60,658	34,587	100,471	247,133

Table 8 Number of households in SBCR

4.2 Anticipated changes in energy demand to 2035

The modelling of anticipated demand growth for heat and electricity in the SBCR has been done at a relatively high level. Anticipated energy demand changes have included:

Demand Change	Description
Energy efficiency	Measures that are expected to produce a base case 20% reduction in energy demand with a stretch target of 30%.
Economic factors	Economic growth and changes in the use of energy within the economy. Note, economic growth has tended, and is expected to continue to increase demand for electricity. Commercial and industrial demand for heat has however been falling as the UK continues to move from industrial to service industries.
Housing and population growth	The model incorporates housing growth based on StatsWales dwelling figures[7].
Electrification	Demand shift to electricity for heat and transport.

Table 9 Demand change factors

Taken together these factors are projected, by 2035, to increase overall SBCR demand for electricity to 4.7 TWh per annum and to reduce demand for heat to 4.2 TWh.

[7] StatsWales https://statswales.gov.wales/Catalogue/Housing/Dwelling-Stock-Estimates/dwellingstockestimates-by-localauthority-tenure

[8] Estimates of new build properties in the SBCR are very rough based on statistics from StatsWales. A more rigorous analysis of new build properties based on a review of local authority development plans is currently being undertaken by Regen on behalf of Western Power Distribution. Unfortunately this data is not yet available.

[9] StatsWales https://www.gov.uk/government/statistics/sub-national-estimates-of-households-not-connected-to-the-gas-network

In part, the fall in demand for heat is due to increased energy efficiency but also a continued shift in commercial and industrial use of heat which, even without efficiency measures, is projected to fall by 9%[10] as the UK continues to move towards a less industrial, more service orientated, economy.

Changes to demand to 2035	Base Growth Electricity	Base Growth Heat
Potential residential demand change per household - based on increased consumption due to economic growth/affluence and new appliances.	10%	5%
Potential commercial and industrial demand change - based on average of 'Industrial' and 'Non-residential' average CCC 5th Carbon Budget Baseline scenario UK figures.	21%	-9%

Table 10: Relative change of electricity and heat demand from existing baseline to 2035, used in modelling.

4.2.1 Breakdown of demand growth for electricity and heat to 2035

Current and projected demand for Electricity GWh	Domestic	Commercial and Industrial	Total electricity demand
Current Demand	**1,087**	**3,460**	**4,547**
New Domestic Build	78		78
Demand Growth - economic	117	737	853
Energy efficiency savings	-233	-839	-1,072
Efficiency saving %	-20%	-20%	
Electricity for Transport Demand	231	168	399
Electricity for Heat Demand	117	21	138
Projected electricty demand in 2035	**4,754**		**4,754**

Table 11: Current and projected demand for electricity in SBCR - Source Regen modelling

Current and projected demand for heat GWh	Domestic	Commercial and Industrial	Total heat demand
Demand from Mains Gas	2,999	1,245	4,244
Non mains gas heat demand	548	117	666
Total Current Demand	**3,547**	**1,362**	**4,909**
New Domestic Build	256		256
Demand Growth - economic and change of use	190	-122	68
Energy efficiency savings	-761	-272	-1,033
Efficiency saving %	-20%	-20%	
Projected heat demand in 2035	**3,233**	**968**	**4,201**

Table 12: Current and projected demand for heat in SBCR: Source Regen modelling

[10] Based on Committee on Climate Change 5th Carbon budget : central scenario demand growth for non-residential heat 2015-2035 (published 06/07/2016

4.2.2 Simulated energy demand profile in 2035

A summary of the 2035 breakdown between different demand types for electricity is shown in Figure 13. This highlights the significant commercial and industrial demand in the region, which remains after baseline figures have been adjusted for efficiency savings and sector reductions.

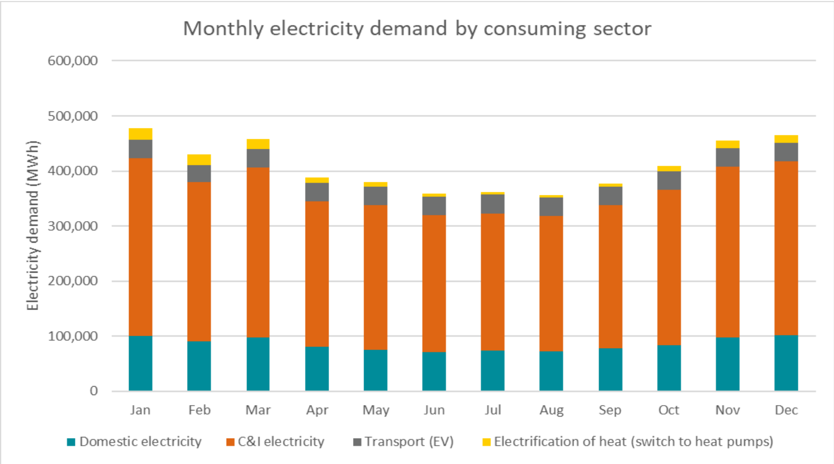


Figure 13: Monthly electricity demand totals for SBCR in 2035, including demand from domestic and C&I consumption, electric vehicle demand and the power demand from heat pumps.

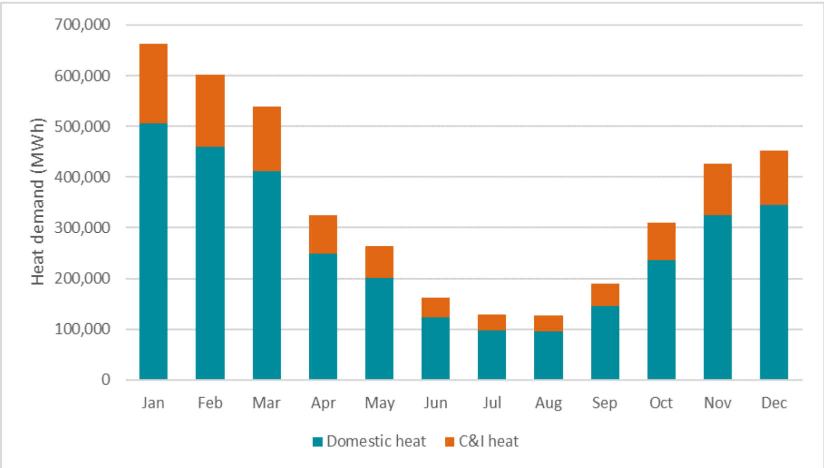


Figure 14: Monthly heat demand totals for SBCR in 2035 for domestic and C&I consumption (note in the fictional weather year used – based on 2015 temp. data - December was mild with a late spring).

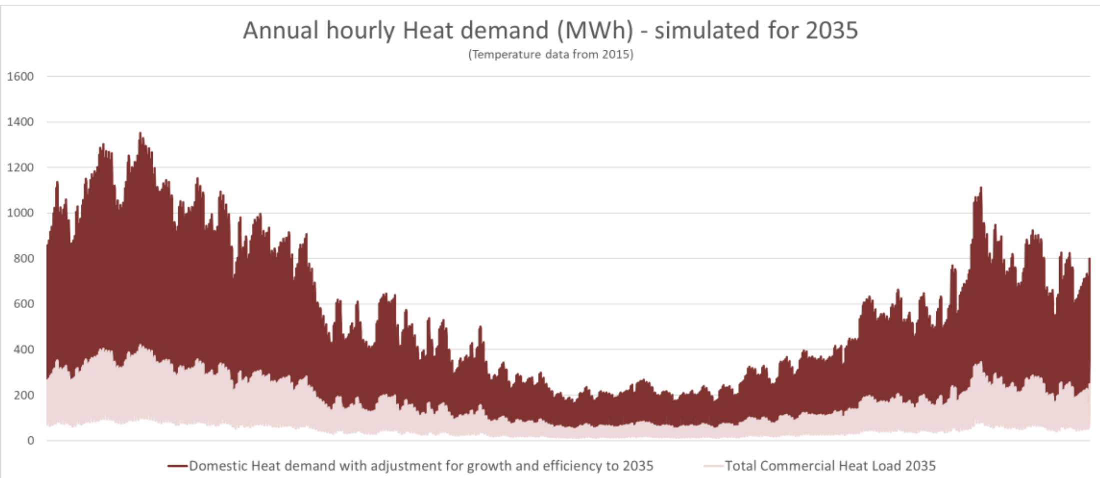
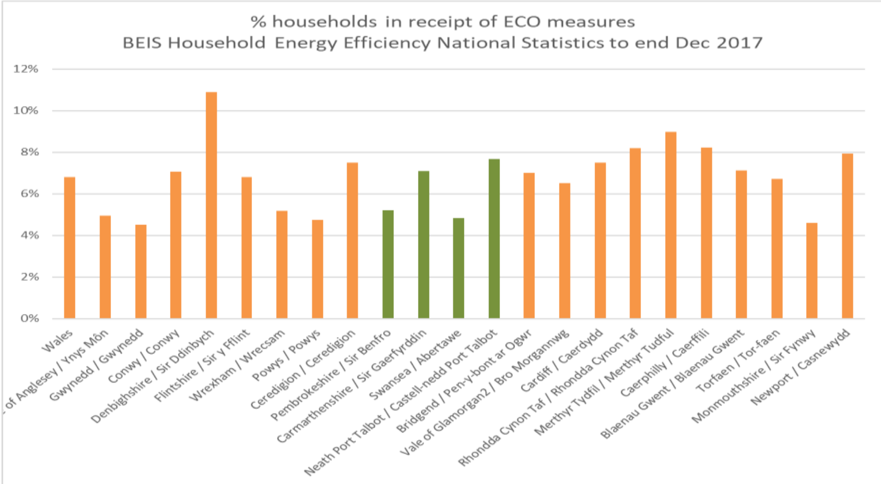


Figure 15: Simulated hourly heat demand for 2035 based on 2015 temperature and demand profiles

4.3 Energy efficiency 2035 energy system vision

Energy efficiency presents an opportunity to reduce emissions across all sectors and covers energy demand reduction measures such as insulation in lofts, cavity walls and solid walls, improvements in lighting, boilers and appliance efficiency, home monitoring systems and smart products to allow users to monitor and manage their consumption.

Welsh housing stock includes a large amount of older, traditionally constructed buildings with high levels of fuel poverty across Wales. Citizens Advice research suggests that 49% of off gas properties in Wales are in fuel poverty[11].



Currently around 7% of households in Wales have been in receipt of at least one Energy Company Obligation(ECO) funded measure, of which the most common is loft insulation.

The overall percentage in the SBCR is 5% or around 18,000 households.

Figure 16: percentage of households with at least one ECO measure – BEIS statistics March 2018

Analysis of the existing SBCR properties, based on Energy Performance Certificates (EPCs) logged between 2008 and 2017, suggests that over 70% of the existing housing stock is EPC rating D or below. This represents a significant opportunity to both achieve energy efficiency savings and to reduce consumer and business energy bills.

SBCR (2008-2017)

Property Type	Number of EPCs	Total Floor Area (m2)	No Habitable Rooms (RdSAP Only)	Number of EPCs lodged, by Energy Efficiency Rating(based on Fuel Costs)						
				Rating A	Rating B	Rating C	Rating D	Rating E	Rating F	Rating G
Bungalow	24,951	2,356,617	107,286	44	808	4,224	10,188	5,977	2,667	1,041
Flat	29,133	1,638,146	67,079	37	4,053	11,770	8,977	2,956	969	371
House	140,658	14,686,799	655,618	219	9,088	24,918	53,154	35,035	13,268	4,976
Maisonette	2,282	147,829	6,553	0	119	857	749	348	154	55
Park home	32	1,886	119	0	0	2	3	13	6	8
All Dwellings	**197,056**	**18,831,278**	**836,655**	**300**	**14,068**	**41,771**	**73,071**	**44,329**	**17,064**	**6,451**

SBCR (2008-2017)

Property Type	Percentage by energy rating						
	Rating A	Rating B	Rating C	Rating D	Rating E	Rating F	Rating G
Bungalow	0.2%	3%	17%	41%	24%	11%	4%
Flat	0.1%	14%	40%	31%	10%	3%	1%
House	0.2%	6%	18%	38%	25%	9%	4%
Maisonette	0.0%	5%	38%	33%	15%	7%	2%
Park home	0.0%	0%	6%	9%	41%	19%	25%
All Dwellings	0.2%	7%	21%	37%	22%	9%	3%
Avg Energy consumption per property (kWh/year)	3,058	4,683	7,932	11,276	14,621	17,727	20,785

Table 13: Analysis of EPC bandings in SBCR local authorities 2008-17 - source www.energyrating.org.uk

The existing funding and level of commitment within Wales to achieve energy efficiency savings, to tackle climate change and fuel poverty, help to justify a high level of ambition for energy efficiency improvements and future reduction/shifting of demand in our SBCR future energy system vision.

[11]Citizens advice https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Livingwithoutmainsgas.pdf

To achieve an overall energy efficiency saving of 20% would require a radical shift in the energy performance of new and existing Welsh housing stock. Measured in EPC bandings this shift would equate to a step change from the existing 28% of properties rated bands A-C to over 62% by 2035. Achieving a more ambitious 30% efficiency improvement target would require over 77% of properties to be EPC banded A-C.

How this is achieved and the most effective strategy in terms of the buildings targeted needs further investigation. The modelling analysis looked at three illustrative strategies, all of which involve measures to circa 200,000[12] properties:

- Improvement programme A – a broad brush across all current housing types
- Improvement programme B – slightly more focus on the worst properties F and G
- Improvement programme C – more focus on getting properties into the higher A and B bands

Step change in energy efficiency to achieve a 20% energy demand reduction									
EPC Rating Band	A	B	C	D	E	F	G	A-C rating	D-G rating
Current SBCR bandings based on EPCs lodged 2008-17	0.2%	7.1%	21.2%	37.1%	22.5%	8.7%	3.3%	28%	72%
Example of step change needed in EPC bandings to achieve 20% energy efficiency savings targets								Overall Change	
Energy saving programme A "Across the board"	5%	21%	36%	21%	13%	4%	1%	62%	38%
Energy saving programme B "more focus on the worst"	4%	15%	39%	31%	11%	0%	0%	58%	42%
Energy saving programme C "more focus on the best"	8%	24%	26%	22%	13%	5%	2%	59%	41%

Table 14: A radical shift in energy efficiency is needed to achieve a 20% efficiency saving

The opportunity to increase energy efficiency also represents an opportunity to save householders millions in energy costs per year. Figure 17 shows the average household energy bills for each EPC banding taken from the Governments Clean Growth Strategy (2017).

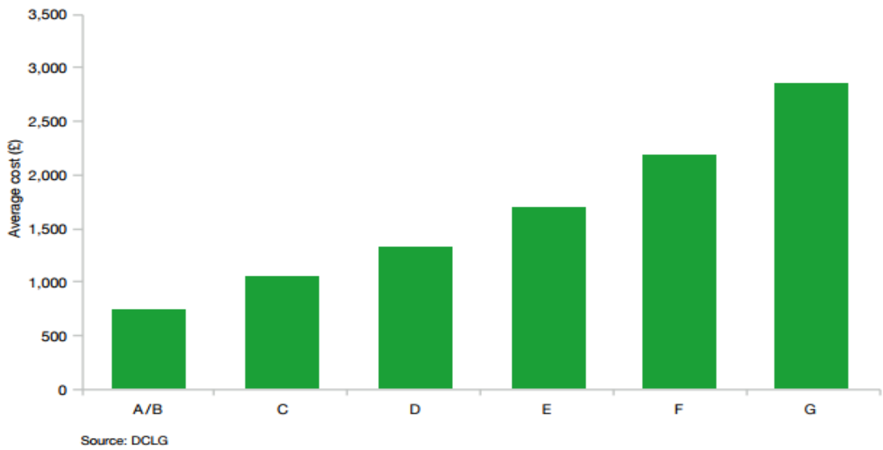


Figure 17: Average annual cost of energy in homes by energy efficiency rating, 2014. Source: BEIS, Clean Growth Strategy (2017)

[12] The number of properties to which measures are made is a function of the level of improvement. Small improvements would require more properties to be improved but would also spread benefits more widely, more extensive improvements and whole house solutions would require less properties to achieve the same saving.

Applying these estimates to the current SBCR EPC bandings suggest that a 20% increase in energy efficiency could save domestic energy costs in the SBCR between £100 and 130 million, while a more ambitious 30% saving could save over £160 million.

Energy saving EPC profile	SBCR Energy Saving MWh 20%	SBCR total consumed energy cost saving per year £millions	Avg saving per household improved	households improved (approx)
20% energy saving profile A "Across the board"	788,597	£76	£378	202,175
20% energy saving profile B "more focus on the worst"	788,597	£84	£420	200,641
20% energy saving profile C "more focus on the best"	788,597	£72	£354	204,808

Table 15: Bill savings associated with an increase in energy efficiency for the SBCR. Calculations based on BEIS estimates of costs for each EPC banded properties (Clean Growth Strategy 2017)

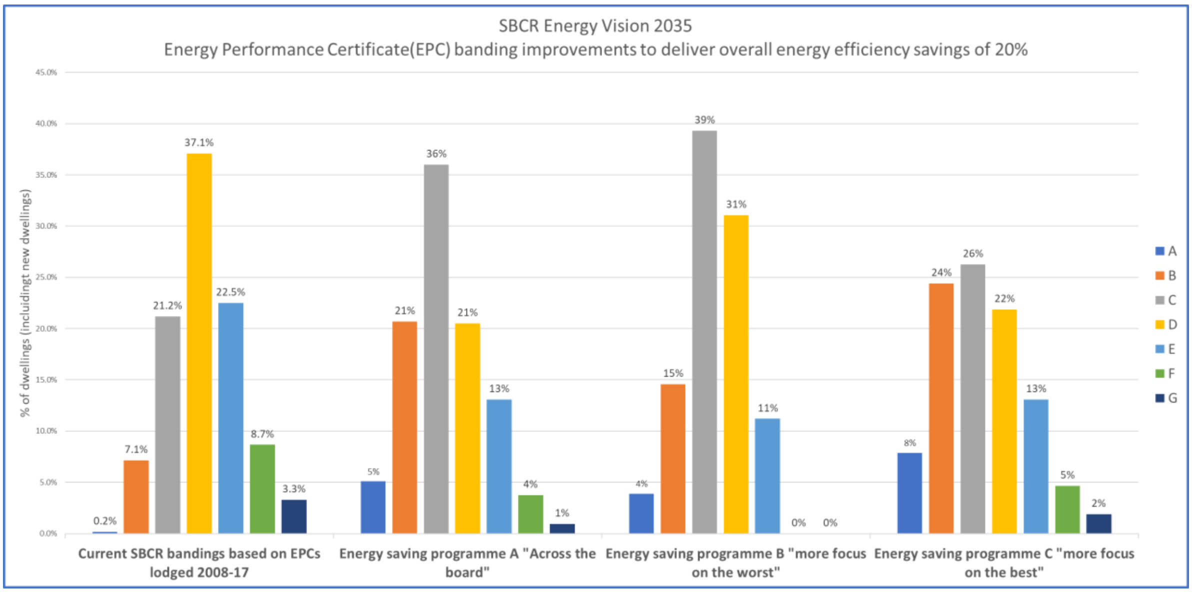


Figure 18: Changes in EPC banding profiles to achieve a 20% energy efficiency saving

4.4 Policies and initiatives to build on

The UK Government Clean Growth Strategy[13] released in 2017 also has significant proposals for both domestic and commercial energy efficiency in the UK, including:

- Developing a package of measures to support businesses to improve their energy productivity, by at least 20% by 2030, including, raising minimum efficiency standards on commercial buildings.
- An aspiration that as many homes as possible are improved to EPC Band C in the UK by 2035, where practical, cost-effective and affordable.
- For privately rented homes, legislation from April 2018, landlords of the worst performing properties will need to improve those properties to a minimum of EPC Band E.
- All fuel poor homes to be upgraded to EPC Band C by 2030.

[13] BEIS https://www.gov.uk/government/publications/clean-growth-strategy

In reality the efficiency measures outlined in the UK Clean Growth Plan[14] are not sufficient to meet the carbon reduction commitments of the Climate Change Act 2008.

Energy efficiency improvements are a key cost-effective tool to tackle fuel poverty and guarantee better quality homes to meet the goals of the Welsh Government's Well-being of Future Generations (Wales) Act. This Act covers tackling poverty and the global threat of climate change, building resilience for our communities, boosting green growth in the economy and addressing the health inequalities caused by poor energy efficiency[15].

Current funding for energy efficiency in Wales includes the Welsh Government Warm Homes programme, including Nest and Arbed, which provide means tested home improvements, including heating controls and insulation. The Nest scheme has fitted free energy efficiency improvements to 29,000 Welsh households since 2011.

4.5 Key enablers to achieve the system energy vision 2035

The analysis done as part of this study has merely scratched the surface of the energy efficiency opportunity in Wales and the SBCR.

Combining the work done in Re-energising Wales workstream 1 and the energy system vision presented here, an important next step would be to develop a full implementation strategy for energy efficiency in Wales. This could involve:

- An assessment of the existing housing and commercial building stock
- Evaluation of the energy savings and cost effectiveness of improvement measures
- A detailed plan and targets, at Local Authority level, of target building categories and the quantum of measures needed
- Quantification of anticipated costs and savings
- Strategies to fund and finance public and private initiatives
- A deployment strategy for private, public and social housing as well as commercial buildings, including the priorities of off-gas properties and the fuel poor
- A plan to incentivise and engage with commercial property owners and businesses.

[14] Committee on Climate Change An independent assessment of the UK's Clean Growth Strategy: From ambition to action January 2017

[15] Welsh Government http://gov.wales/docs/desh/publications/160223-energy-efficiency-in-wales-en.pdf

5 Electricity generation in 2035

2035 Energy System Vision

Maximise use of regional energy resources to achieve a target of renewable electricity generation equivalent to 100% of electricity consumption on an annual basis.

Delivering an overall carbon intensity < 50g CO_2e/KWh from local renewable generation and imported (or backup) electricity.

5.1 Existing renewable energy generation mix in SBCR

The baseline for the energy generation mix shown in Figure 19 is based upon Regen collated data for the Welsh Government's 'Energy Generation in Wales report'[16] with a cut-off date for inclusion of 1 January 2017. The installed renewable energy capacity at that time is over 700 MW across both electricity and heat generation. More detail of the breakdown of the existing generation mix, including non-renewable energy, is given in the Phase 1 report.

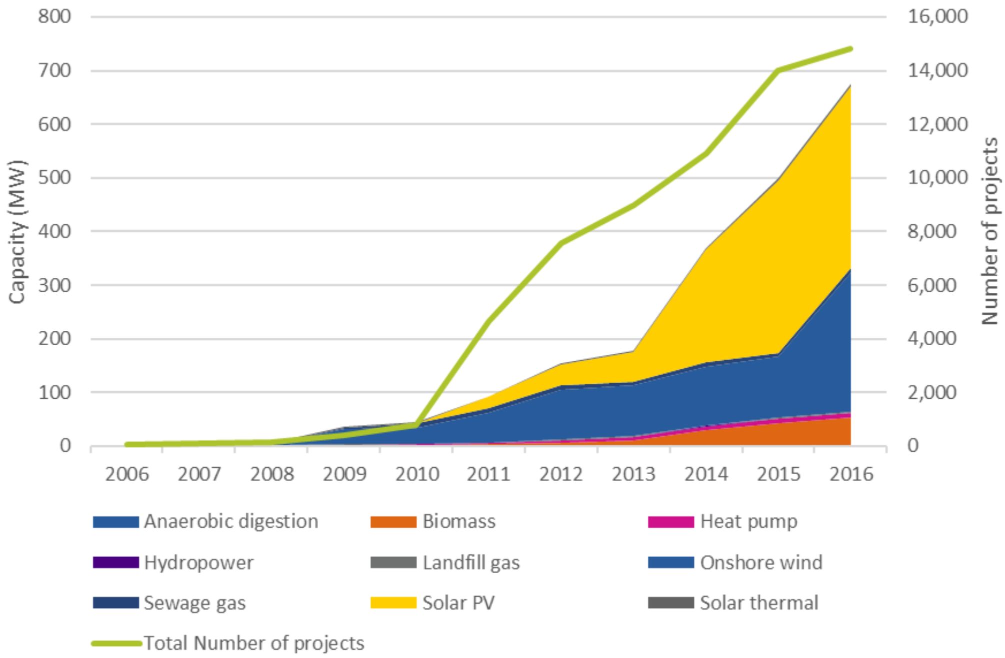


Figure 19: Renewable energy capacity and project numbers in SBCR in 2016. Data source: Welsh Government, 'Energy Generation in Wales report' (1 Jan 2017)

[16] Welsh Government http://gov.wales/topics/environmentcountryside/energy/renewable/energy-generation-in-wales/?lang=en

5.2 Renewable energy system vision 2035

In order to meet the 2035 energy vision objective to generate electricity equivalent to an annual consumption of 4.9 TWh (plus network losses) a mix of renewable energy technologies would be required with the capacity to generate 5.2 TWh.

There are several ways this energy output could be delivered with more, or less, of each technology type. The base case scenario which is presented below, is an example of an energy capacity mix of 2.7 GW that achieves the generation target of 5.2 TWh and the target carbon intensity of <50g CO_2e/kWh.

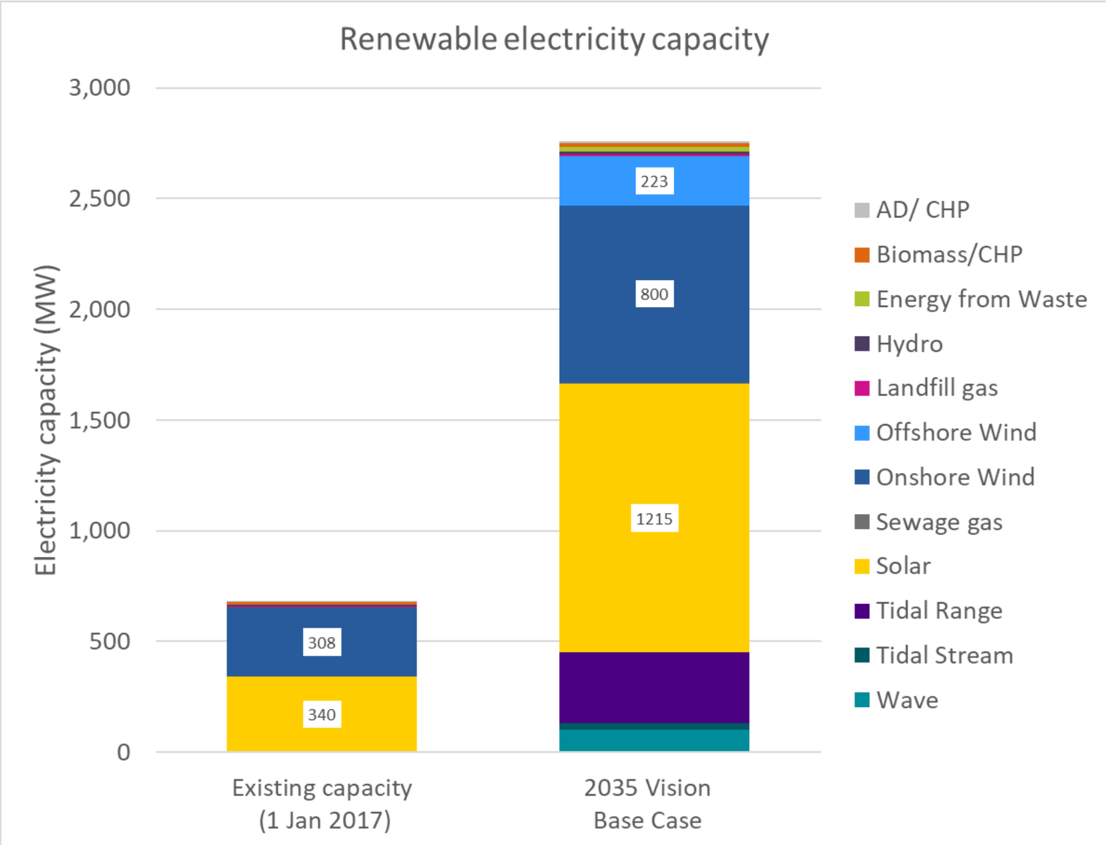


Figure 20: SBCR Energy Vision 2035 - Base Case renewable energy capacity mix

The basis of the weighting of each technology has been to exploit and make best use of the "developable" resource within the SBCR with a focus (or merit order) of:

- exploiting onshore renewable energy first – onshore wind, solar PV, hydro, AD and biomass – which have the greatest potential for local ownership
- assuming that the Swansea Bay Tidal (SBTL) Lagoon is built
- assuming that wave and tidal stream will reach maturity
- assuming that SBCR has a share of generation from at least one new offshore wind farm off the south wales coast (irrespective of whether electricity from the offshore wind farm is brought ashore within the region).
- having a varied mix of energy sources to improve system balancing.

Technology type	Current Capacity	2035 Energy Vision Base Case Capacity MW	2035 Generation mix MWh
Solar PV	340	1,215	1,329,347
Hydro	5	13	43,869
Onshore wind	308	800	1,884,829
Tidal range	-	320	504,854
Tidal stream	-	30	95,119
Wave	-	100	303,156
Offshore wind	-	223	759,548
Anaerobic digestion / CHP	0.02	10	50,820
Biomass /CHP	14.00	15	102,701
Energy from waste	-	20	104,569
Landfill gas	7.19	8	37,092
Sewage gas	3.52	5	20,727
Not included in SBCR vision			
Nuclear		-	-
Geothermal		-	-
Total	**678**	**2,759**	**5,236,632**

Table 16: 2035 Energy system vision - base case energy and generation mix

5.3 Electricity carbon intensity in 2035

The carbon intensity of electricity generated from renewable sources is just over 20g CO_2e/kWh. Combined with energy imports equivalent to 12.3% of consumption at an assumed carbon intensity of 200g CO_2/kWh[17] gives an aggregate figure of 43.4g CO_2/kWh of energy consumed, less than the 50g CO_2 target.

Capacity factors and carbon intensity factors for established technologies have been based on estimates of current capacity factors, either taken from BEIS Digest of UK Energy Statistics 2016 or from Regen generation models. Capacity factors for tidal stream and tidal range are outputs from Regen's tidal energy modelling. The capacity factor for wave energy is based on a generic assumption from previous engagement with technology developers.

[17] See Phase 1 report – for analysis purposes 200g CO_2/kWh was agreed as a fair assumption for average imported electricity on the basis that a) imported electricity could also be renewable (or nuclear) but it was likely that at peak import periods a significant amount would also be gas generation. A further level of complexity could be added to assess import carbon intensity for each balancing period.

2035 Energy system vision - Electricity		
Electricity generation and carbon	**Base Case scenario**	
Total Electricity Demand/Supply	4,943	GWh
Peak electricity demand	936	MW
Renewable energy variable technology	2701	MW
RE capacity controllable technoloy	58	MW
Renewable electricity generation	5,237	GWh
GHG CO_2e from generated electricity	106,333	tonne CO_2e
Carbon intensity of electricity generated	20.31	gCO_2e/kWh
Imported Electricity	606.52	GWh
Imported % of consumption	12.3%	
Peak Import Required	450	MW
Occurances > 350 MW	183	hours per year
Assumed carbon Intensity of imported electricity	200	gCO_2e/kWh
CO2e of imported electricity	121,304	tonne CO_2e
Total Carbon of Consumed Electricity	214,589	tonne CO_2e
Carbon intensity of consumed electricity (including imports)	43.4	gCO_2e/kWh

Table 17: Electricity generation and carbon intensity

It is expected that by 2035, capacity factors for technologies such as solar PV and wind will have continued to improve with ongoing technology development and innovation, there is therefore a degree of underestimation, or caution, in the generation figures which could be higher in future.

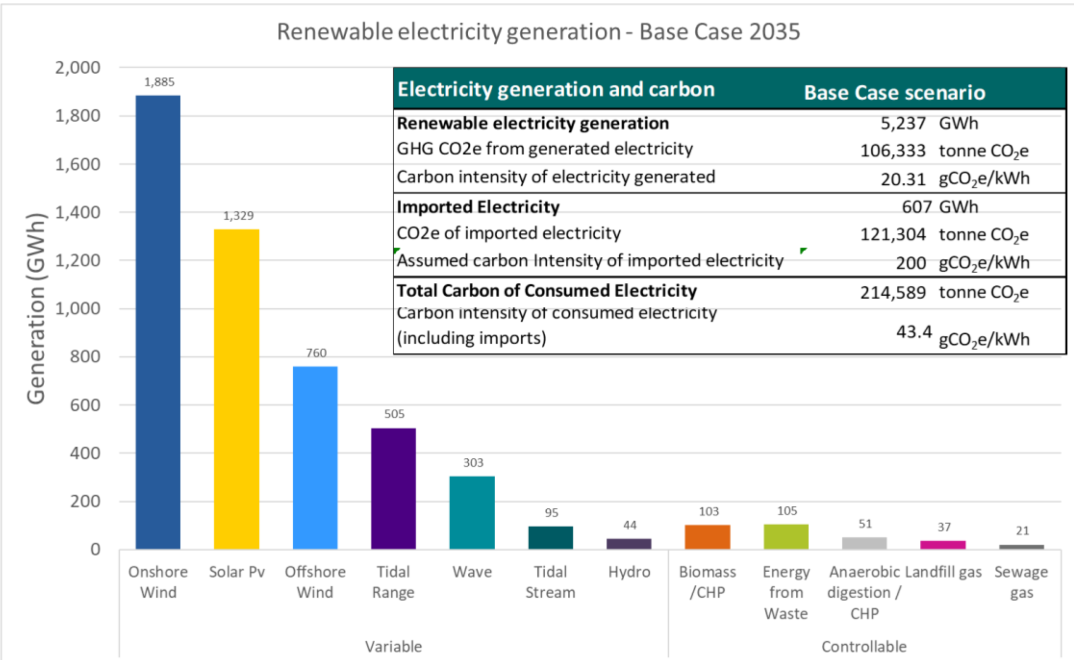


Figure 21: Energy generation by renewable technology type

5.4 Alternative mix of renewable energy technology

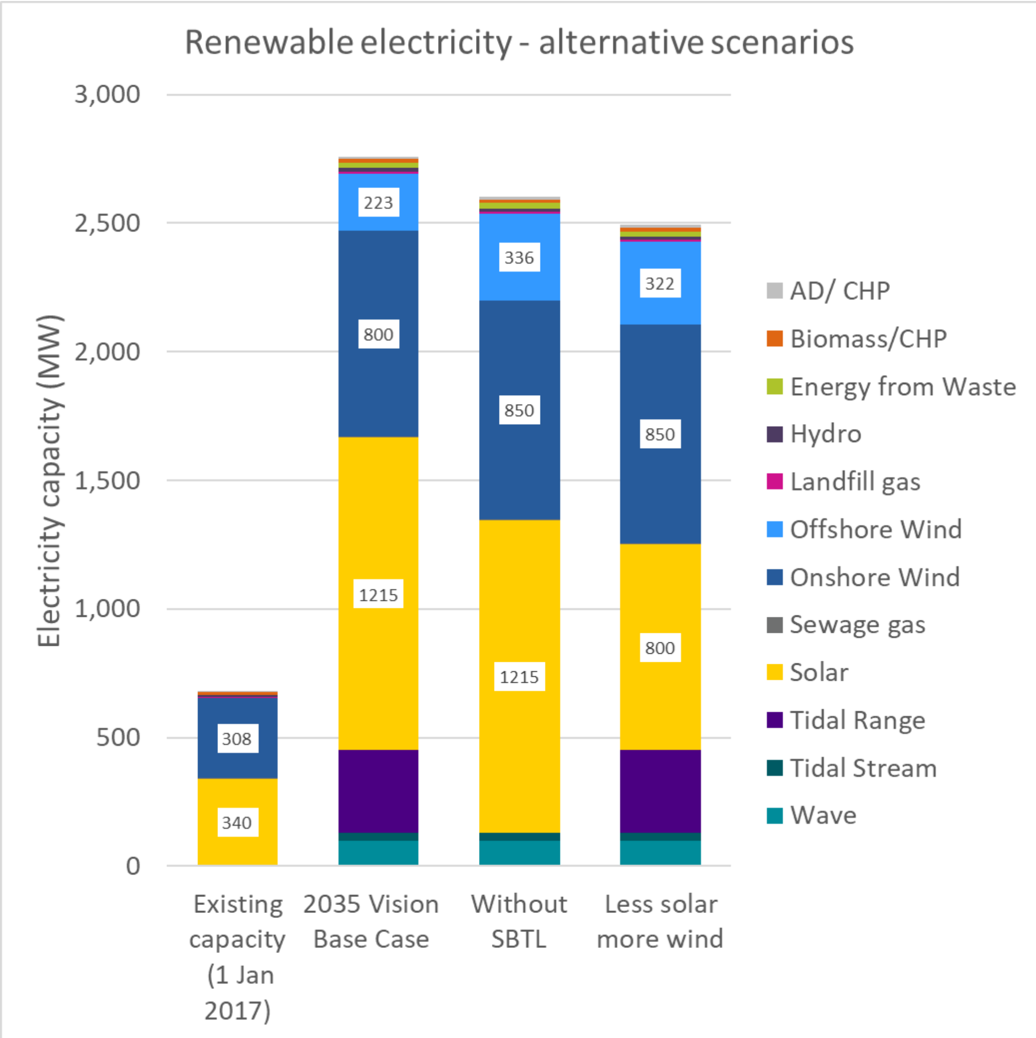


Figure 22: Alternative scenarios without tidal lagoon and with less solar

The base case scenario for the future energy system vision is only one of a number of potential outcomes that could achieve an electricity objective to generate the equivalent of 100% of consumption. There is a general point therefore that, although the base case has been designed to best exploit the available SBCR energy resource, it is not a prescribed outcome in terms of technology mix.

As part of the modelling sensitivity analysis a number of alternatives were considered including a scenario without the building of the Swansea Bay Tidal Lagoon and a scenario with somewhat less solar and more wind.

The Swansea Bay Tidal Lagoon, at 320 MW and delivering over 500 GWh per year, is an important strategic project for the region and for Wales. If this project did not go ahead, and given the limitations and constraints on onshore development, more offshore wind would be needed in the energy mix.

Solar makes up a comparatively high proportion of the base case vision, **more than would be expected for a Welsh or GB energy mix**. The higher proportion of solar reflects the resource availability in the SBCR compared to other technologies, such as onshore wind and hydro. Less solar would require more wind but this would improve inter-seasonal energy balancing.

5.5 Onshore wind

5.5.1 Onshore wind baseline and pipeline

As of 1 January 2017, SBCR had 281 onshore wind projects totalling 308 MW of installed capacity.

Local Authority	Number of projects	Capacity (MW)	Generation (GWh)
Carmarthenshire	127	83	195
Neath Port Talbot	10	204	580
Pembrokeshire	138	20	46
Swansea	6	1	3
SBCR Total	281	308	824

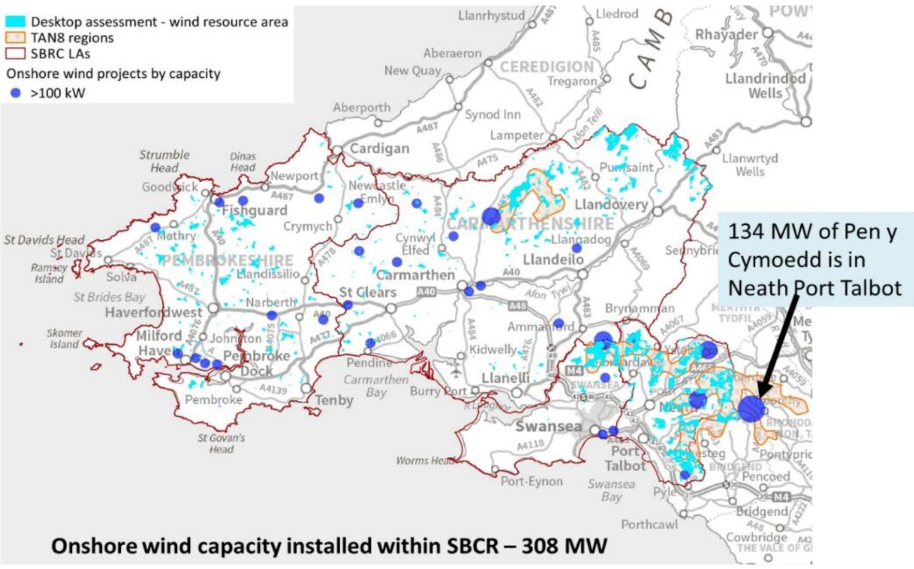
Table 18: Existing onshore wind projects, capacity and generation figures based on Regen collated data up to 1st Jan 2017 for the Welsh Government, 'Energy Generation in Wales report'

In addition, there were 173 MW of pending projects within the TAN 8 development zone pipeline within SBCR, of which:

- 52 MW (consisting of 3 projects) have been built in 2017.
- 109 MW (3 projects) are under-construction or planned to be built in 2018
- The status of the remaining 12 MW is unclear

Therefore SBCR has the potential to reach an onshore wind capacity of **469 MW** by the end of 2018. Beyond that there is a hiatus, caused mainly by the withdrawal of onshore wind subsidies and planning constraints and there are few or no projects currently progressing through the planning system.

The map in Figure 23 shows the importance of the TAN 8 regime for supporting onshore wind development, particularly for large scale projects. Outside of the TAN 8 strategic search areas, wind development is much more challenging and existing projects are geographically diverse and smaller.



Despite the relatively supportive planning policy in Wales within Strategic Search Areas, the development pipeline has also stalled in Wales due to the removal of subsidies for onshore wind and there are now very few new projects coming into the pipeline for consent in SBCR.

Figure 23: Wind resource areas, existing onshore wind projects and the TAN 8 SSAs in SBCR

5.5.2 2035 Energy system vision for onshore wind

A Regen desktop assessment which follows the Welsh Government's Practice Guidance: Planning for Renewable and Low Carbon Energy[18] has identified a maximum developable resource potential of **1.3 GW** of onshore wind capacity in SBCR. This assessment applies high-level assumptions within the existing planning context and technical constraints, including:

- 600m buffer from housing
- Minimum average windspeed of 6m/s (based on NOABL data)
- Transport infrastructure (150m buffer from primary road network and railway lines)
- Physical constraints – woodland, inland waters (lakes, canals, rivers, reservoirs)
- No developments in Areas of Outstanding Natural Beauty and National Parks
- Environmental designations and heritage constraints (Special Protection Area, Special Area of Conservations, RAMSAR sites, National Nature Reserves, Sites of Special Scientific Interest, Scheduled Ancient Monuments)

This assessment provides an estimate maximum development potential to inform the level of opportunity for onshore wind and future growth rates to 2035, it is not a detailed site assessment.

The Phase 1 report projected a base case scenario of 708 MW, based on a more positive pipeline projection and higher support for community scale projects. This base case projection has been increased to **800 MW** by 2035, approximately 60% of the developable potential.

To achieve this high level of development it has been assumed that:

- Current installed capacity of 308 MW is maintained.
- The majority of projects within the TAN 8 strategic search areas that are currently in planning, and those that are consented, will be built, adding approximately 160 MW.
- 30% of the remaining developable resource is built by 2035, adding 250 MW.
- There will be a significant amount of micro (< 1 MW) and community scale (1-10 MW) wind projects – mainly restricted to brownfield sites and projects of 1-5 turbines on community supported sites adding an additional 80 MW.

5.5.3 Key enablers for onshore wind to achieve the system energy vision 2035

For our future energy vision scenario, it will require a continuation of a positive planning environment and good market conditions. It takes time to develop new wind projects and so getting the pipeline of new projects restarted should be a key priority.

To achieve that it will be necessary to:

- Establish a strategic policy in Wales on infrastructure, building on the TAN 8 policy.
- Identify new strategic search areas (SSAs) for development in areas with good wind resource.
- Support new network infrastructure with strategic grid and network upgrades removing constraints to wind development in SSAs by mid 2020s.
- For the industry to achieve price parity with other forms of generation by 2020.
- Positive economic and social climate for wind – including additional support for local and community energy schemes, and wind farms providing energy directly to end users through local supply initiatives.

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[18] Welsh Government AECOM, http://gov.wales/docs/desh/publications/151021renewable-energy-toolkit-en.pdf

5.6 Solar PV

5.6.1 Solar PV baseline and pipeline

As of 1 January 2017, there were 340 MW of solar PV with nearly 12,000 installations in the SBCR. Pembrokeshire has nearly half of the total capacity with 173 MW.

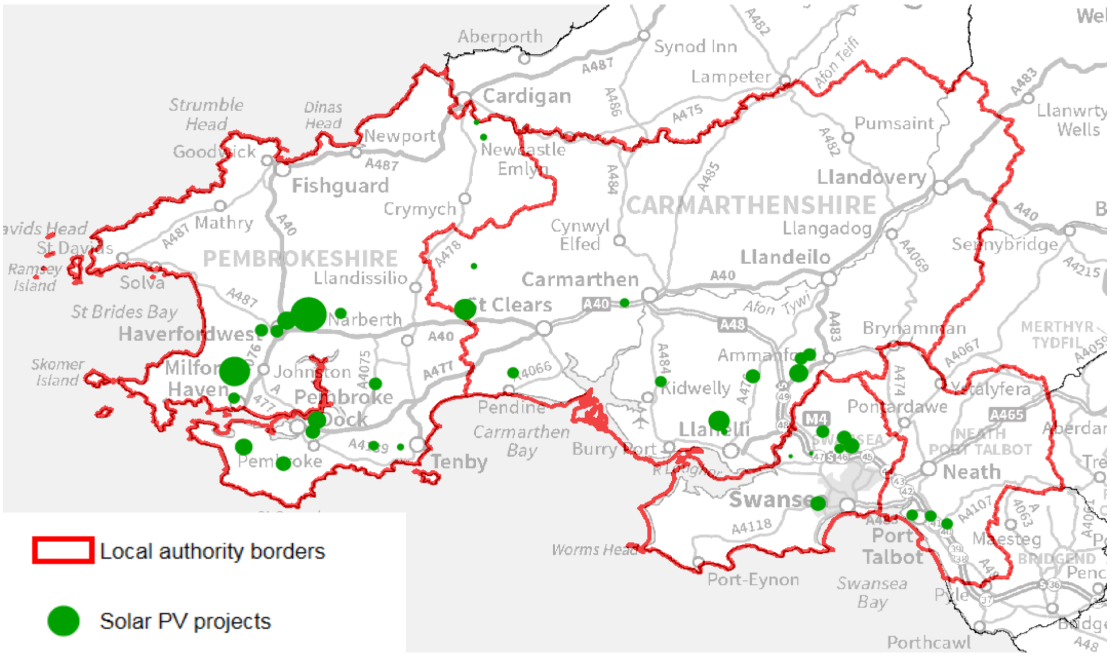

Figure 24: Existing solar PV projects over 500 kW in SBCR, based on Regen collated data for the Welsh Government's 'Energy Generation in Wales report' (2017)

Approximately 58 MW is from roof-mounted schemes. 3.4% of households in SBCR have domestic roof-mounted solar with Pembrokeshire the highest with 5.2%, and Swansea with 2.2%. The highest in the UK is currently Peterborough with over 10%, due to a social housing scheme.

	Number of domestic roof-mounted solar PV installations (Jan 2017)	Number of households	Percentage of households
SBCR	11,097	324,835	3.42%
Wales	47,644	1,300,000	3.66%
England	647,983	22,100,000	2.93%

Table 19: Comparison of domestic roof-mounted solar PV installations in SBCR, Wales and England, based on FIT installations report[19]

5.6.2 2035 Energy system vision for solar PV

SBCR has good solar irradiance levels and land availability, with significant potential for future installations at the domestic and commercial scale. SBCR future energy system vision will have a high-level of ambition for the future growth of roof-mounted, building integrated PV (BIPV) and ground-mounted solar PV installations in the region.

[19] Ofgem https://www.ofgem.go.uk/environmental-programmes/fit/contacts-guidance-and-resources/public-reports-and-data-fit/installation-reports

Solar PV Base case capacity projection to achieve 2035 energy system vision		
Ground mounted solar PV	**840 MW**	For ground-mounted solar Regen have completed a high-level assessment following the Welsh Government's toolkit[20] approach, with GIS analysis of available developable land space, which includes factors such as planning and technical constraints. Solar deployment is limited by many factors including market uptake and competing uses for land however, it is expected that solar will continue to be deployed at scale as costs continue fall.
Roof mounted and building integrated (for break down see Table 21**)**	**375 MW**	SBCR has a significant opportunity in the area of roof mounted and building integrated PV. Social housing and new build have deployment around 40% due to LA and Registered Social Landlords (RSLs) actions. Commercial also has high deployment as the investment case improves. Retrofit domestic is hardest to improve and PV installation increases to a maximum of 15% of houses across the LAs.
Base Case Scenario	**1,215 MW**	**2035 Energy system vision for solar PV**

Table 20 Base case capacity assumptions for solar PV

Property type	Percentage of properties with roof-mounted/BIPV	Number of installations	Average capacity per installation
Residential (excluding social housing)	15%	40,750	4 kW
Social Housing[21]	40%	21,268	4 kW
New Build[22]	40%	9,384	4 kW
C&I (TBC property numbers from OS Address Base)	20%	4,483	20 kW
Total new installations		**75,885**	**375 MW**

Table 21: Modelling assumptions for roof-mounted and BIPV by property type up to 2035

5.6.3 Key enablers for solar PV to achieve the energy system vision 2035

The removal and reduction of subsidy for solar PV has slowed deployment in solar categories across the UK. Other constraints are network capacity restrictions, which are limiting larger ground-mounted projects. In order to achieve a high level of solar PV installations in SBCR by 2035 the technology needs

[20] Welsh Government AECOM, http://gov.wales/docs/desh/publications/151021renewable-energy-toolkit-en.pdf
[21] StatsWales https://statswales.gov.wales/Catalogue/Housing/Dwelling-Stock-Estimates/dwellingstockestimates-by-localauthority-tenure
[22] Estimates of new build properties in the SBCR are very rough based on statistics from StatsWales. https://statswales.gov.wales/Catalogue/Housing/Households/Projections/Local-Authority/2014-Based/householdprojections-by-localauthority-year A more rigorous analysis of new build properties based on a review of local authority development plans is currently being undertaken by Regen on behalf of Western Power Distribution. Unfortunately this data is not yet available.

both a positive planning environment, attractive economics and grid capacity. We have projected the following conditions for SBCR future energy system vision.

Ground-mounted solar

- Post-subsidy investment case improves as technology costs continue to fall, achieving price parity with other forms of generation by the end of the decade.
- Co-location investment models, with battery storage a further boost to investment in solar PV from 2020s.
- Strategic network infrastructure planning and investment removes capacity constraints.
- Positive planning environment exists with strong public support.

Roof-mounted and building integrated solar

- Investment returns continue to improve as technology costs fall, removing the need for FIT subsidy.
- A positive government policy agenda helps to encourage roof-top solar and building integrated solar with permitted development rights and building regulations.
- Local Authorities and Registered Social Landlords invest to improve social housing and stipulate renewables in planning permission for new build developments
- Additional investment in innovation to develop building integrated solar PV.

5.7 Offshore wind

5.7.1 Approach for offshore wind

The treatment of offshore wind differs from other renewable energy opportunities in that:

1. In the base case it is assumed that there will be at least one new offshore wind farm, off the south or west Wales coast by 2035.
2. Wherever the windfarm is built (Bristol Channel, Celtic Sea, off Pembrokeshire, West of Lundy or Cardigan Bay) and wherever the cable to bring electricity ashore is landed, it is assumed that windfarm development, construction and operations and maintenance (O&M) activity will involve SBCR ports such as Swansea, Port Talbot and Pembroke.
3. Therefore, it has been agreed that a share of the electricity generated by any south Wales offshore wind farm is treated as part of the future generation of SBCR.
4. The share of the generation (in the Base Case Energy Vision 223 MW) has been treated as a balancing resource to achieve the renewable energy target.

This is not intended to suggest that an offshore wind farm of exactly 223 MW should be built, in reality any new offshore wind farm is likely to be much larger than that; (example, 600-1,200 MW).

Although this is a slightly manufactured scenario, it is likely that more offshore wind will be built off the Welsh coast and SBCR has the opportunity to play a major role to achieve that. The scenario also reflects the fact that Wales, and GB, will not be able to meet their future energy goals without a significant contribution from offshore wind. It was therefore important to include offshore wind in the SBCR future energy system vision.

5.7.2 Future of offshore wind in Wales

Currently there are not any planned or identified offshore wind sites in seas around the SBCR. The Atlantic Array to the south of the region, and Celtic Array off the North Wales coast, were both cancelled by the developers.

However, the UK target for offshore wind, and commitments recently made in the Clean Growth Plan[23], suggest that the UK shall see significant growth in offshore capacity with at least a further 10 GW and potentially 20 GW added in the next decade. The recently published Energy and Emissions Projections 2017 report[24] actually suggests that 45 GW of new renewable energy capacity will be required by 2035. The Crown Estate is currently re-looking at offshore resources and is consulting on further leasing opportunities around the UK coast.

With current offshore projects concentrated on the Eastern seaboard, there is an increasing need to diversify offshore generation with projects on the West coast to improve energy security. As the financial case for offshore wind has rapidly improved, further innovations such as floating turbines should open up more opportunities and facilitate projects in deeper waters, such as off the Pembrokeshire coast.

Meanwhile SBCR has already identified floating wind as a priority area for innovation and economic development and there are now plans to redesign the Pembrokeshire Wave Energy Test zone so that it can also be used to test and demonstrate offshore floating wind.

5.7.3 2035 Energy system vision for offshore wind

In the energy system vision for 2035 it is assumed that there will be at least one offshore wind project around the coast of SBCR. For the purpose of modelling offshore wind will be treated as the balancing generation technology required to meet the overall scenario objectives. The capacity could therefore vary but is likely to be between 600-1,200 MW.

It is possible that due to network constraints in the area, an offshore wind grid connection may not connect into SBCR itself. Previous projects proposed in the Bristol Channel have planned to connect across the Bristol Channel to North Devon. However, for the purpose of this work it is proposed to consider any project which is within the project area would still be considered SBCR generation.

5.7.4 Key enablers for offshore wind to achieve the energy system vision 2035

With the cancelling of Atlantic Array and Celtic Array offshore wind farms, there is now a lack of new offshore wind farms coming through the development pipeline around Wales. This is a problem not only for future energy decarbonisation but also to make best use of the investment in ports, infrastructure and skills that Wales has already made.

A top priority therefore should be to push to get more Welsh water windfarms within the upcoming Crown Estate leasing rounds.

To support this there is a need to:

- Rebuild the strong case for offshore wind in Wales, including the advantage of a more balanced UK energy portfolio and regional economic benefits

[23] The Government's Clean Growth Plan 2017 states that there should be 10 GW of new offshore wind capacity built in the 2020s, with additional deployment if it is cost effective

[24] The BEIS Updated Energy and Emissions Projections 2017 (Annex K) – suggests that an extra 45 GW of renewable energy capacity will be required to meet the 5th Carbon Budget. Although it is not specified it can be assumed, given previous announcements, that a significant portion of this will be offshore wind

- Restate the investment and economic case to support infrastructure and capability investment
- Support early stage project development including support to identify and assess potential development zones e.g. through funded geophysical surveys and wind resource assessments
- Work with and encourage project developers to bring forward site proposals
- Continue to invest in innovation – such as the Pembrokeshire demonstration zone – particularly around floating wind and new foundation solutions for deeper and more challenging sites
- Encourage, and potentially mandate, a degree of civic, Welsh institution and community ownership of new Welsh wind farms – which will probably require an investment vehicle to aggregate and channel investment funds.

5.8 Swansea Bay Tidal Lagoon

5.8.1 Current Progress

The 320 MW Swansea Bay Tidal Lagoon project has been granted a Development Consent Order by the UK government but despite support at many levels, the project has not yet progressed to construction and is still in discussions with UK government about the level of price support available through a Contract for Difference (CfD) agreement.

5.8.2 2035 Energy system vision for tidal lagoons

Given the level of local support and importance of the lagoon both for the energy and socio-economic development of the city region, the lagoon has been firmly included in the base case vision scenario.

The planned installed capacity is 320 MW, which would generate over 500 GWh per annum[25]. This has been modelled on the movement of the tides, and the resulting power output at five-minute intervals over a two-week lunar cycle and then scaled up to a year's yield.

As part of the sensitivity analysis the study has also considered an alternative scenario without the Swansea Bay Tidal Lagoon and the need for additional capacity from offshore wind that would be required to meet the annual energy generation target.

5.9 Marine energy – wave and tidal stream

Wave and tidal stream are still considered to be emerging technologies and although there are a number of demonstration projects, and one larger scale tidal stream project in the Pentland Firth, Scotland (MeyGen), there are no commercial scale tidal stream, or wave energy projects, deployed in Wales.

Wales does however have a significant amount of wave and tidal stream resource, both off the coast of Pembrokeshire, into the Celtic Sea and off the coast of Anglesey. The development of marine energy is also seen as a strategic priority by the Welsh Government and SBCR stakeholders. This is supported by the Marine Energy Wales[26] partnership and an active marine energy sector in SBCR particularly around the port of Pembroke and the Haven Enterprise Zone. Tidal demonstration projects

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[25] Tidal Lagoon Power http://www.tidallagoonpower.com/projects/swansea-bay/key-statistics/ Regen's tidal range model, with a high turbine efficiency, estimates energy yield at roughly 505 GWh per annum, which is similar to the developers estimate of c.530 GWh.
[26] http://www.marineenergywales.co.uk/wp-content/uploads/2016/01/MEW-Brochure-Final.pdf

have been deployed in Ramsey Sound and there is now a designated wave energy demonstration zone off the coast of Pembrokeshire. The Welsh National Marine Plan which has also identified Strategic Resource Areas for marine energy, providing clear policy support from a planning perspective.

The Swansea Bay City Region Deal includes proposals for the development of a major marine energy centre at Pembroke Dock. Pembroke Dock Marine would include:

- An Energy Engineering Centre of Excellence (MEECE)
- Investment in Pembroke port
- A Marine Energy Test Area (META) in Milford Haven
- South Pembrokeshire Wave Demonstration Zone (SPWDZ).

It is important therefore that wave and tidal energy will form a key part of SBCR's future energy vision, both in terms of energy generation and for the development of jobs and skills within the city region.

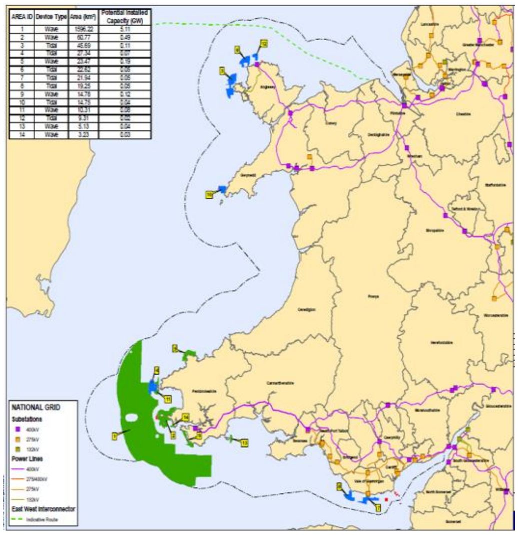


Figure 25: Marine energy opportunities around Wales and Pembroke Dock - Marine Energy Wales

5.9.1 2035 Energy system vision for marine energy

There is significant marine energy resource off SBCR, however it is difficult to predict how quickly that resource will be harnessed at commercial scale. Once developed, the market for wave and tidal stream technology could grow quickly, however, for the base case vision it is assumed that 130 MW of marine energy could be deployed by 2035.

For the purpose of future energy scenario modelling the following deployment is assumed by 2035:

Technology	Capacity Deployed	Capacity Factor	Modelled
Wave Energy	100 MW comprising 2/3 projects within the SPWDZ	35% estimated	Rough profiled based on Significant Wave Heights averaged from 3 coastal observatory buoys off Pembrokeshire
Tidal Stream	30 MW comprising projects in Ramsey Sound and St David's Head	36% modelled	Profile and energy yield based on Regen tidal stream model and tidal velocity from Ramsey Sound

Table 22: 2035 Base Case system vision for wave and tidal stream deployment

5.10 Additional electricity generation technologies

Technology	Current capacity (Jan 2017)	SBCR 2035 future energy vision scenario modelling	Base Case Vision 2035
Energy from Waste	No plants currently constructed in SBCR and one only in Wales (Cardiff's Trident Park).	One Energy Recovery Facility (ERF) (incineration) constructed by 2035, sufficient waste stream in SBCR to support a new plant.	20 MWe and 45 MWth (heat generation for DHNs)
Hydro	Existing SBCR project installations of 5.4 MW for hydro from the Welsh Government 'Energy Generation in Wales' report (2017)[27].	Based on growth rates from the highest projections in FES 2017 and WPD South Wales 2016 analysis – hydro increases by over 100% in areas with good resource. 70% of resource in SBCR is in Carmarthenshire.	13 MWe
Biomass and Anaerobic digestion CHP	At 1 January 2017 there was very little AD CHP. There were 14 MW of biomass CHP.	This is a high growth area and with the commercialisation of feedstock resources, capacity could increase significantly. There is a risk however that underutilised heat wastes bioenergy resource.	25 MWe
Landfill and sewage gas	As of 1 January 2017: 7 MW landfill 3.5 MW sewage gas	Landfill and sewage gas capacities are not expected to grow significantly with better waste management and reduction in landfill waste.	8 MW Landfill 5 MW sewage gas

Table 23: Data sources, assumptions and outputs for additional electricity generation technologies

[27] Welsh Government http://gov.wales/topics/environmentcountryside/energy/renewable/energy-generation-in-wales/?lang=en

5.11 Technologies not modelled in the 2035 energy system vision

The energy system vision model does not include every possible low carbon technology that could be deployed in the SBCR. Some of these are listed in Table 24. In some cases the omission was mainly down to the inevitable time and resource constraints of the project and should not be taken to mean that the technologies have no potential.

Technology	Rationale for non-inclusion
Nuclear energy	The energy system vision is not intended to be pro or anti-nuclear. However, there are no nuclear plants in the SBCR and there are no plans to develop nuclear plants within the 2035 timeframe.
Gas fired electricity generation with Carbon Capture and Storage (CCS)	CCS could play a significant role in the UK's energy future, development of the technology has however been delayed and the form of technology, including its carbon emission saving, is uncertain. If the technology was developed and could be shown to be both cost effective and fully low carbon, then the newer gas generating plants within the SBCR would be prime candidates for CCS technology. However, since the objective goal of the study was to explore the maximum use of renewable energy to achieve a 100% of annual consumption target, CCS in relation to electricity generation has not been considered within the 2035 timeframe.
Other heat technologies	With limited time the model did not look in detail at every possible heat technology including, for example, solar thermal and hybrid pre-heat solar boiler systems. Also heat recovery and waste, although this would form part of the energy efficiency measures required to deliver a 20% efficiency saving for domestic and commercial properties.
Other innovative technologies	There are a number of other innovative generation technologies that could play a role in Wales' energy future (deep geothermal for example) however unless there was specific resource, opportunity and development activity within SBCR (such as wave and tidal), these have not been included in the energy vision

Table 24 Technologies not included in the energy system vision model

6 Decarbonisation of Heat

2035 Energy System Vision

40% of heat supply from decarbonised* heat sources – through electrification, gas decarbonisation and use of renewable energy sources.

Reducing the overall carbon emission from supply of heat (including through energy efficiency improvements) by at least 40% compared to 2017.

* "**Decarbonised heat"** is defined as heat from a lower carbon source, but not necessarily zero carbon. E.g. the proportion of "green gas" injected into mains gas is considered to be decarbonised. Electricity used to generate heat is considered to be decarbonised if it is predominantly from low carbon sources. In the 2035 energy vision the carbon intensity of electricity is <50gCO_2e/kWh.

6.1 Meeting the heat challenge

Heat represents roughly one-third of the UK's greenhouse gas emissions and 45% of our country's energy consumption, the vast majority of which comes from natural gas.

It is understood that the decarbonisation of heat is going to be the most challenging aspect of the future energy transformation required to meet our carbon reduction commitments. The UK has so far failed to deliver significant decarbonisation of heat to meet the 2020 target of 15% of energy from renewable sources. Across the UK energy efficiency measures delivered under ECO, and previous schemes, have fallen[28] and although circa 60,000 installations have been delivered under the Renewable Heat Incentive(RHI), since 2014, the rate of growth of RHI accreditations has been disappointing[29].

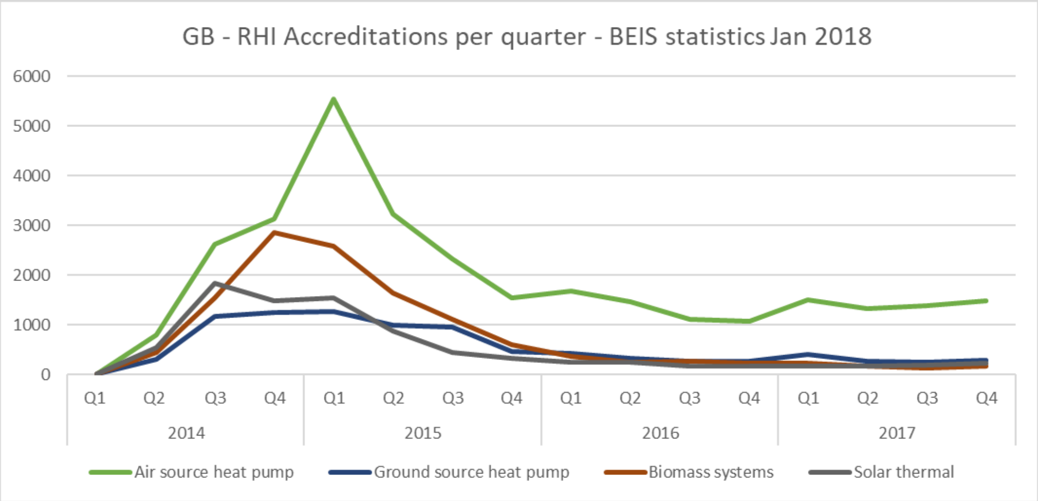


Figure 26: Accreditations under the RHI scheme 2014-2017 (GB data BEIS Jan 2017)

[28] ECO measures reduced by 87% comparing 2015 to 2012, although the deployment rate is set to increase again http://www.energysavingtrust.org.uk/sites/default/files/reports/ERP2_The%20Clean%20Growth%20Plan_Tackling%20Fuel%20Poverty.pdf

[29] BEIS January 2018 https://www.gov.uk/government/statistics/rhi-deployment-data-december-2017 The domestic RHI has to date been dominated by heat pump (54%) and biomass (22%) installations, predominantly in off-gas areas (76% of installations)

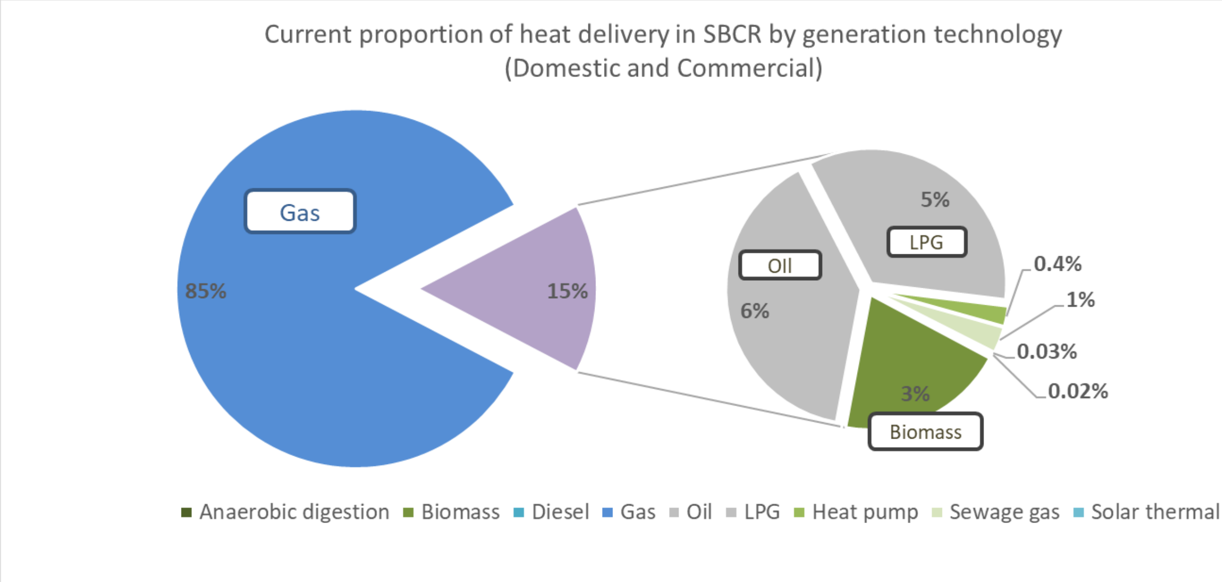


Figure 27: The current heat provision in the SBCR is dominated by gas with circa 85% of heat, while oil and LPG are still widely used in off-gas grid areas

As well as the financial cost, part of the challenge is that heating systems are an integral part of both domestic and commercial buildings, they are replaced infrequently and redesigning an existing heating system to use a completely different technology, delivery system or fuel may not be viable without significant structural work and impact.

Deployment of lower carbon heating systems in the SBCR has mirrored progress across the UK. The anticipated deployment of high numbers of ground and air-source heat pumps has so far failed to materialise. Across the UK deployment has remained relatively flat at 9,000 heat pumps per year[30], although the latest figures for 2017 suggest a jump to 22,000 per year as a result of the RHI[31]. Within the SBCR heat pump deployment is currently 0.29%[32] of households, which is consistent with the rest of Wales and a little higher than in England.

6.1.1 Decarbonisation strategies

All options are difficult and there is no single solution that can deliver the heat decarbonisation level that is needed to meet the UK's carbon reduction goals. There is an emerging consensus[33] that a multifaceted approach to decarbonise heat will be required.

The approach taken to meet the objectives for the SBCR energy vision case study has been to consider the source of heat demand, analyse the various modes of heat delivery and develop strategies by which each delivery mode can be decarbonised.

Decarbonisation strategies considered within the study and system modelling have included five key carbon reduction strategies.

[30] Committee on Climate Change - Next Steps for the UK Heat Policy (2016) https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/
[31] 2017 https://www.openaccessgovernment.org/uk-heat-pump-market-is-growing-again/44301/

[32] Re-energising Wales workstream 2 Phase 1 report
[33] See for example UK Government Clean Growth Plan, National Grid "The future of gas"

Heat decarbonisation strategies	
Strategy	**Description**
1. Energy efficiency	These have already been described in Section 4 "Demand and Energy Efficiency" with a 20% reduction target
2. Electrification of heat	With a principle focus on the deployment of heat pump and hybrid heat pump system technology, although other technologies could be considered
3. Decarbonisation of gas	Through injection into the mains network of "green gases" such as biomethane and hydrogen
4. Renewable heat	Direct delivery of renewable heat energy from sources such as biogas and biomass
5. District heat networks (DHNs)	Delivery of heat through district heat networks which could then in turn be decarbonised

Figure 28 Heat decarbonisation strategies

There are other options and many other technologies that could be considered. There is a growing debate about the right heat strategy and the UK government has recently launched a new consultation[34] to ascertain industry and stakeholder views.

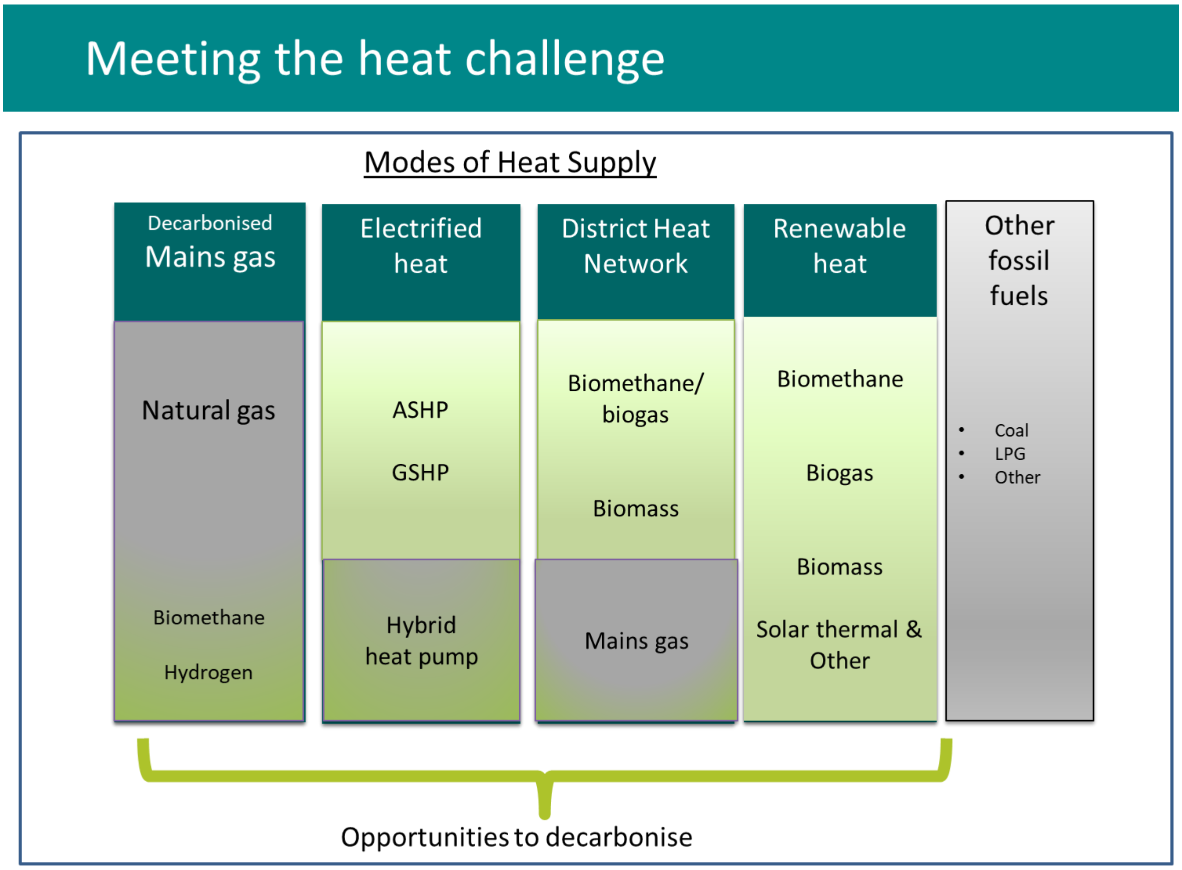


Figure 29 Meeting the heat challenge

[34] BEIS consultation on heat March 2018

6.2 2035 Energy system vision for heat

The case study shows that a combination of these strategies could deliver the objective that 40% of the 42 TWh of heat demand is delivered from lower carbon sources, with a net carbon saving of over 40% when measured against 2017 estimates. **However, it should be noted that in order to do this a number of very ambitious and challenging assumptions have been made**.

The mains gas network still delivers around 66 % of heat demand[35] either directly, via district heat networks or as a backup fuel for hybrid heat pump systems. The 2035 case study however envisages that mains gas will be decarbonised with a proportion of 20 % made up of "green gas" such as biomethane or hydrogen. So, for each MWh of heat delivered from mains gas, 200 kWh is considered to be decarbonised.

The full breakdown of heat delivery is depicted in Figure 30:

- Mains gas directly delivers 61% (of which 20% is green gas)
- Heat pumps and hybrid heat pump systems deliver 14% of heat, of which:
    - 12% is from decarbonised electricity while the remaining
    - 2% is from hybrid back-up sources including mains gas, biomass, oil and LPG.
- District heat networks deliver 11% of heat, of which 4% is from mains gas.
- 8% of heat delivered by renewable sources such as biogas and biomass
- 6% of heat is delivered by oil, LPG and other fossil fuel sources
- Other heat solutions such as solar thermal, and boilers with solar pre-heat systems could also be deployed but have not been modelled.

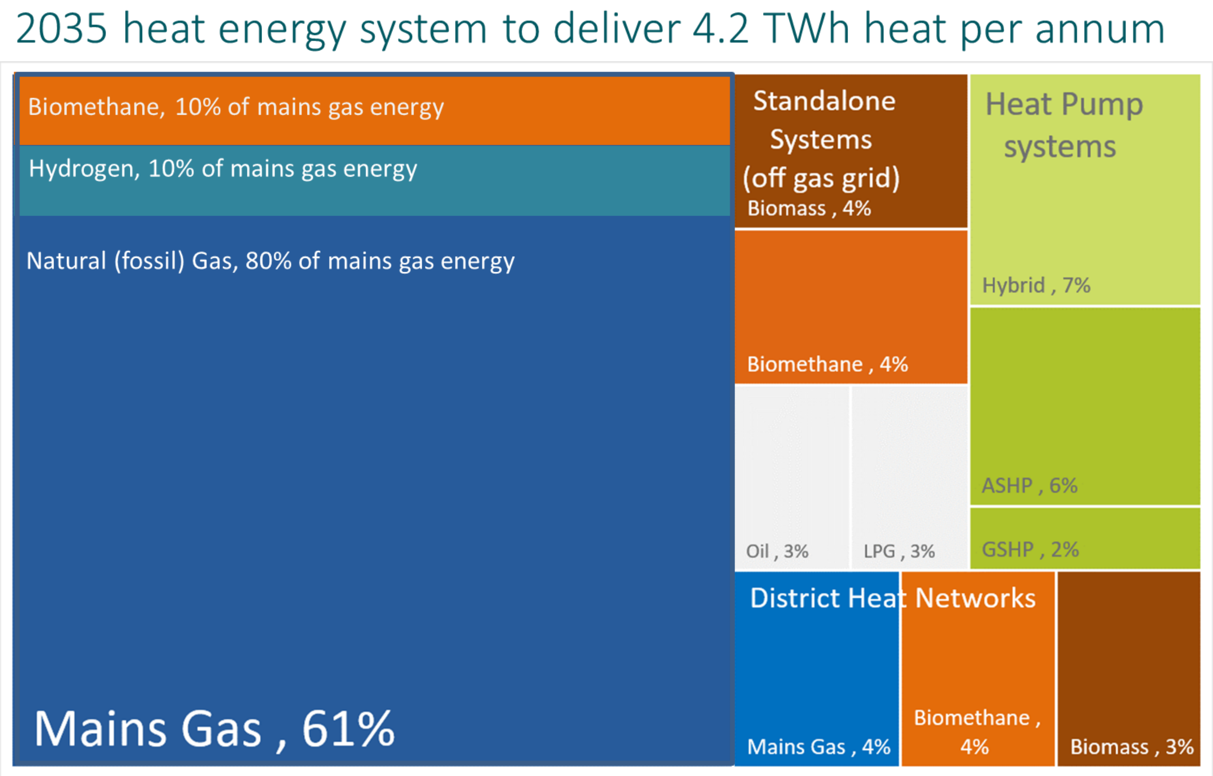


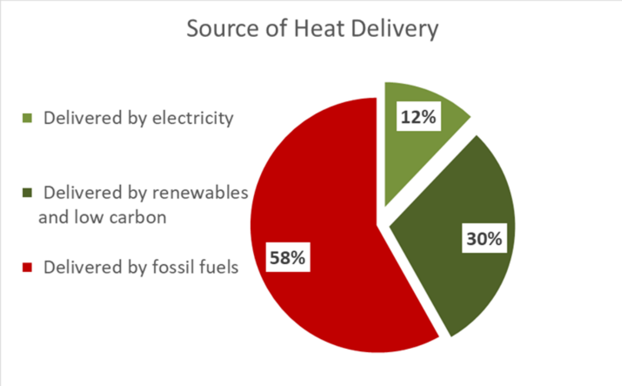
Figure 30: Portfolio of technologies and channels to deliver heat in 2035

[35] For clarification mains gas delivers 66% of total heat – 61% "directly", 4% as fuel for district heat networks and just over 1% as backup fuel for hybrid heat pump systems

The net result is a future energy system that is able to deliver both the energy system vision objectives set, with over 42 % of heat delivered from decarbonised sources (including electricity and the decarbonised element of mains gas) and an overall carbon emission saving of 41%.

Meeting the 2035 energy system vision for heat

Over 40% of heat delivered from decarbonised sources



Over 40% of carbon saving compared to current emissions

Heat Carbon Savings

Carbon	CO2e tonne	Carbon Intensity
	Tonne	gCO2e/kWh
Current emissions	940,768	178
2035 Energy System	557,341	133
Carbon saving	383,427	45
Percentage saving	41%	

Reduced carbon intensity plus energy efficiency → 41% carbon emission reduction

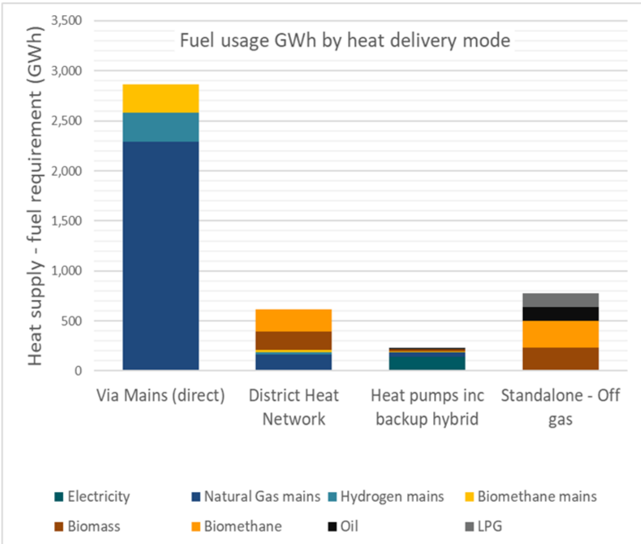
Figure 31: Energy system vision objectives would be met

6.2.1 Breakdown of fuel used for heating

2035 Energy system vision - fuel usage in heat delivery

2035 Energy Vision Case Study - Fuel usage for heat

MWh Fuel Used	Via Mains (direct)	District Heat Network	Heat pumps inc backup hybrid	Standalone - Off gas
Electricity			138,053	
Natural Gas mains	2,292,993	166,750	45,164	
Hydrogen mains	286,624	20,844	5,646	
Biomethane mains	286,624	20,844	5,646	
Biomass		181,812	23,192	232,548
Biomethane		223,000		265,769
Oil			4,571	137,254
LPG			6,400	137,254
Total (MWh) fuel	**2,866,241**	**613,249**	**228,671**	**772,826**
Electricity			60%	
Natural Gas mains	80%	27%	20%	
Hydrogen mains	10%	3%	2%	
Biomethane mains	10%	3%	2%	
Biomass		30%	10%	30%
Biomethane		36%		34%
Oil			2%	18%
LPG			3%	18%
Total Percentage	100%	100%	100%	100%



Note quantum and proportion of fuel usage MWh differs from heat delivery MWh owing to different heat conversion factors

Figure 32: Energy system vision fuel usage in heat delivery

6.2.2 Key enablers to meet the heat challenge

A description of each strategy is outlined in the following section, but it is worth highlighting that to achieve this outcome requires significant measures, each of which will in themselves be a major challenge.

- Energy efficiency measures to circa 200,00 properties, with a 60-70% shift of properties into EPC performance bands A-C, as described in section 4 Energy Demand and Efficiency.
- Overcoming the cost and acceptance issues to deploy heat pumps to 50,000 domestic and commercial properties – 14% of buildings from a current baseline of less than 1%.
- Commercialisation of biomethane resource and the development of cost effective hydrogen manufacturing technology to support the injection of green gas to the mains network.
- Development of new domestic and commercial heat networks to deliver 11% of total heat demand to circa 10% of buildings.

6.3 Electrification of heat and the role of heat pumps

6.3.1 Exponential growth needed

Heat pump technology has been at the cornerstone of the UK heat decarbonisation strategy for over a decade.

In 2013, DECC's 'The Future of Heating: Meeting the Challenge'[36], suggested that heat pumps will be the main heat source for off-gas areas in the future and could become a key technology to enable the decarbonisation of heat in the UK.

As discussed above the anticipated deployment of high numbers of ground and air-source heat pumps has so far failed to materialise and across the UK has remained relatively flat at 9,000 heat pumps per year[37] with an uplift to 22,000 reported in 2017. Regen analysis has identified heat pump installations in SBCR total 0.29% of households which is consistent with the rest of Wales and a little higher than in England. The majority of heat pump installations are air source and have been deployed in off-gas grid properties. The RHI has been helpful to support heat pump installations.

To get anywhere near the electrification of heat that is envisaged in a decarbonised energy scenario[38] requires an exponential growth in heat pump deployment over the next decade. Heat pump deployment and efficiencies have therefore been a key focus for the 2035 energy system vision.

Both National Grid and the Committee on Climate Change project the dominant low carbon source of heating will be from heat pumps by 2030/2035. The FES and Committee on Climate Change high growth scenarios present a rapid increase in the deployment of heat pump technology.

To date these growth levels have not been seen in the market and heat pumps face two significant challenges:

1) To date their cost efficiency has been limited to off gas grid properties, which are relatively well insulated, the case for installing heat pumps in on-gas and less well insulated homes is difficult
2) For heat pumps to deliver a significant portion of the regions heat energy, significant grid and distribution network upgrades will be required. In a highly electrified system it is widely accepted that the electricity networks could not deliver the peak heat demand (during the

[36] DECC https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/190149/16_04-DECC-The_Future_of_Heating_Accessible-10.pdf
[37] Committee on Climate Change - Next Steps for the UK Heat Policy (2016) https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/
[38] Eg National Grid FES 2017 Two Degrees scenario has almost 5.9 m heat pumps across the UK by 2030 and 7.9m by 2035, Committee on Climate Change 'Report to Parliament Meeting Carbon Budgets Closing the policy gap' (2016) suggest 2.5m heat pumps by 2030 will be needed.

coldest days) when air source heat pump conversion of electricity to heat performance will be at its lowest.

Although, the majority of heat pumps in today's market are air/ground source heat pumps, hybrid heat pump systems present an opportunity to directly compete in the on-gas market, enabling the use of an air-source heat pump when electricity is cheaper than gas.

6.3.2 Role for hybrid heat pump systems

One avenue of innovation to address these issues is the deployment of hybrid heat pump systems. These systems which could come in a variety of configurations essentially combine a heat pump (air source) with a back-up heating system such as a gas boiler, biomass or possibly an existing oil or LPG boiler.

The basic principle is that the heat system controls use the heat pump during times when the heat pump Coefficient of Performance (COP) is high and electricity costs are low, but will revert to the backup system when the COP falls below a given level or the cost of electricity is high.

Hybrid heat pump systems offer a number of potential advantages and disadvantages which have been considered as part of the study.

Possible advantages and disadvantages of hybrid heat pump systems	
Potential advantages	
Energy Cost	Could be energy cost efficient since the hybrid system would make best use of the heat pump when performance is high, but revert to (lower cost) backup system when electricity cost and/or performance falls.
Reduce peak electricity load	Would potentially reduce the peak load requirement on the electricity network during especially cold weather, since a higher proportion of systems would be using the back-up technology and more peak energy delivered via the gas network.
Carbon	In certain circumstances there could be carbon savings if the electricity being used to power the heat pump during peak load (cold weather) periods is from marginal high carbon peaking plant sources, such as gas.
Accelerated Deployment	Hybrid heat pump systems may be easier to deploy and have a higher uptake from on-gas grid properties and harder to treat properties that would otherwise not consider a heat pump solution.
Potential disadvantages	
Delayed or less carbon reduction	To some degree hybrid systems may be seen as a compromise solution since the property would still use a backup system that will predominantly be fossil fuel gas. Excessive use and reliance on the backup, for example through bad heat management, would further reduce carbon savings.
Avoided energy efficiency	The advantage of being able to deploy hybrid systems in less efficient homes may mean that there is less incentive to tackle the underlying issue of poor quality housing and fuel poverty.
Badly sized systems	Developers on new builds, and installers of heat pumps generally, may take the view that to save money it is acceptable to install an undersized heat pump, and place more reliance on the backup system. This issue is discussed and modelled in more detail below.
System capital costs	So far, a key challenge for hybrid systems is the very high capital costs to deploy a heat pump, a control system and a boiler backup system (which are usually replaced at the same time). Without significant cost reduction or grant support the growth in deployment of hybrid systems will also be slow.

Figure 33 Hybrid heat pumps advantages and disadvantages

6.3.3 2035 Energy System Vision – Heat Pumps

The 2035 energy system vision includes a very rapid and extensive deployment of heat pump technologies to over 50,000 properties representing around 14% of properties in the SBCR region. Extrapolated to Wales this would represent over 170,000 heat pumps and across the UK just over 3 million.

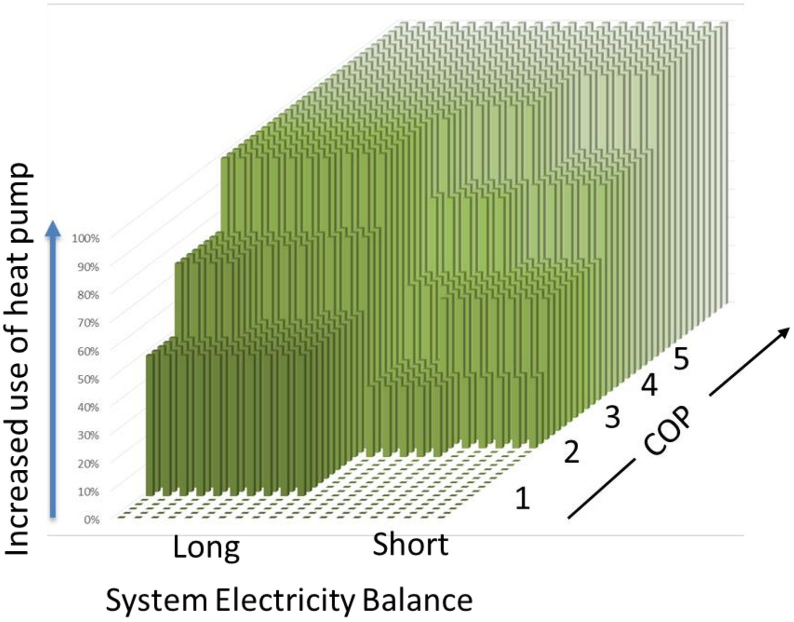
The proportion of properties with heat pump solutions is highest for new build and off-gas grid but there is a significant proportion also deployed in commercial and on gas grid properties. Just under half the heat pumps are assumed to be linked to hybrid systems.

Heat Supply	Percentage of properties with a heat pump	Of Which			
Heat pumps		ASHP	GSHP	Hybrid	No Properties
On Gas grid	8%	20%	5%	75%	19,771
Off Gas Grid	25%	60%	15%	25%	19,426
New development homes	40%	55%	25%	20%	9,384
Commercial and Industrial	10%	20%	5%	75%	2,241
Total properties		**21,219**	**6,361**	**23,242**	**50,822**

Table 25: Base case assumptions for 2035 energy system vision

6.3.3.1 Heat pump performance and control logic

The 2035 energy system vision for heat includes the extensive use of hybrid heat pump systems.

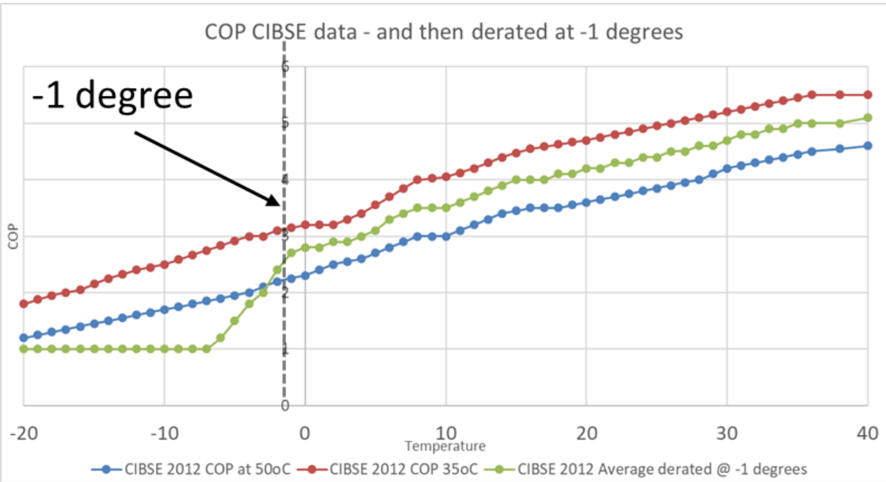


To simulate hybrid system behaviour the control logic within the energy system model, which controls the switching between heat pump and backup source is driven by two key factors:

1) the COP of the heat pump at temperature and
2) the relative balance of locally sourced renewable energy.

If the performance is low, during colder weather, and the balance of electricity is "short" implying a higher electricity price, the proportion of backup heating systems in use is increased.

Figure 34: Simulation of heat pump control logic



The base case scenario uses an average of the CIBSE (2012)[39] 35 and 55 degree temperature output performance curve with a significant derating variable based on the heat pump sizing.

Heat pumps for the base case have been assumed to be sized on average at minus 1 degrees.

Figure 35: Relationship of COP to outside temperature and system sizing

6.3.3.2 Heat pump contribution to the energy system in 2035

Based on these parameters and assumptions the overall contribution of heat pump and hybrid systems to energy system mix is:

- 580 GWh per annum (14% of total heat demand)
- 500 GWh of which the air, ground and hybrid heat pumps deliver (12% of heat demand)
- the difference being met by hybrid back-up systems.

[39] Heat pump performance has improved since 2012 and so this is a conservative estimate. Although with widespread deployment the instances of heat required at 55 degrees is also likely to increase.

Electricity required to delivery this quantum of heat is estimated at 137 GWh giving an overall conversion rate from electricity to heat of 3.8.

The peak electricity required from the heat pumps (during the simulated year of 2035) was modelled at 81 MW or 9% of peak electricity power demand[40]. The average demand per heat pump in this peak demand period was 1.58 kW.

An important point to make is that the peak period of electricity demand from heat pumps does not correspond to the overall peak demand or peak system imbalance period. During the peak system imbalance period, the electricity demand from heat pumps fell to 43 MW at that time all hybrid systems were using their back-up heat supply.

6.3.3.3 Performance of hybrid heating systems

The ratio between the use of heat pump and back-up boiler or other source in hybrid systems was modelled at 70:30, with heat pumps providing 70% of the heat demand.

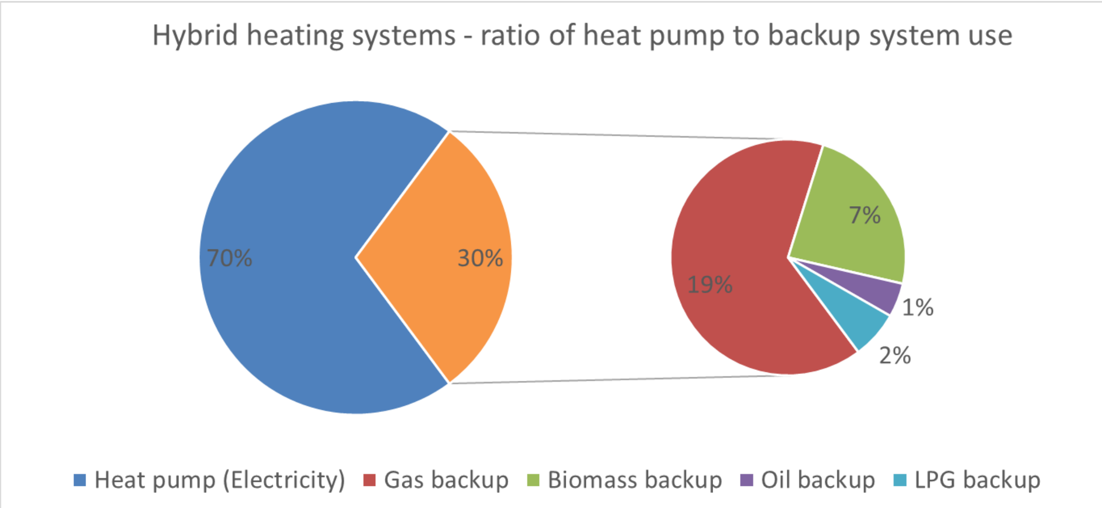
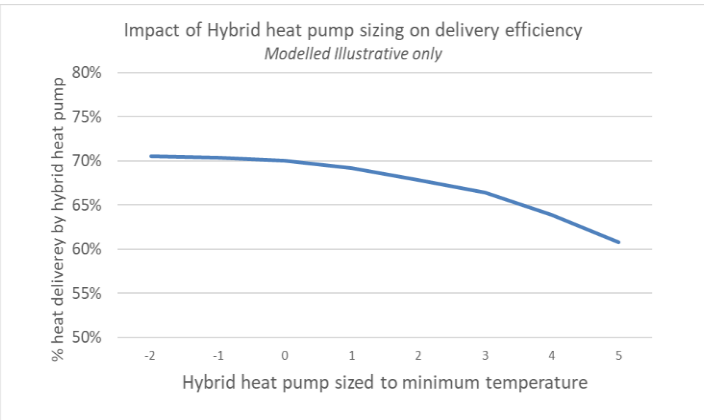


Figure 36: Modelled data showing ration of heat pump v backup system usage



The performance of hybrid heating systems within the model was heavily influenced by the minimum temperature rating. Undersized heat pumps, sized for higher minimum temperatures, relied more heavily on the backup systems. While this model data is illustrative only (and is not based on field trial measurements) it does demonstrate the importance of maintaining standards for properly sized heat pumps within hybrid heating systems.

Figure 37: Impact of heat pump sizing on backup system usage

[40] Note the peak period of electricity demand from heat pumps does not correspond to the overall peak demand or peak system imbalance period overall

6.4 Decarbonisation of gas

Alongside electrification of heat, and energy efficiency, the decarbonisation of gas is expected to become critical within the overall carbon reduction plan. A number of recent studies and forecasts have looked at the potential to decarbonise the gas network using the injection of "green gases" .

Fuel	Fuel Source
Biomethane (Inc BioSNG)	Converted from: ○ Biogas produced from anaerobic digestion using organic feedstocks (plant material and waste), needs further upgrading processes to create biomethane suitable for injection into the gas gird. ○ Or Bio Substitute Natural Gas (BioSNG) which is biomethane often produced with gasification of municipal solid waste (MSW), or other solid sources using methanation this converts gas from biomass gasification into methane.
Hydrogen	Extracted by: ○ Electrolysis (using low cost/low carbon "excess" electricity). ○ Or steam methane reforming (SMR) of natural gas (combined with a carbon capture and storage(CCS) to capture the by-product carbon dioxide).

Table 26 Biomethane and hydrogen fuel sources

The latest in a series of reports produced by National Grid on the Future of Gas[41] has depicted a potential high decarbonisation sensitivity scenario[42] under which the gas network would be radically decarbonised through biomethane and hydrogen injection, with hydrogen playing an increasingly important role in the period up to 2050.

The 2035 energy system vision for SBCR includes an ambitious role for both biomethane and hydrogen which together could provide over 20% of heat delivered. The use of both gases to the extent envisaged in the vision will be extremely challenging and, as is discussed in more detail below, will require significant support and enabling actions to deliver.

Note, the proportions of biomethane and hydrogen assumed within the mains gas energy mix has been revised during the modelling process with more decarbonisation of mains gas assumed from hydrogen injection.

Mains gas energy content (note energy not volume)	Phase 1 interim scoping report assumptions	Phase 2 modelling and final report assumptions
Biomethane (including BioSNG)	620 GWh fuel Equiv. 20% of mains gas energy content	313 GWh fuel Equiv. 10% of mains gas energy content or 6% of total heat
Hydrogen	7% of mains gas energy content	10% of mains gas energy content or 6% of total heat

Table 27 Biomethane and hydrogen assumptions

The reasons for the change are:

- Through the modelling process it was recognised that more biomethane would be used for district heat network and also direct supply via CHP plant. The resource available for grid injection would therefore be reduced.

[41] National Grid : http://futureofgas.uk/wp-content/uploads/2018/03/The-Future-of-Gas_Conclusion_web.pdf
[42] National Grid http://futureofgas.uk/wp-content/uploads/2017/10/Decarbonised-Gas-sensitivity.pdf

- Recent studies including National Grid's Future of Gas analysis have projected a potentially greater role for hydrogen to decarbonise gas.

6.4.1 2035 Energy system vision for gas – role of biomethane

Within the period to 2035, and the priority to harness opportunities within the SBCR to make best use of indigenous resource, the energy system vision envisages biomethane playing a significant role to deliver 612 GWh (15%) of total heat demand.

Biomethane* contribution to heat delivery 2035				
Biomethane delivery	% of mains gas energy content	% of total heat demand	Heat energy (MWh)	Fuel usage (MWh)
Via injection to mains (inc DHN using mains gas)	10%	6.5%	270,762	313,113
Via district heat networks (inc those with CHP)		4%	186,038	223,000
Standalone heat systems including CHP		4%	156,100	265,769
		15%	612,900	801,882
*Biomethane is used as a generic terms for all biogas, bioSNG and derivative gases whose core energy content is biomethane				

Table 28: Heat delivery and fuel required from biomethane (not including electricity generation)

6.4.1.1 Use of biomethane to generate electricity

In addition to the fuel requirements for heat the 2035 energy system vision also includes the use of biomethane (biogas) for the generation of electricity with 58 MW of biomass, AD, energy from waste, sewage and landfill gas plants generating an estimated 315 GWh of electricity per annum.

Bioenergy (Biomethane and Biomass) use for CHP			
Electricity generated		315,910	MWh e
Potentially usable heat		634,979	MWh th
Total Fuel used @ 70% efficiency		1,365,365	MWh
Nominal fuel for Electricity		453,610	MWh
Nominal fuel for Heat		911,755	MWh
Heat utilised -heat delivery via DHN and CHP	54%	491,270	MWh
Heat wasted (not used or not captured)		420,485	MWh
Nominal bioenergy fuel used for electricity plus wasted heat.		874,095	MWh

Table 29: Bioenergy use for CHP

If this electricity generation was in the form of CHP plant, (which is less efficient than a non-CHP gas turbine) it would require an estimated 1.3 TWh of bioenergy fuel and would also produce circa 634 GWh of heat.

It is assumed that a high proportion (over 50%) of the heat generated would be utilised and is therefore part of the 612 GWh of heat supplied in Table 28.

The net increase in biomethane for electricity production is therefore calculated at 874 GWh made up of 453 GWh used for electricity generation and 420 GWh of heat that is "wasted" and not utilised.

The total fuel requirement from biomethane is 1.67 TWh made up of 801 GWh of heat and 874 of electricity plus wasted heat CHP generation.

The analysis is conservative and it is expected that the efficiencies of CHP plant will improve and better use will be made of CHP generated heat. Nevertheless the analysis highlights some major policy questions over the extent to which biomethane feedstocks should be encouraged for use in electricity generation and the extent to which, if it is, it must be accompanied by efficient use of any heat generated.

6.4.1.2 Feedstocks for biomethane and bioSNG gases

An extensive study of UK potential bioenergy feedstocks has been conducted on behalf of Cadent Gas ltd[43]. Analysis of this research by Wales & West Utilities suggests that the total renewable gas potential for Wales could, if fully exploited, reach as high as 7-8 TWh in the period from 2030 to 2040.

Other studies by Ecotricity[44], National Grid[45] and the Committee on Climate Change[46] have also suggested that various forms of green gas could provide a very significant proportion of the UK's heat requirement. National Grid's FES 2017 Two Degrees scenario projects as 100 TWh of green gas energy by 2050.

Sources of waste and non-waste feedstocks include traditional sources, such as sewage sludge, as well as currently less harnessed sources such as agricultural arisings and macro-algae. Dedicated energy crops could play a role although, this would have to be balanced with food production and other land use and it is noticeable that dedicated energy crops make a relatively small contribution to the 7-8 TWh that could be available in Wales.

A detailed estimate of feedstock availability within the SBCR has not been undertaken, and this would therefore be a very useful piece of follow on analysis. However, it is estimated that SBCR produces 21%[47] of Wales' waste and has significant agricultural industries. If a 21 % figure was applied to the overall Welsh resource estimate it would imply a potential resource within the SBCR of circa 1.6 TWh of biomethane and bioSNG fuel.

This is only just enough to meet the fuel requirement for biomethane for heat and electricity. The energy system vision is therefore viable in terms of biomethane feedstock only if:

- A very high proportion of developable feedstocks were utilised to manufacture biomethane
- Additional energy crops and sources of feedstocks will very likely be needed

[43]Cadent Gas Ltd : https://cadentgas.com/getattachment/About-us/The-future-role-of-gas/Renewable-gas-potential/Promo-Downloads/Cadent-Bioenergy-Market-Review-TECHNICAL-Report-FINAL.pdf
[44] Ecotricity 'Green Gas – The opportunity for Britain' (2016) https://www.ecotricity.co.uk/our-green-energy/our-green-gas/campaign-for-green-gas/green-gas-report
[45] National Grid The future of gas : Supply of renewable gas 2016 http://futureofgas.uk/documents/future-of-gas/
[46] Committee on Climate Change Next steps for UK heat policy' (2016) https://www.theccc.org.uk/wp-content/uploads/2016/10/Next-steps-for-UK-heat-policy-Committee-on-Climate-Change-October-2016.pdf
[47] StatsWales https://statswales.gov.wales/Catalogue/Environment-and-Countryside/Waste-Management/Local-Authority-Municipal-Waste/Pre-2017-18/Annual/wastereusedrecycledcomposted-by-localauthority-source

- Electricity generation using biomethane is predominantly via CHP plants
- A high proportion of the heat generated in CHP plants is actually utilised

Potential sources of biomethane and bioSNG energy	
Waste feedstocks	Residual waste Wood waste Food waste Sewage sludge
Non-waste feedstocks	Decidcated energy crops Dry agricultural residues Forestry residues Small round wood Arboricultural arisings Sawmill co-products Short rotation forestry Wet manure Macro-algae

Table 30: Indicative bioenergy potential feedstocks

6.4.1.3 Commercialisation of feedstocks

If the theoretical availability of feedstocks is not a barrier for biomethane production the commercialisation of feedstock and conversions through anaerobic digestion and advanced gasification is a major challenge. There is also a question over the usage of bioenergy and the proportion that would be used for grid injection (or other forms of heat) compared to its use for electricity production and/or transport fuels.

Resource projections typically assume little or no competition for bioenergy resources, however the future potential for bioenergy is limited by competition for land, as food production is prioritised over energy crops on arable land. Waste crops and wood also have other uses such as chipboard manufacture while there will also be competition for biomass resources for other bioenergy uses such as liquid biofuels and biomass electricity generation will limit bioenergy availability[48]. Future reductions in waste and recycling will also limit feedstock supply.

On the other hand, there are opportunities to actively cultivate feedstocks and it is likely that energy crops, including innovation in areas such as algae cultivation, alongside renewed tree-planting and managed forestry, could increase feedstock availability. Improvement in AD processes and BioSNG gasification will also help to increase energy yield.

[48] Imperial College London http://www.sustainablegasinstitute.org/a-greener-gas-grid/

A review of the renewable gas feedstock potential in Wales completed by Wales & West Utilities and based on data from the Cadent review on feedstock potential in the UK[49], suggest by 2030 the split of renewable gas between BioSNG and Biomethane from anaerobic digestion (AD) will be 34% and 66% respectively.

Support from the RHI scheme has encouraged new projects to inject green gas into the gas grid network. The latest RHI statistics[50] suggest that there are now 371 accredited biogas schemes across the UK, compared to 27 at the end of 2015, with the equivalent of 4.3 TWh heat now injected into the gas grid. This 4.3 TWh amounts to 22% of the total 19.5 TWh from the non-domestic scheme to date, an impressive contribution from a rapidly growing technology.

Wales & West Utilities now have 17 biogas schemes with grid injection across their network, although it is noticeable that the majority of these schemes are in the south west of England. These schemes are small scale but biogas production through farm-based AD is becoming a significant opportunity for the rural economy. There is one equivalent AD plant in Wales that is injecting biomethane into the grid.

6.4.1.4 Enabling actions to achieve the 2035 Energy system vision

Much more work is needed to fully quantify and assess the bioenergy potential in SBCR and across Wales. A study to look in more detail at available feedstocks would be useful and should also consider:

- The route to commercialisation of bioenergy and creation of a market
- Competing and alternative uses of bioenergy and how they are supported
- Best and most efficient use of bioenergy for carbon reduction and economic development
- Jobs and economic potential for the local rural (and urban) Welsh economies
- The opportunities for farm based and community schemes to make best use of agricultural and waste resources
- Alternative and new sources of bioenergy
- The role that regulation and policy can play to support (or create barriers) for bioenergy commercialisation in Wales
- Lessons and best practice from other countries and UK regional case studies.

6.4.2 2035 Energy system vision for gas – role of hydrogen

6.4.2.1 Hydrogen energy potential

Hydrogen could become an important fuel source for the decarbonisation of heat as well as use in transport. National Grid's Future of Gas[51] conclusions report (March 2018) suggests that hydrogen could play a major role for the delivery of heat through 100% or blended hydrogen networks within cities, while biomethane could become more focused on rural areas and off-gas grid properties. By 2050, Hydrogen could supply 28% of heat in the UK, across major cities including London, Birmingham,

[49] Cadent, prepared by Anthesis and E4Tech https://cadentgas.com/getattachment/About-us/The-future-role-of-gas/Renewable-gas-potential/Promo-Downloads/Cadent-Bioenergy-Market-Review-TECHNICAL-Report-FINAL.pdf

[50] BEIS Renewable Heat Statistics https://www.gov.uk/government/collections/renewable-heat-incentive-statistics

[51] National Grid http://futureofgas.uk/wp-content/uploads/2018/03/The-Future-of-Gas_Conclusion_web.pdf

and Manchester[52]. Other studies [53] have also projected potential energy scenarios with very high hydrogen content.

Hydrogen is not a new fuel, gas networks with small to medium hydrogen (or town gas) content have been around for decades. It is also the case that many European and international energy systems already have provision for hydrogen to be blended within the mains gas network.

The current consensus is that hydrogen could make up to 10%[54] blend by volume of mains gas without significant impact in terms of network upgrade, appliances and safety, while a 20% blend could be an upper limit. The energy density (Higher Heat Value HHV) of hydrogen depends on the compression but in a blended system the ratio of energy from hydrogen compared to natural gas is about 1:3[55]. In other words, the same volume of hydrogen carries about 1/3 of the energy heat value as the same volume of natural gas.

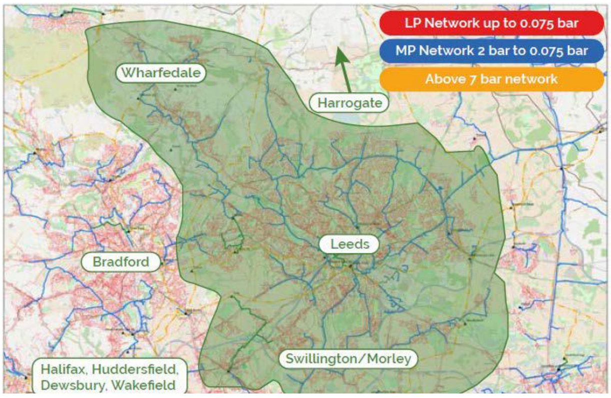


Figure 38: Geographic scope of the H21 Leeds Citygate project

Higher blends and 100% hydrogen networks could be developed. Already in the UK a number of cities are exploring the potential to develop hydrogen networks. The most advanced study is the H21 Leeds Citygate[56] project, which is being developed by a consortium of partners including Northern Gas Networks and Wales & West Utilities.

6.4.2.2 Hydrogen energy challenges

The development of hydrogen for use in heat energy delivery faces a number of challenges:

- Finding a decarbonised source of hydrogen production
- Cost of large scale manufacture
- Gas network upgrades and safety
- Appliance upgrades and household safety.

Hydrogen is an abundant chemical that forms the basis of many compounds including hydro-carbons and water.

[52] National Grid – decarbonised gas high gas sensitivity http://futureofgas.uk/wp-content/uploads/2017/10/Decarbonised-Gas-sensitivity.pdf
[53] For example **KPMG,** 2050 Energy Scenarios. The UK Gas Networks role in a 2050 whole energy system (2016) KPMG www.energynetworks.org/assets/files/gas/futures/KPMG%202050%20Energy%20Scenarios%20-%20The%20UK%20Gas%20Networks%20role%20in%20a%202050%20whole%20en...1.pdf and Carbon Connect http://futureofgas.uk/news/production-of-low-carbon-gas/
[54] See for example **Ofgem,** HyDeploy project summary (2017) https://www.ofgem.gov.uk/ofgem-publications/107840 **and Health and Safety Laboratory,** (2015) HSE http://www.hse.gov.uk/research/rrpdf/rr1047.pdf, **Dodds and McDowall,** The future of the UK gas network (2013)[54]
[55] Energy and the hydrogen economy https://www.afdc.energy.gov/pdfs/hyd_economy_bossel_eliasson.pdf
[56] H21 Leeds Citygate project https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf

The two methods of large scale hydrogen production are:

1) Steam methane reforming (SMR) is the most common method of bulk hydrogen production. To reduce CO_2 the production process requires Carbon Capture and Storage (CCS).
2) Low carbon electricity can produce hydrogen using electrolysis of water, this is limited by cost and available capacity of low carbon electricity generation.

The most significant challenge for large-scale production of hydrogen will be establishing low carbon sources. SMR is currently the cheapest and most widely used production method but is reliant on CCS to avoid increasing emissions. Electrolysis is limited by cost and low carbon energy supply for the production of hydrogen.

Injection figures do not account for substantial upgrade of the gas network to allow for greater concentrations of hydrogen. This is reflected in KPMG's energy scenarios, which suggest converting natural gas from the National Transmission System and distributing it locally. Upgrading the gas system in this way would add substantial cost, both on the distribution and consumer side, as infrastructure would need investment and appliances would need to be changed.

6.4.3 2035 energy system vision - hydrogen

The 2035 energy system vision has not looked in detail at the feasibility of hydrogen-based energy supply within the SBCR and this would be a worthwhile study for further research. However, given the potential of hydrogen to form a key part of the future UK energy system, hydrogen blending within the gas network has been assumed to deliver 10% of mains gas energy content equivalent to 6% of total heat energy delivered.

This energy could be delivered as a blended gas across the entire SBCR network (which would require a 30% hydrogen content blend by volume), or in a number of redesigned networks in urban areas with a higher hydrogen content or dedicated 100% hydrogen networks.

Hydrogen contribution to heat delivery 2035				
Hydrogen delivery	**% of mains energy content**	**% of total heat demand**	**Heat energy (MWh)**	**Fuel usage (MWh)**
Via injection into mains gas	10%	6.5%	270,762	313,113
Electricity required to produce hydrogen (MWh)				493,647
% of "excess" or export electricity generated by SBCR				81%

Table 31: Hydrogen contribution to heat delivery and electricity to generate

The 2035 energy system vision does not define the method of hydrogen conversion, although one possible low carbon route would be to utilise via electrolysis the renewable electricity generation that would otherwise be exported from the SBCR. If this were the case hydrogen production would require 494 GWh of electricity or about 89% of the electricity that would otherwise be exported.

6.4.3.1 Enabling actions to achieve the 2035 energy system vision

There is a huge amount of work still to be done before hydrogen forms a major part of the UK energy mix. In the meantime, there is an opportunity for Wales and SBCR to support the development of this new technology by for example:

- Supporting innovation looking at new means of electrolysis and steam methane reforming
- Carbon capture and storage trial and demonstrations
- Demonstrations and trails to increase the blend of hydrogen in the mains gas network
- Studies looking at the potential for hydrogen-based networks in urban areas

6.5 Low carbon heat networks

To be economically viable, DHNs require a high density of heat demand. Therefore, DHNs are typically well suited to urban areas and new build developments.

There have been several pre-feasibility DHN assessments completed on behalf of local authorities in SBCR to assess the viability of a project in their area. We will discuss with the local authorities the outputs of these assessments including the size and fuel sources being considered.

The Committee on Climate Change projection of 40 TWh of low carbon district heat networks by 2030[57], would imply on a proportional basis[58] approximately 450,000 MWh of heat per annum delivered through low carbon DHNs in SBCR, enough to supply 40,000 houses. This would represent 17% of domestic heat demand. A 1,500 home DHN would require around 18,000 MWh of heat, implying approximately 25 such schemes would be required in the region. This figure seems high given at the moment there are no DHN schemes in SBCR, although there are a number of feasibility studies.

The second challenge for low carbon district heating is the fuel supply. Current options include:

- Supply from an energy recovery facility (ERF) – waste and recycled heat
- Heat pumps
- The use of surplus low-carbon electricity generation for heat storage
- Biomass
- Green gas.

It is however the case that a number of current district heat networks across the UK are also using mains gas either as a back-up or as an interim technology before implementing a low carbon solution.

6.5.1 District heat networks in 2035

The phase 1 interim and scoping report contained a scenario assumption that DHN could provide 20% of domestic heat demand. As a result of modelling this assumption has been reduced to 10%, but with the additional assumption that 15% of commercial and industrial heat energy demand could be delivered via DHNs.

[57] Committee on Climate Change https://www.theccc.org.uk/wp-content/uploads/2017/06/2017-Report-to-Parliament-Meeting-Carbon-Budgets-Closing-the-policy-gap.pdf
[58] Based on number of households in SBCR https://statswales.gov.wales/Catalogue/Housing/Households/Estimates/households-by-localauthority-year

District Heat Networks	Percentage properties on a DHN	Biomass	Biogas	Mains Gas DHN	Equivalent properties
Domestic District heat CHP	10%	3%	3%	4%	34,830
Commercial District heat CHP	15%	5%	5%	5%	3,362

Table 32: District heat network modelling assumptions for 2035 energy system vision

Under these scenario assumptions district heat networks would contribute around 11% of the total heat demand within the SBCR. As an estimate heat would need to be delivered to around 38,000 domestic properties and over 3,000 commercial and industrial properties.

District Heat Network(DHN) contribution to 2035 energy system vision				Delivered by:		
	% of Heat Demand	Number of properties	Heat Energy MWh	Biomass MWh	Biomethane MWh	Mains Gas MWh
Domestic	10%	34,830	319,502	95,851	106,501	117,151
Commercial and Industrial	15%	3,362	148,797	49,599	49,599	49,599
Total	**11%**	**38,192**	**468,299**	**145,450**	**156,100**	**166,750**

Table 33: District heat network contribution to the 2035 energy system vision

6.5.1.1 Enabling actions to achieve the 2035 Energy system vision

The 2035 energy system vision to connect over 38,000 properties to district heat networks is extremely ambitious and challenging.

Delivering district heat networks at this rate will require a variety of small and very large scale projects. The Bridgend Town and the Upper Llynfi Valley Heat Network Projects[59] aim to do just that. With targets to transition 11,000 properties to a series of district heat networks, these projects could deliver over 25% of the 2035 energy system vision for district heat networks.

More incentives for new developers to install the infrastructure for DHNs is needed and greater collaboration between the public and private sector. The opportunity to take and reuse heat from commercial and industrial sources should be exploited.

59 https://democratic.bridgend.gov.uk/documents/s8887/160510%20Smart%20System%20and%20Heat%20Programme.pdf

7 Transport revolution

2035 Energy System Vision

Become a leading region for the reduction of vehicle emissions through:

- **the electrification of transport with 80% of new cars and over 30% of all cars EV by 2035**
- **decarbonisation of public transport with 100% Ultra Low Emission Vehicles 2035**

The 2035 energy system vision analysis has looked briefly at the area of transport. Using Regen's transport model, assumptions have been made around the growth of Ultra Low Emission Vehicles (ULEVs) and Electric Vehicles (EVs) to achieve the objectives set out in the energy system vision.

An estimate of the electricity required to provide energy to EVs has been included in the overall energy system model. Estimates of the biofuel, biogas and hydrogen that would be required to provide energy for other forms of ULEVs has not been included in the energy system model. More work would be needed to produce a full transport system energy model for the SBCR. Note the scope of the study did not include rail, aviation and marine transport.

7.1.1 Baseline transport figures for SBCR

Table 34 shows road transport energy demand by local authority, for 2015. The total carbon footprint is estimated at 1.1m Mt CO_2e.

Local Authority	Road transport petroleum demand (GWh)
Carmarthenshire	1,502
Neath Port Talbot	1,013
Pembrokeshire	794
Swansea	1,306

Table 34: Petroleum demand from transport by local authority (2015)[60]

Table 35 shows the baseline figures for different vehicle and fuel types in SBCR, and the historic growth trend of different vehicle types in Wales 1996-2016. These will form the baseline of vehicle growth statistics for both petrol and electric fuel type vehicles.

Vehicle Data from DfT	Car	LGV	HGV	Buses
Total vehicles (SBCR 2016)[61]	356,958	52,172	54,56	2,265
Historic growth rate (Wales 1990-2016)[62]	1.02	1.02	1.05	0.99
Electric vehicles (SBCR 2016)[63]	594	123	0	0

Table 35: DfT figures on the existing number of vehicles and historic growth rates in SBCR

[60] BEIS https://www.gov.uk/government/collections/total-final-energy-consumption-at-sub-national-level
[61] DfT https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01
[62] DfT https://www.gov.uk/government/statistical-data-sets/tra01-traffic-by-road-class-and-region-miles
[63] DfT https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01

7.2 Energy system vision for transport

7.2.1 Electric cars

The growth of Ultra Low Emission Vehicles (ULEV) is projected to increase to such a level that 60% of new cars are ULEV by 2030 and 80% of new cars are ULEV by 2035. Of the ULEV sold the vast majority (95-98%) are assumed to be electric. By 2035, there are 110,000 electric cars in circulation within the SBCR making up around 34% of the car population.

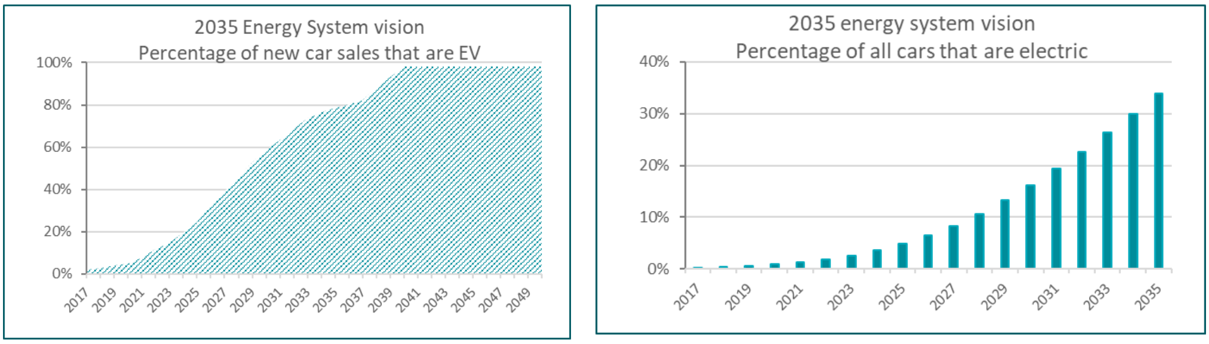


Figure 39: 2035 energy system vision growth of electric cars in SBCR

7.2.2 Light goods vehicles (LGVs)

The rate of LGV conversion to become ULEV is assumed to be slower than for cars with a lower proportion of electric vehicles and more bioenergy and hydrogen alternatives. 54% of new LGVs are ULEV by 2030 and 72% of new LGV are ULEV by 2035. Of the ULEV sold 70%, increasing to 90%, are assumed to be electric. By 2035 there are 19,000 electric LGVs in circulation within the SBCR making up around 30% of the LGV population.

Figure 40: 2035 energy system vision growth of electric LGVs in SBCR

7.2.3 Buses and public transport (excluding trains, planes and marine)

It is a key objective of the 2035 energy system vision that all buses and other forms of public road transport is converted to become ULEV by 2035.

Of the ULEVs buses deployed, 50% are assumed to be electric while the remainder are hydrogen or bioenergy. By 2035 there are just under 1,500 electric buses in circulation within the SBCR making up around 50% of the bus/public transport vehicle population.

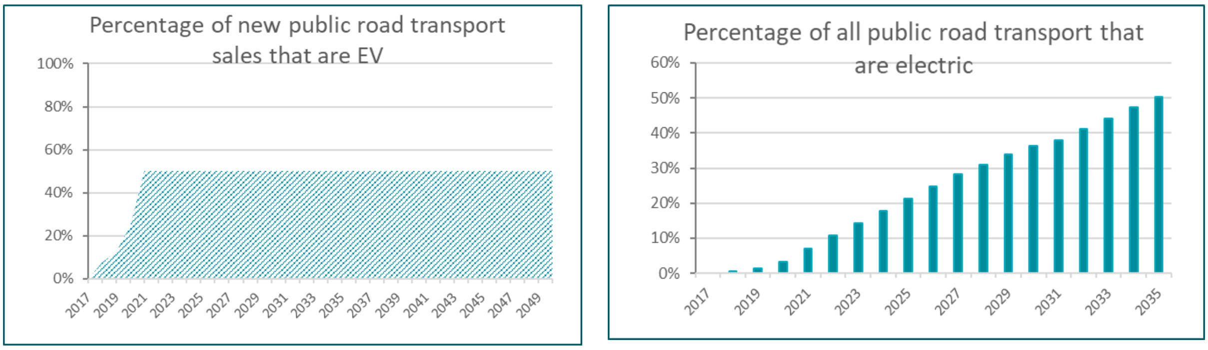


Figure 41: 2035 energy system vision growth of electric public transport/buses in SBCR

7.2.4 Heavy goods vehicles (HGVs)

The rate of HGV conversion to become ULEV is lower with less electric, more bioenergy and hydrogen alternatives. 15% of new HGVs are ULEV by 2030 rising to 30% of new HGVs by 2035. Of the ULEVs HGVs sold most are non-electric and only 9% are electric by 2035. By 2035 there are less than 500 electric HGVs in circulation within the SBCR making up around 6% of the HGVs in circulation.

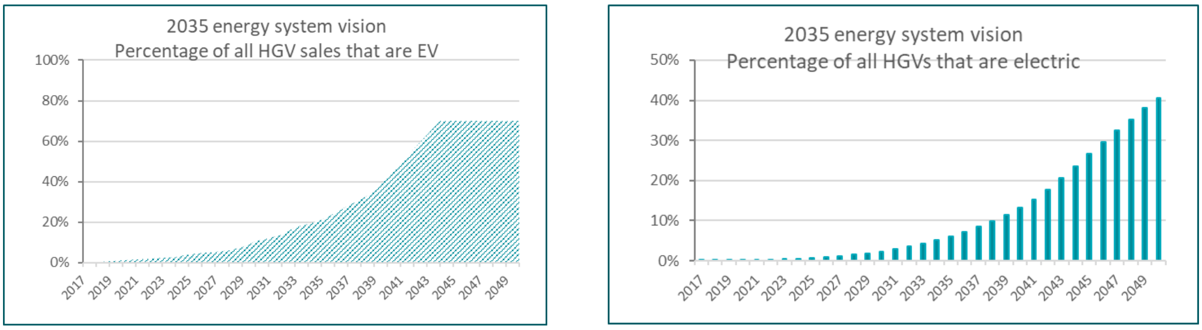


Figure 42: 2035 energy system vision growth of electric HGVs in SBCR

7.2.5 Electricity required and carbon savings

In total over 131,000 electric vehicles are projected to be in circulation in 2035. For the purpose of analysis all EVs are assumed to be pure EVs by 2035, plug in hybrids are not included.

The total electricity required is calculated at 399 TWh per year.

The Committee on Climate Change has projected that total transport emissions need to fall by 44% by 2030 to meet the 5th Carbon Budget[64].

The total carbon saving from EVs is calculated at 324,000 Mt CO_2e, which equates to 30% of the current SBCR CO_2 emissions from road transport. This is less than the 44% needed but does not include additional savings from non-electric ULEVs, such as biofuel and hydrogen, and anticipated fuel efficiency saving from fossil fuel fleets.

Note: this analysis does not include the relative carbon footprint of electric versus diesel or petrol car production. Electric vehicle manufacturing currently has a higher carbon footprint than diesel and petrol vehicles, mainly due to the manufacture of the battery.

[64] CCC https://www.theccc.org.uk/publication/2017-report-to-parliament-meeting-carbon-budgets-closing-the-policy-gap/ Chapter 5 transport

2035 Energy System Vision EV electricity demand and carbon saving					
	Cars	LGV	HGV	Buses	Total
Vehicles	110274	19673	442	1487	131,877
Miles Per Vehicle	8369	14565	32389	44150	
Vehicle Miles	922,897,988	286,539,766	14,330,901	65,669,708	1,289,438,363
Miles per kWh	4.00	2.50	1.50	1.50	
Electricity kWh	230,724,497	114,615,906	9,553,934	43,779,805	398,856,143
Electricity gCO_2e/kWh	46.4	46.4	46.4	46.4	
EV kg CO_2e	10,705,617	5,318,178	443,303	2,031,383	18,498,480
EV MT CO_2e	10,705.62	5,318.18	443.30	2,031.38	18,498
Fossil gCO2/mile*	225	240	850	825	
Fossil kg CO_2e	207,652,047	68,769,544	12,181,266	54,177,509	342,780,366
Fossil Mt CO_2e	207,652	68,770	12,181	54,178	342,780
Carbon saving KG CO_2e	196,946,431	63,451,366	11,737,964	52,146,126	324,281,886
Carbon saving Mt CO_2e	196,946	63,451	11,738	52,146	324,282
***Adapted from BEIS/TFL data 2009 with slight improvement for enhanced performance**					

Table 36: EV electricity and carbon savings in 2035 energy system vision

7.2.6 Electricity demand profiles

Within the energy system vision energy model EV electricity demand has been profiled using four demand profiles:

- Cars with and without a time of use tariff[65]
- LGV and buses – whose charging is weighted to home/depot charging (Regen)
- HGV – whose charging is weighted to overnight charging (Regen)

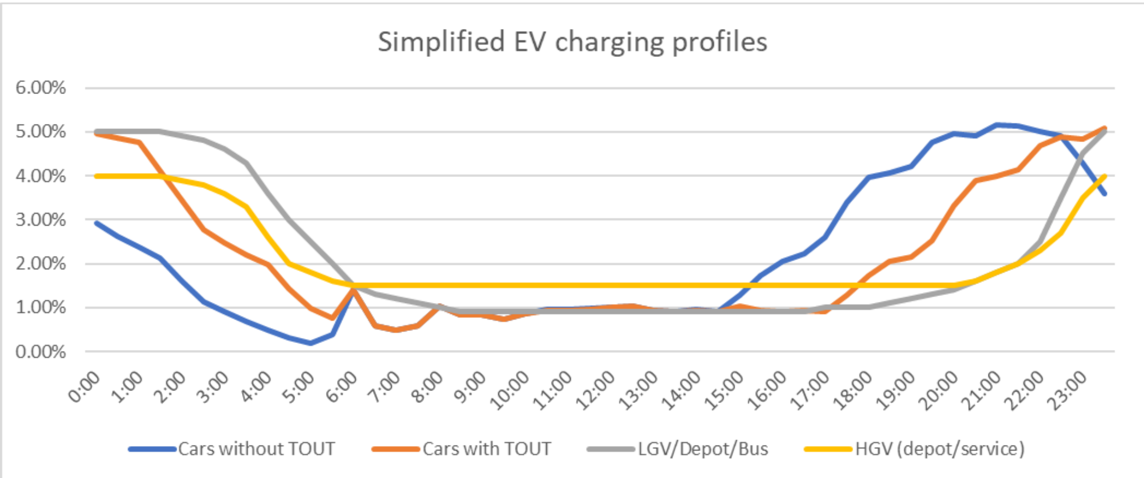


Figure 43: Vehicle charging profiles for demand modelling - before flexibility demand side response

[65] Adapted from National GRID FES 2017

7.2.6.1 Enabling actions to achieve the 2035 Energy system vision

Wales has seen a lower than average uptake of electric vehicles. This is not yet a problem as the whole EV market is starting from a very low base. Of more concern is the deployment of EV charging points[66], which appears to be lower in Wales compared to the rest of the UK.

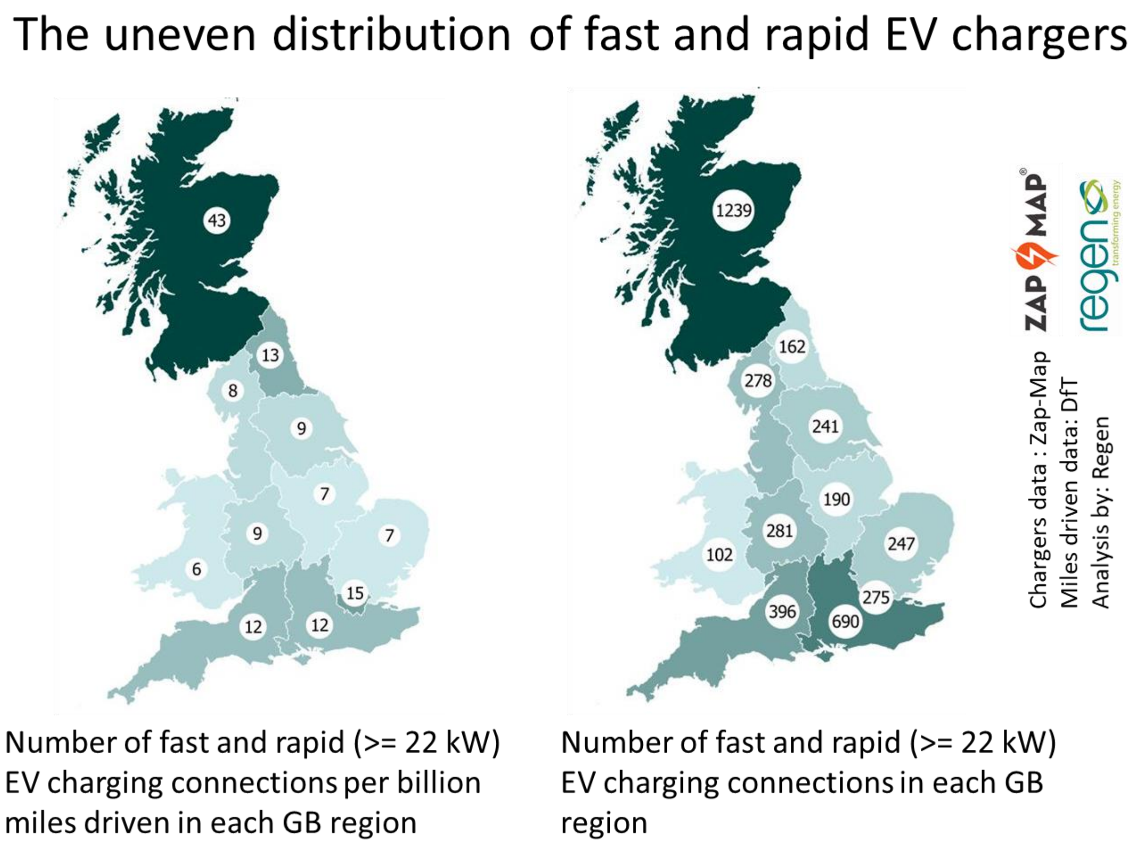


Figure 44: Distribution of fast and rapid EV charging points - source Zap-Map data/Regen analysis

A key enabling action therefore would be to increase the deployment of EV charging points especially at major transport nodes, city park and ride locations, destination sites, main routes and in rural areas which attract tourists.

Further actions might include:

- Encouraging the designation of low emission zones within Welsh cities, to encourage use of public transport and a switch to low emission vehicles
- Policy targets to shift all publicly owned vehicles, including buses, to become ultra-low emission by the early 2020s
- A concerted drive to increase use of urban and rural public transport.

[66] As measures by chargers per vehicle mile driven – source Zap-Map and Regen analysis.

7.2.7 Additional transport data sources

Source Usage	Source
Regional vehicle numbers, trends and usage statistics	Government Department for Transport statistics[67]
Welsh public transport	Welsh Government statistics[68]
Projections of uptake rate	National Grid Future Energy Scenarios[69]
	Committee on Climate Change policy reports[70]

Further reading on electric vehicles and low carbon transport
Regen has now published a new paper exploring the impact and opportunities presented by the electric vehicle revolution. See **Harnessing the Electric Vehicle Revolution** (April 2018)

Table 37: Summary of the main data sources which will be used to create the 2035 projections

[67] DfT https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01
[68] Welsh Government http://gov.wales/statistics-and-research/public-service-vehicles/?lang=en
[69] National Grid http://fes.nationalgrid.com/media/1253/final-fes-2017-updated-interactive-pdf-44-amended.pdf
[70]Committee on Climate Change https://www.theccc.org.uk/publications/

8 Smart and flexible energy and system balancing

2035 Energy System Vision

Maximise use of regional energy resources and limit imports (and exports) of electricity to less than 15% of consumption.

Use smart and flexible energy solutions to increase energy efficiency, reduce consumer bills and enable greater local ownership and control of energy.

Manage peak imports in order to demonstrate the energy system robustness – no import limit objective has been set, although for modelling purposes an imagined limit of 450 MW (just under half of peak demand) was used.

8.1 A smart and flexible energy system

The security and cost effectiveness of future low carbon energy systems is predicated on development of new technology and new business models that will provide increased levels of flexibility. This flexibility will enable best use of variable energy resources, harnessing energy to the maximum extent possible when the sun shines and the wind blows, and to allow system operators to balance the energy system to ensure security of supply at a national and local constraint level. The addition of "smart" technology and business models to the paradigm will also enable the future energy system to be consumer led allowing them to take advantage of lower energy costs[71].

Investment in infrastructure including backup generation will still be needed, but the older paradigm, of simply building more redundant capacity within the system, would be impractical and hugely expensive, potentially costing an additional £8 billion a year by 2030 according to studies by the National Infrastructure Commission[72].

"Innovations will help us deliver greater flexibility – interconnection, storage, and demand flexibility – which have the potential to displace part of the need for new generating capacity, save money for businesses and domestic consumers and help the UK meet its climate reduction targets. The saving could be as large as £8 billion a year by 2030."
Lord Andrew Adonis, Chair, The National Infrastructure Commission

The UK government has also recognised the necessity of developing a smart and flexible[73] energy system and the commercial opportunities that innovation will bring. Smart flexibility is now a cornerstone of the government Clean Growth Plan, Emissions reduction plan and Industrial strategy[74].

"A system that allows disruptive innovation…New business models could challenge incumbents… Where these could bring overall benefits to consumers, we should allow them to do so"
UK Government : A smart, flexible energy system 2016

[71] Regen – Energy Storage Towards a Commercial Model (2016) and Energy Storage:The Next Wave (2017)
[72] National Infrastructure Commission : Smart Power
[73] UK Government Call for evidence "A Smart, Flexible Energy System" November 2016
[74] UK Government : Clean Growth Plan 2017 and Industrial Strategy 2017

UK Policy Landscape

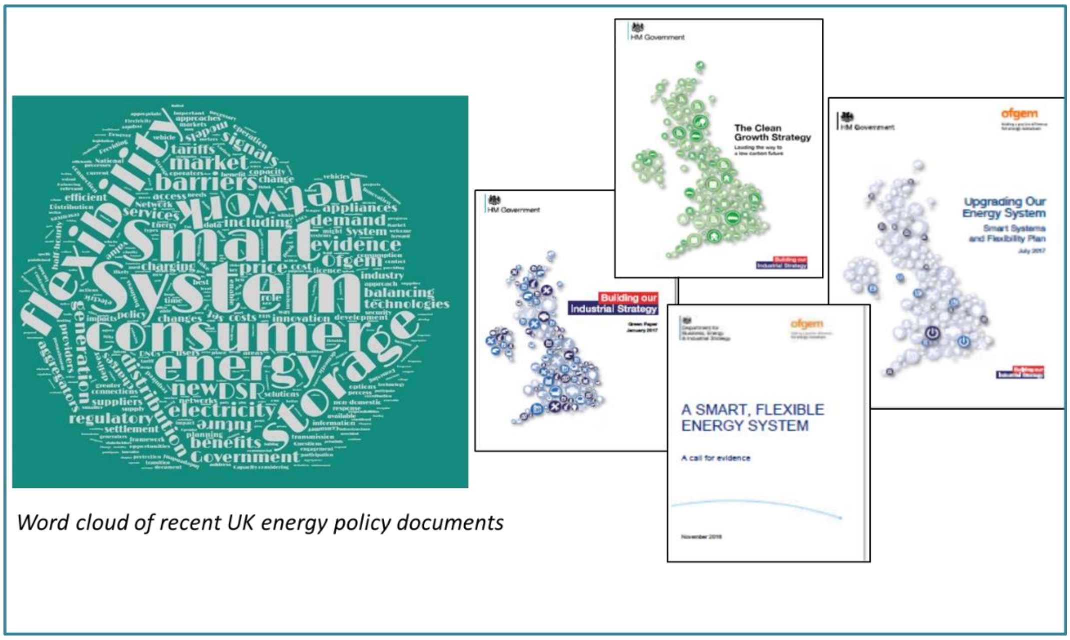


Figure 45: Smart and flexible (and consumer) have become the buzzwords of UK energy policy

Already a number of new technologies and business models are beginning to emerge including energy storage, with a market potential that has grown significantly on the back of falling battery costs, and a variety of local supply models[75] including local energy clubs[76], local generation tariffs and private wire systems.

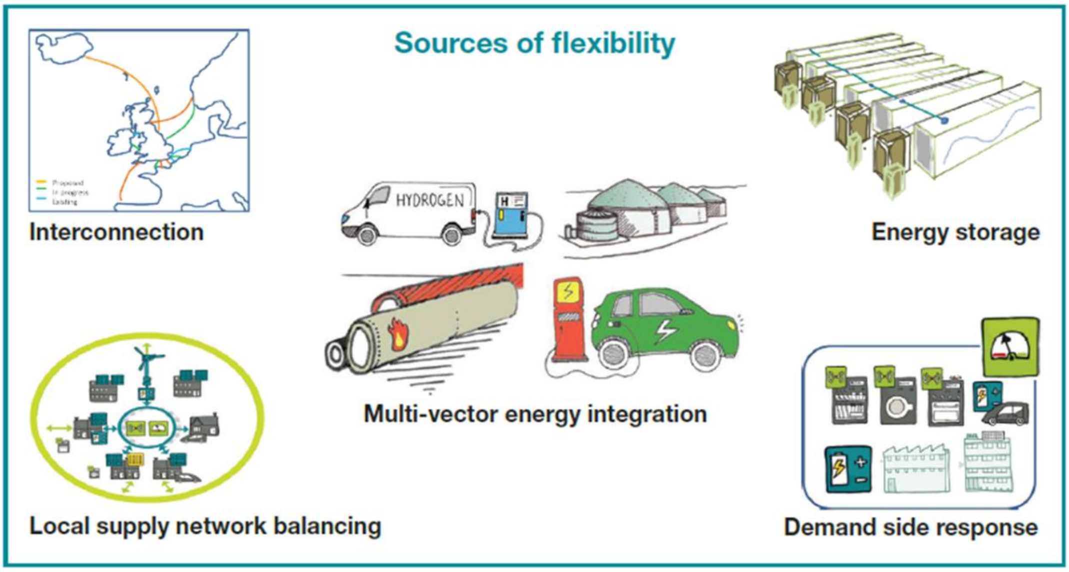


Figure 46: Future sources of flexibility

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[75] Regen – Local Supply Models 3rd edition
https://www.regensw.co.uk/Handlers/Download.ashx?IDMF=a2053ab5-f5c3-4ed9-a413-2f9861ba1a27
[76] For example Bethesda Energy Club in North Wales see http://www.energylocal.co.uk/

The bedrock of new flexibility services will be new information technology platforms and data exchange linked to smart technology and appliances. For example, the roll-out of smart meters (and smart chargers for electric vehicles), which will enable half-hourly settlement and potentially half-hourly billing. Another good example of smart technology are the trials to install data gathering and exchange technology at local low voltage sub-stations such as the Open LV project[77].

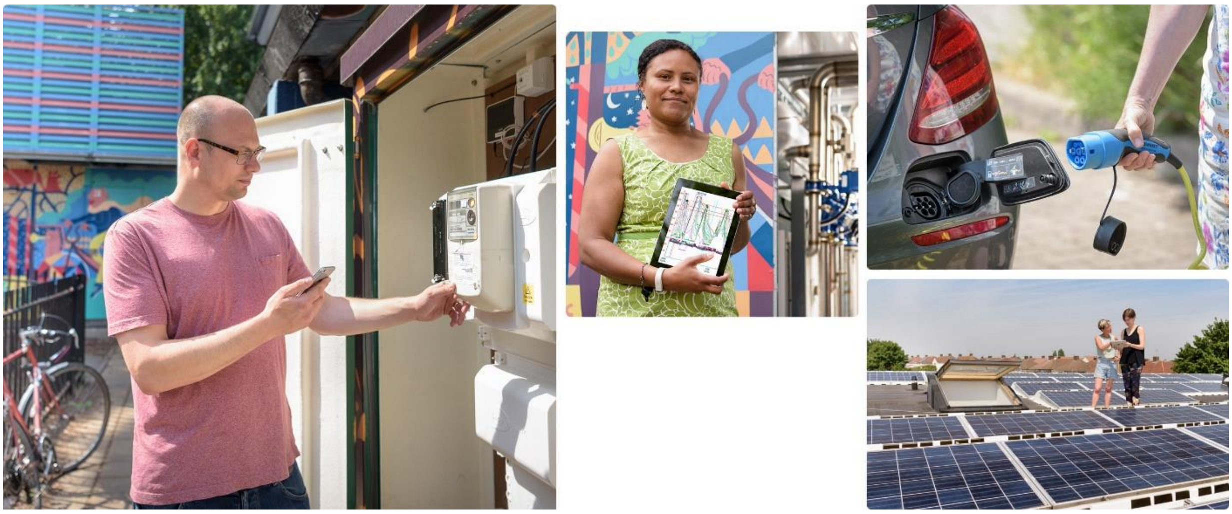

Figure 47: Open LV project will enable community groups to access energy data from local substations: Image Open LV

In the future it is anticipated that new innovation and new market models will greatly increase the level of smart flexibility available within the energy system. For example:

- Digital and blockchain innovation that will enable peer-to-peer trading and new local supply markets
- The transition to Distribution System Operator that will enable network operators to procure or facilitate new markets to supply flexibility
- Smart electric vehicle charging solutions including optimised and managed charging and Vehicle to Grid (V2G) or Vehicle to Consumer (V2G) models
- Aggregation and flexibility trading platforms that will enable communities and businesses to trade energy flexibility services and demand side response (DSR) capability
- Multi-vector flexibility, including the transfer and conversion of energy between different end uses for power to heat and to transport, such as hydrogen conversion.

[77] Open LV project – WPD, EA Technology, CSE Regen, Lucy and Nortech

8.2 Energy system Vision 2035

While it is difficult to predict the extent of the smart energy revolution it is right that the 2035 energy system vision for SBCR includes a significant amount of flexibility within the overall energy system vision.

Flexibility could come from many sources but within the constraints of the modelling for the energy system vision the main sources that have been modelled include: Time of Use Tariffs (ToUTs); energy storage; the impact of hybrid heat pumps and controllable generation; plus the use of flexibility in the form of both optimised and managed smart energy solutions.

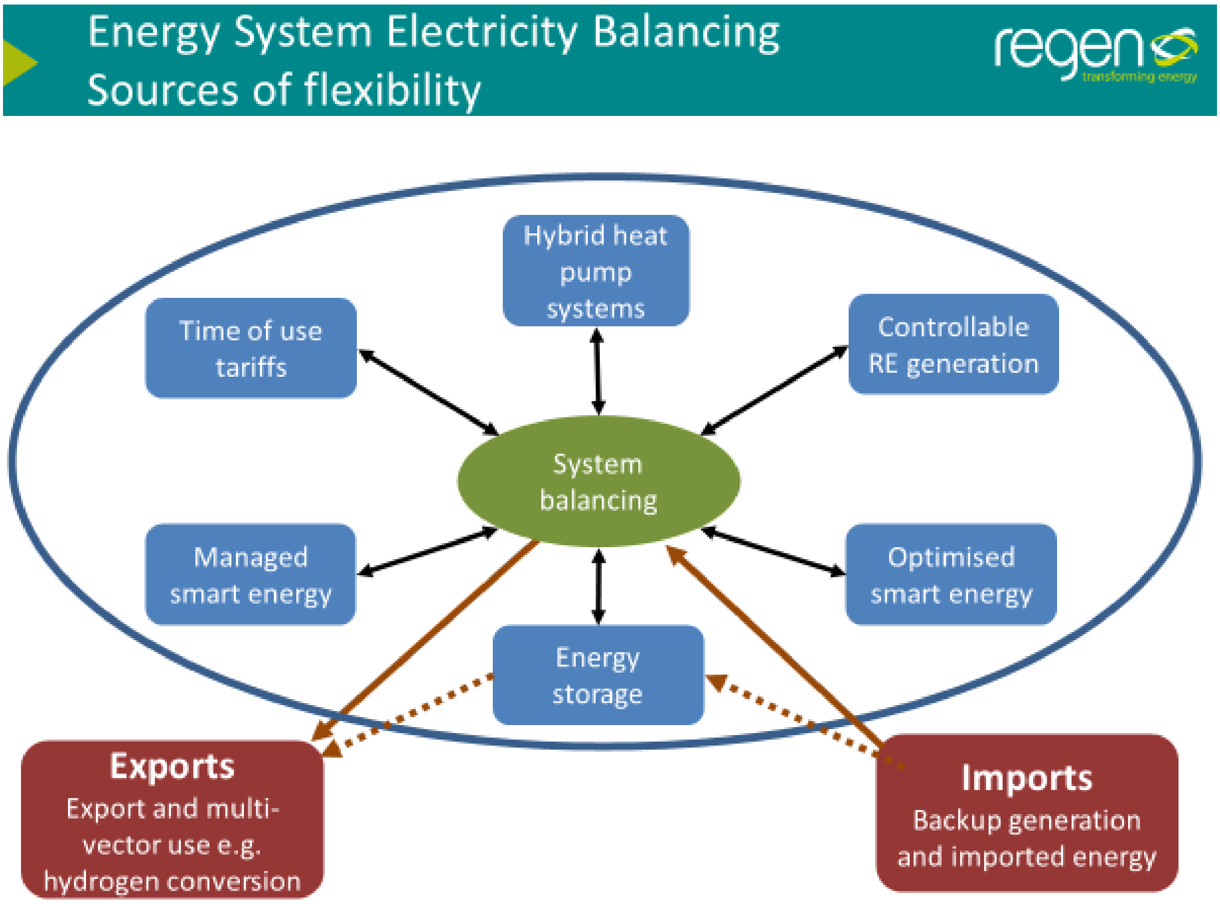

Figure 48: Sources of flexibility used for 2035 energy system vision modelling

Source of flexibility	Notes on usage and constraints	Variables and targets used in modelling
Time of use tariffs	Time of use tariffs, linked to smart meters and half-hourly billing, that will encourage energy use during off-peak periods. The impact is a reduction in peak demand, but ToUTs are **not** dynamic.	Up to **10% of peak time demand** can be shifted to off-peak day and overnight
Hybrid heat pump systems	Hybrid heat pump systems with a backup heat source. Switch to backup determined by heat pump performance and also the "cost" of electricity modelled by whether balance is long or short.	**45%** of HP systems hybrid, **30%** of hybrid heat delivered by backup source
Controllable RE generation	Controllable energy generation (CHP plants inc. biomass, AD, energy from waste) whose commercial operation tracks the market price and will target peak imbalance periods.	**58 MW of RE capacity**, weighted towards peak short imbalance periods
Energy storage	Energy storage assets with a primary operation to target price arbitrage – charge when system is long and discharge when system is short - weighted towards peak imbalance periods.	**350 MW** power **1585 MWh** capacity 10% minimum capacity
Optimised smart energy	Smart energy optimised based on price and value. Smart meters and appliances linked to dynamic price tariffs. Smart EV charging. Local supply balancing such as energy clubs, local generation tariffs and community schemes.	**Up to 10% of demand and 12% of EV** demand is "smart" flexible
Managed smart energy	Energy that is in some way managed or under contract and can be called upon to reduce or increase demand during peak imbalance periods. E.g., DSO and TSO dispatched DSR, local flexibility markets, DSO constraint managed, managed or cycled EV charging	**Up to 6% of demand** and **8% of EV demand**. But only used during peak imbalance
Imports Backup generation and imported	In order to test and demonstrate the role of flexibility within the system an <u>example 450 MW</u> capacity limit on energy imports (or backup peaking plant) has been assumed. In reality, with capacity of over 3 GW, SBCR is not import limited at the transmission network level. Within SBCR there are currently a number of CCGT and peaking gas generating plants, so in fact, while those plants remain in operation, there would be no need to limit "import" or backup electricity. No targets set but amount of biomethane and hydrogen has been cross checked against available bio energy feedstock and excess electricity respectively.	Target of **less than 15%** of electricity consumption may be imported or sourced from peaking (gas) plant An **<u>example limit of 450 MW</u>** peak import or backup capacity Biomethane balanced with feedstock estimate.
Exports and multi-vector use	Overall objective is to limit electricity exports however this is less critical since, in the future, it is assumed that electricity could be used for the production of hydrogen or other multi-vector use such as supply of heat in district heat networks.	Target **less than 15%** of renewable electricity generated.

Table 38 Sources of flexibility

8.3 Analysis and comments on sources and use of flexibility

8.3.1 Short and long imbalance periods

Within the balancing model (see section 9), the balance of electricity within each settlement period is analysed as "Short" or "Long" depending on whether the electricity supply demand balance is short of electricity or has excess electricity. Short 1 is the lowest percentile when electricity is just short of balance while Short 10 is the highest percentile when electricity is significantly short of balance and has exceeded, or is in danger of exceeding, the import limit of 450 MW. In reverse Long 10 is the highest imbalance percentile for excess electricity generation.

8.3.2 Time of use Tariffs

By 2035, smart metering and half-hourly settlement will enable the widespread use of ToUTs. These are time-based tariffs with peak and off-peak pricing periods. Conceptually very similar to Economy-7 but in the future these will be more targeted and precise. Consumer behaviour is also likely to be more sensitive to tariff changes through the use of smart meter technology and apps.

Static ToUTs, not linked to dynamic pricing, are not in themselves "smart" in the sense that they do not respond to real-time changes in the energy supply balance and energy prices. Dynamic price tariffs linked to smart technology is discussed under the heading of optimised flexibility.

The impact of ToUTs is to shift demand from peak demand periods. In the model it has been assumed that up to 10% of demand can be shifted from peak to off-peak periods with some seasonal variation. The impact of this shift is helpful in reducing peak demand but the shift does not respond to energy imbalance and is not therefore targeted at the most extreme short or long periods.

8.3.3 Controllable generation

Most renewable energy is generated from variable resources (wind, solar and tidal etc) and therefore, although it can be forecasted it is not controllable without a source of energy storage. Some renewable energy, such as biomass and biomethane AD plants (including CHP plants), can however be controlled and would therefore be expected to respond strongly to peak energy price signals during periods of short imbalance.

By changing the operation of sluice gates and turbines, energy from tidal lagoons could, within certain parameters, also be controllable. At La Rance, in France, barrage operations do respond to changes in price signals and can delay or bring forward peak generation periods by an hour or two. However there is an energy yield loss incurred in moving away from an optimised mode of operation and therefore the price signals have to be quite strong, and coincide with the tidal cycle, in order for this to be viable. Tidal lagoon flexibility and storage has not been modelled but could be considered as an additional source of flexibility provided the lagoon operators are incentivised to provide flexibility. As a policy recommendation it has been proposed that lagoon subsidy payments should include a degree of market price sensitivity[78].

[78] Regen response to Hendry review

8.3.4 The role of electricity storage[79]

As a source of flexibility and security, energy storage is expected to become one of the key enabling technologies to help to revolutionise the way we use and manage our energy systems in the future.

Energy storage is not a new concept; stockpiles of fossil fuels, pumped hydro, flywheels, stored heat and even the humble hot water tank have been at the heart of our energy system for years. Energy storage is in fact all around us: in our computers, phones, cars, hand tools, vacuum cleaners and a host of other applications.

The reason there is so much focus on energy storage now is that the anticipated fall in costs for storage technologies, combined with the use of ICT platforms to integrate, aggregate and manage storage assets, has opened the possibility for much smarter storage solutions and new business models to harness its potential.

The 2035 energy system vision includes storage assets able to provide 350 MW of energy power charge or discharge and over 1,500 MWh of storage capacity. The energy vision does not specify the type of storage technology but it is likely to come from a variety of sources including:

- Commercial scale battery storage projects typically 1-100 MW
- Small scale domestic and community storage
- Larger scale reserve storage such as pumped hydro and in the future compressed air
- Commercial and industrial energy storage used by high energy users and critical industries

A key assumption is that the underlying business model (and therefore operating mode) of most energy storage is assumed to be sensitive to price volatility and opportunities for price arbitrage. It is therefore assumed that storage operation will target energy supply imbalances, charging when the energy system in "Long" and discharging when it is "Short"[80].

Within the balancing model storage is therefore highly sensitive to system balance and weighted towards extreme imbalance periods. It is constrained however by the available balance.

350 MW (and 1500 MWh) of electricity energy storage, within an energy system with peak electricity demand of 940 MW, represents a significant amount of energy storage. If this were extrapolated to the GB energy system it would equate to around 18 GW of storage which is greater than the 10-12 GW[81] that is currently forecast as a high growth scenario. Care should be taken however as the SBCR energy system has a different overall mix to that of the GB system including the absence of nuclear, less hydro and very little biomass used for electricity generation. Storage has also been preferred over other options such as greater interconnection capacity (enabling flexible imports). So GB extrapolation is not straight forward.

The ratio of storage capacity MWh to MW is also greater than is currently seen in the market although increases in capacity ratio are predicted as storage costs fall and, price arbitrage and flexibility services (as opposed to grid ancillary services) become more profitable.

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[79] For more detail see Regen Energy Storage Towards a Commercial Model https://www.regensw.co.uk/Handlers/Download.ashx?IDMF=c85b8d3d-9fa8-4f8e-a26e-17b124930a9b and Energy Storage : The Next Wave. https://www.regensw.co.uk/Handlers/Download.ashx?IDMF=9d010979-7cc4-4515-b900-a65a4a4765b7

[80] The model uses a simplified version of the Energy Storage Operating Mode analysis and model Regen produced for WPD see https://www.westernpower.co.uk/docs/About-us/Our-business/Our-network/Strategic-network-investment/WPD-Storage-Consultation-Paper-Results-(11082017-F.aspx

[81] Regen Energy Storage The Next Wave page 9.

8.3.5 Optimised smart energy

Optimised smart energy incorporates a very wide variety of potential smart and flexible energy solutions which "optimise" energy usage, in response to price or other market signals, in order to create additional value for the energy customer. A key point here is that energy optimisation will, for the most part, either be invisible to the customer or will be at the customers behest in order to harness value, reduce cost or increase energy efficiency.

This is the biggest and most exciting area for innovation and commercial opportunities, this includes:

- Dynamic price tariffs linked to smart meters and smart appliances
- Local energy supply models such as local energy clubs and local generation tariffs
- Digital platforms that will enable peer-to-peer and microgrid applications
- Energy trading and flexibility platforms which will allow energy customers to sell flexibility services
- Electric vehicle smart charging, vehicle to grid and vehicle to consumer models

"Optimised" demand flexibility is driven by dynamic price and value signals within the energy market. Price and value signals could include:

- Dynamic energy price signals responding to retail, wholesale or system (spot) price movements
- Network and grid cost differences – distribution and transmission price signals
- Flexibility service price and dispatch signals
- Local energy supply signals
- Other signals from new business models not yet identified

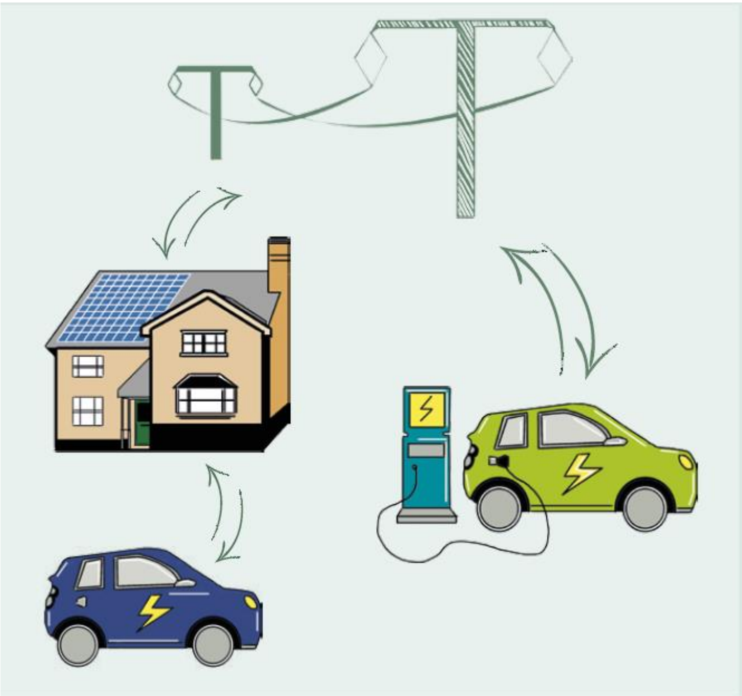

Figure 49: V2G and V2C - two examples of optimised smart energy to capture additional consumer value

It is difficult to assess the extent to which consumer demand will be sensitive to dynamic price movements. It is plausible to imagine a scenario when most domestic consumers and nearly all businesses are smart energy enabled (with a smart meter and some form of dynamic tariff) however, it is also the case that a lot of demand is not elastic and cannot easily be shifted. Electric vehicle charging, electric heating (to an extent) and larger business processes (including ICT process) may be relatively price elastic. For modelling purposes it is assumed that up to 10% of electricity demand and 12% of EV charging demand is price elastic and can be shifted from an imbalanced period. Note however that the availability of optimised demand reduces as the “demand deficit” increases .

8.3.6 Managed smart energy

In reality there is a grey area between “optimised” smart energy and “managed” smart energy, but for the purpose of modelling, and to differentiate between different modes of operation, the term managed smart energy refers to demand which is managed under a Demand Side Response (DSR) or another form of managed contract. Examples of managed demand would include DSR contracts entered into by larger energy users, or aggregators on behalf of a number of customers. Another example would be managed EV charging, e.g. use of charge cycling[82], under the control of distribution system operators.

Under these models, electricity demand is explicitly managed by a network or transmission operator or a third party agent/aggregator, in order to achieve system balancing and to overcome network constraints. It is assumed that customer that enter into such contracts would still receive value, through availability payments, for the flexibility service that they are providing.

Within the energy model managed demand flexibility is only utilised during peak short periods when the import or peaking plant limit of 450 MW would be exceeded.

8.3.7 Reduction in the availability of optimised and managed demand flexibility

The balancing model simulates a limitation on the availability of both optimised and managed demand flexibility. This recognises that it is not possible to repeatedly turn demand down (or up) over consecutive periods without incurring a penalty from the energy customer.

Within the model, demand that is deferred (or brought forward) must eventually be met*. The “demand deficit” is the quantum of cumulative deferred demand which has not yet been met. If the demand deficit increases the availability of flexibility reduces.

The “demand deficit” has been measured using a metric of equivalent hours of peak demand deferred.

$$\text{Demand Deficit}_{\text{Hours}} = \frac{\sum \text{Demand deferred}_{\text{MWh}}}{\text{Peak demand}_{\text{MW}}}$$

An energy system with a peak demand of 900MW and cumulative deferred demand of 450 MWh would have a demand deficit equivalent to 0.5 hours of peak demand.

82 See for example Electric Nation and Electric Avenue trials

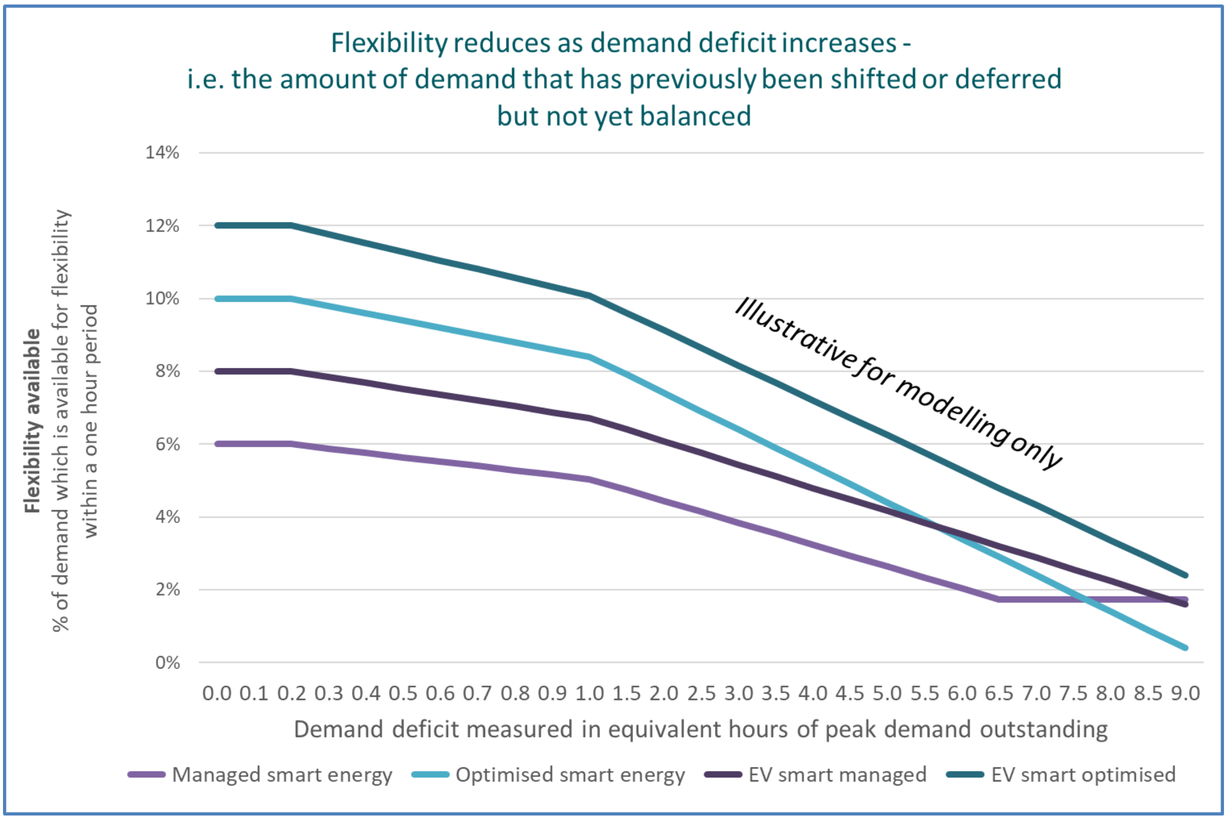

Figure 50: Illustrative relationship between flexibility availability and demand deficit

For modelling purposes the availability of demand flexibility reduces as the demand deficit increase as show in Figure 50. This is illustrative only – further studies are needed to understand exactly how energy customers will respond within a smart energy system and how the availability of demand flexibility may be reduced.

Note:

***The requirement to meet all demand is an artificial constraint within the model. Within the model simulation no demand is shed by being deferred. In reality a portion of demand that is deferred through flexibility would be shed – if a household or commercial consumer turns down demand in response to a price signal, they do not necessarily subsequently turn up demand to the same extent. Exposing consumers to a stronger price time signal (e.g. through half hourly metering) would be expected to increase energy cost awareness and therefore efficiency.**

8.4 Energy balancing model results

Balancing within the energy system model was achieved in a four stage process (see Figure 51). Firstly applying time of use tariffs, then flexibility from hybrid heat pump systems and controllable generation, followed by energy storage and finally optimised and managed demand flexibility.

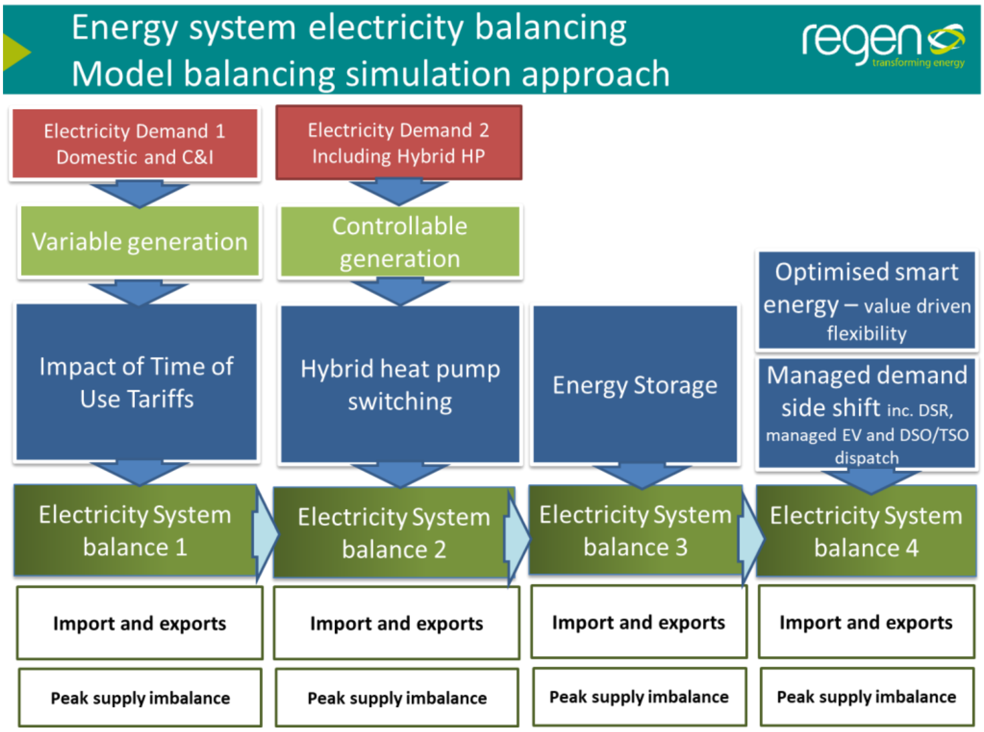

Figure 51: Four stages of system balancing with the energy system model

The summary results of the simulated system balancing are shown in Table 39

Within the limitations (see section 9.2) of the balancing model it was relatively easy to meet the target of less than 15% electricity imported or exported. The addition of energy storage reduced annual electricity imports to 12.6% of annual consumption, while the addition of optimised and managed smart energy flexibility reduced imports further still, to 12.3% of consumption.

Maintaining peak imports within the example limit of 450 MW was also achieved however this required a significant amount of demand side response and incurred a peak “demand deficit” of 0.6 hours. In other words at the peak imbalance period over 36 minutes of peak demand, 531 MWh, has been deferred and would have to be satisfied over subsequent periods.

It does not sound like a lot but 36 minutes of peak demand equivalent is a lot of demand within an energy system. There is a question about how acceptable this would be to the end energy consumer. The modelling does however illustrate the trade-off between the cost-benefit of more demand side flexibility versus maintaining higher level of backup and import capacity.

There were 183 hours of import peaks (> 350 MW) throughout the year, most during winter high demand periods, but a significant number also occurred during spring and autumn during periods of low generation.

Simulated energy system balancing scorecard

		Balance 1	Balance 2	Balance 3	Balance 4
Energy System Balancing Scorecard		Raw demand with time of use tariff (TOUT) demand shift (balanced with variable generation only)	Addition of controlable generation (CHP etc) Heat load shift from hybrid heat pumps backup systems.	Use of energy storage to reduce import and exports and target peak imbalance periods	Impact of flexibility. 1) Optimised flex based on price signals and market 2) Managed flex (DSR) and EV managed during max import periods only
Electricity import and export required - MWh			**776,213**	**624,065**	**606,521**
Imports as % of Demand Consumption		17.5%	15.7%	12.6%	**12.3%**
Export as % of generation (inc losses)		18.1%	14.8%	11.9%	**11.6%**
Peak import of electricity					
Max Import Power required MW		654	631	533	**450**
Max Power as % peak Demand		70%	67%	57%	**48%**
Number Import peaks >350 MW occurrences (1 hour periods) in one year		539	404	302	**183**
Maximum demand "deficit" - flexible demand deferred and not yet met					
Maximum demand deficity in hours		**0.6**	hours of peak demand equivilent		
Maximum demand deficit (MWh)		**531**	MWh of demand "deferred"		
	Peak import	**Import Average**	**Export Average**	**Import Top 10% Percentile avg.**	**Export Top 10% percentile avg.**
Hourly Balance MWh & MW	**450**	**109**	**189**	**277**	**454**
Daily Balance MWh	**8,600**	**1,662**	**1,662**	**4,904**	**5,150**
		Average Winter Import	**Avgerage Summer Export**	**Peak import Month**	**Peak Export Month**
Monthly Balance Analysis MWh		**83,256**	**80,748**	**123,830**	**94,519**
				January	**October**

Table 39 Energy system balancing summary results

Analysis of monthly and seasonal balancing shows that the energy system exported more during summer months and imported more during winter months. However the highest export month was October which, in our example 2035 year, was an exceptionally windy month. The highest import month was January, which combined cold weather and several periods of low wind speed on consecutive days.

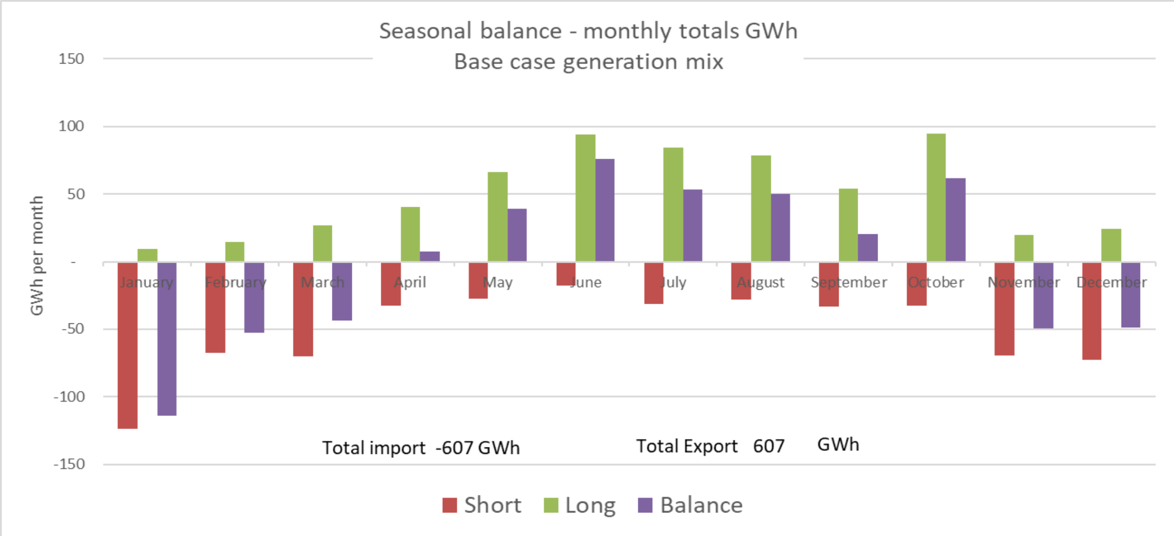

Figure 52: Monthly analysis of import and export balances

Changing the energy mix to increase the proportion of wind, compared to solar, improved the overall system balancing only slightly but did improve monthly and inter-seasonal balancing. See Figure 53: System balance with an alternative energy mix with more wind and less solar.

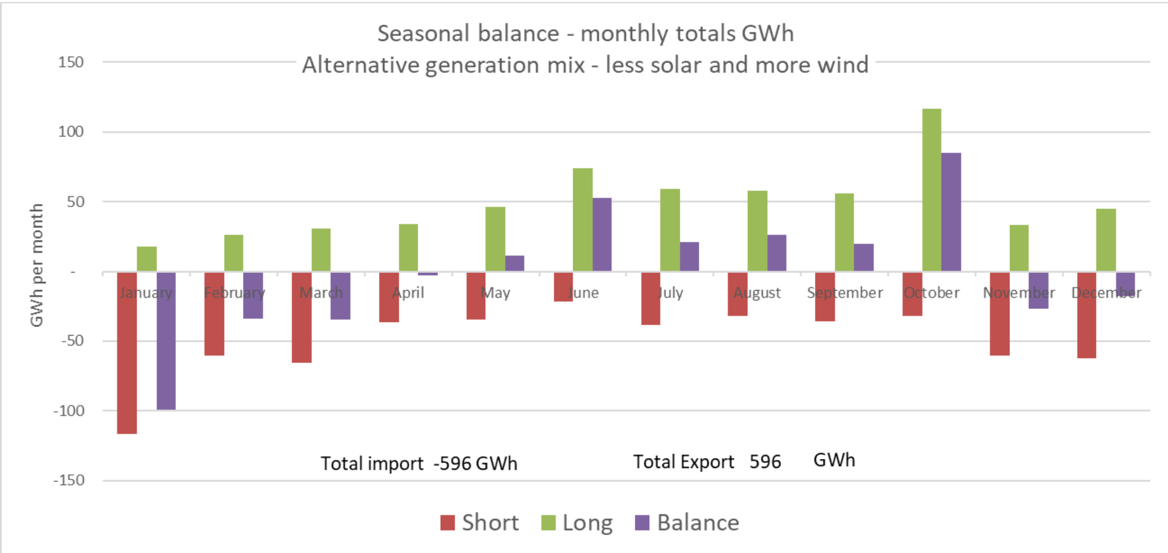

Figure 53: System balance with an alternative energy mix with more wind and less solar

8.4.1 A (bad) day in the life of an energy system (19 January 2035)

The 19 January 2035 is an illustrative example of how cumulative system imbalance can effect an energy system. After two days of low (wind) generation and high demand, energy storage capacity has been expended and a peak demand imbalance of over 530 MW is reached before the impact of optimised and managed demand side response brings the system imbalance back below the example import limit of 450 MW.

Simulated peak imbalance – 19th January 2035

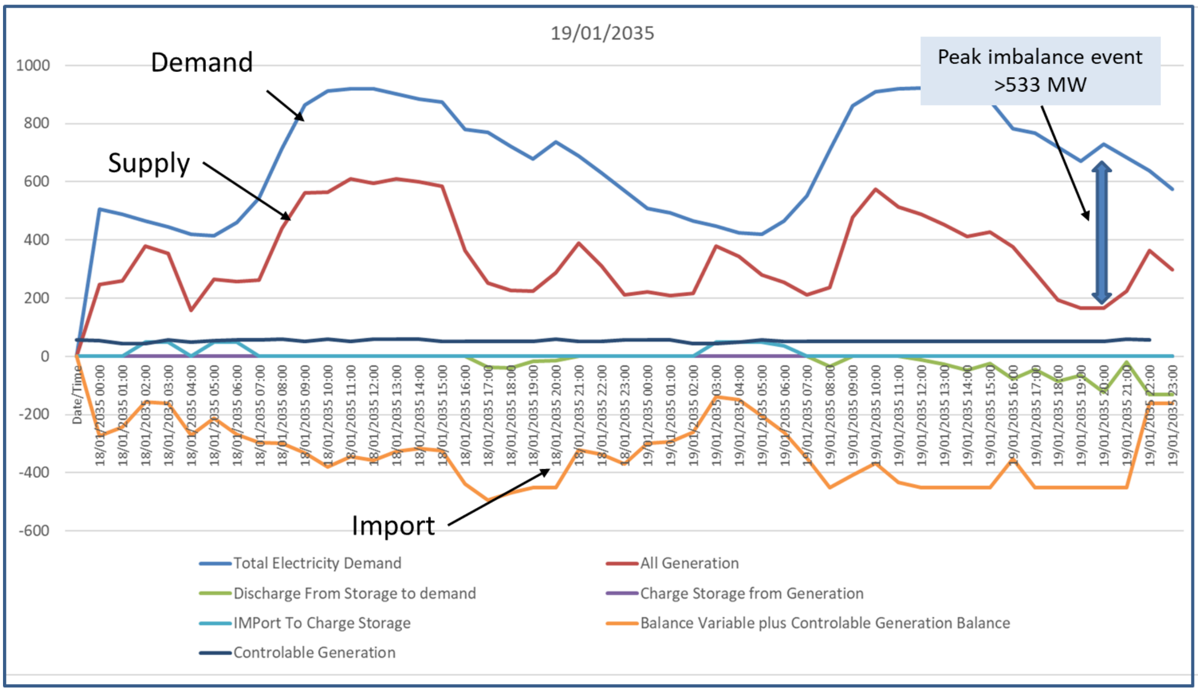

Figure 54 Simulated peak imbalance 19th January 2035

9 Modelling and analysis approach – integrated energy modelling

A key objective of the project has been to look at the holistic energy demand and supply for a city region incorporating electricity, heat and transport. This analysis therefore required an integrated energy model which could be used to analyse how demand for heat and transport would have a direct and indirect impact on the demand for electricity (for example, because of the growth in the use of heat pumps and EV charging).

The modelling also needed to consider not just the overall or aggregate energy flows but also how energy supply and demand would be balanced within daily and hourly time periods (settlement periods : 24 hourly periods over 365 days). The model therefore has a balancing and flexibility function that attempts to balance supply and demand within a number of constraints.

9.1 Integrated energy supply and demand model

As a starting point the project was able to use an adapted version of the Wales & West Utilities Energy Simulator project (the energy Pathfinder simulator) using underlying demand and demographic data from the SBCR. To this core model Regen has added a number of sub-models to model heat demand, transport, storage and flexibility, energy efficiency etc, and to create an overall energy supply balance.

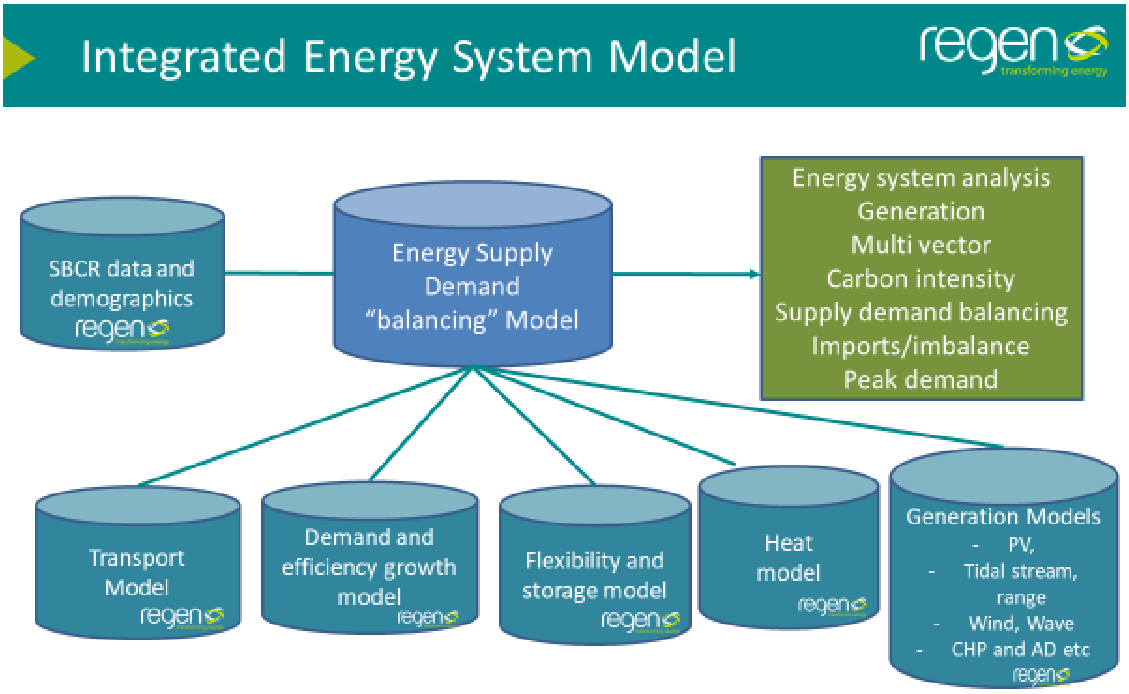

Figure 55: Integrated energy system model and sub-models

Integrated Energy System Model Overview	
System model	Main elements and model functions
SBCR data and demographics	Regional input and demographic data such as households, off and on gas grid properties, commercial and industrial properties, car registrations, EPC banding.
Transport model	Vehicle registrations and growth assumptions. Growth model for new vehicles and existing fleet for ULEV, and within that electric vehicle growth for cars, LGV, HGV and buses. Base charging profiles (before smart charging) for cars, LGV, HGV and buses.
Demand and efficiency growth model	Base demand for electricity, gas and heat for domestic and commercial and industrial consumers based on sub-national data reconciled with WWU gas demand and Cardiff university SBCR demand analysis for buildings. Underlying growth assumptions for new build, population and economic growth within SBCR EPC bandings for SBCR local authorities by building type and relative energy demand. An energy efficiency model to show shift in EPC banding needed to achieve the targeted efficiency savings of 20%. Seasonal and daily (hourly) demand profiles based on WWU heat demand, national demand profiles and Elexon domestic and C&I demand profiles.
Flexibility and storage model	Energy storage based on Regen storage business models and operating modes. Variables of storage power (MW) and the ratio to capacity (MWh) for each storage business model. Assumptions/variables on impact of (static) ToUTs based on % demand shift from peak to off-peak tariff rates. Assumptions/variables on effectiveness of dynamic price tariffs, smart technology, DSR and EV charging management to shift demand from Short to Long imbalance periods.
Heat model	Baseline heat demand for domestic on gas, domestic off gas and commercial and industrial consumers. Variables and assumptions for electrification of heat by property type, on and off gas grid and by heat pump type. COP for heat pumps based on temperature and sizing parameters. Note: model temperatures based on 2015 which had a mild December and a late spring. Variables for decarbonisation of gas using biomethane and hydrogen.

	Variables for deployment of district heat networks (DHNs) – domestic, commercial by fuel type. Hybrid heat pump model with control logic based on COP and system energy imbalance (as a proxy for price of electricity).
Generation models	Generation profiles and capacity factors for renewable energy technologies • Onshore wind – based on annual BMI wind • Offshore wind – based on Elexon/BMI • PV – Regen solar model • Wave energy – Regen wave energy model profile based on wave data for sites off Pembrokeshire • Tidal range – Regen tidal range/lagoon model for Swansea Bay Tidal Lagoon • Tidal stream – Regen tidal stream energy model based on tidal data for Ramsey Sound/St David's Head • Hydro – Regen generated profile • Controllable energy generation – AD, biomass, EfW, biogas, sewage gas - based on national capacity factors and control logic for balancing.
Energy supply/demand balancing	Combining hourly energy demand and supply data with 4 stages of energy system balancing – described in more detail in section 8. System imbalance measured in 20 percentiles, 10 Short and 10 Long system balances.
Energy system analysis reports and outputs	Energy system analysis – demand and generation. Carbon intensity and footprint. Peak demand and peak imbalance analysis including import(backup) and "export" generation. Multi vector – analysis of energy for heat and transport.

Table 40 Integrated Energy System Model

9.2 Modelling balancing and flexibility – an integrated energy model

The main purpose of the energy balancing function within the energy model has been to show the extent to which the profile of energy demand and renewable generation were matched (or mismatched) in order to better understand how a future regional energy system would perform with very high levels of renewable energy.

The balancing function has also been used to explore the role that can be played by energy storage and other forms of "smart" flexibility, and to give a indicative estimate of the quantum of flexibility that would be required within the system.

By its nature the energy system simulation of the balancing function is very basic (compared to the millions of individual transitions and decision points that would make up a true energy systems) and the modelling is therefore indicative and illustrative only.

In order to simulate energy balancing it has been assumed that the Swansea Bay City Region is managed and behaves like an energy system. In reality The SBCR is not an energy system; there is no wholesale market, price setting or system balancing based on the city region geography. There is no system operator managing the energy balance of the city region. The balancing model can therefore only ever be a simulation, that is trying to replicate the operation of an energy market that would in reality be determined by millions of individual transactions based on complex and interactive price signals. In a future world of smart flexibility those transactions and the price/balance signals that will inform them are expected to increase exponentially. As will the sophistication and capability of the tools and technologies that will be used to optimise the energy system (digital, blockchain, telemetry, internet of things, flexibility platforms etc).

Limitations of modelling simulation	
Objective to minimise imports and exports	The SBCR is <u>not treated as an energy island</u>, but it is imagined that an objective of the system optimisation is to minimise energy imports (or use of backup fossil generation) in order to maximise use of local renewable energy generation. In a real integrated energy system, energy flows would be a function of energy prices and the merit order of marginal costs (which could well favour local renewable energy).
An import or backup limit has been assumed	In order to test and demonstrate the role of flexibility within the system an example 450 MW capacity limit on energy imports (or backup peaking plant) has been assumed. In reality SBCR is not import limited at the transmission network level. Within SBCR there are currently a number of CCGT and peaking gas generating plants, so in fact, while those plants remain in operation, there would be no need to limit "import" or backup electricity.
Energy mix is specific to the 2035 energy system vision and the resources within the SBCR	There is a good energy mix in the SBCR, but it is not as diversified as the Welsh or GB energy system. There is no nuclear (and no plans to build nuclear plant within the timeframe) and very limited hydro. The use of biomass used for electricity generation is limited. The proportion of solar energy in the base case is higher (reflecting SBCR resource) than it would be in a future Welsh or GB energy system. Extrapolation of SBCR outcomes (such as the amount of energy storage, import capacity or flexibility required) to the rest of Wales or to GB should therefore be made with care.
Balancing but not operability	The energy model has been designed to look at energy system balancing – the supply and demand balance of electricity – but not system operability. For example, it is assumed that import and backup generation is entirely flexible and can be brought on line instantaneously to manage system imbalance without ramping issues and the bullwhip effects that are seen in today's energy system. To an extent this is an unrealistic assumption however with improvements in the way systems are managed and greater plant flexibility and sophistication of control tools future operability is expected to be more easily managed.

Simulated data and profiles	While trying to be as realistic as possible it is nevertheless the case that data and profiles that have been used to populate the model are simulated to create an example energy year in 2035. So for example: • Temperature data used was taken from 2015 – which had a late spring, mild winter and a very windy October • Offshore and onshore wind profiles are adapted from Elexon data • PV, wave, tidal and hydro profiles are modelled • Energy demand for heat is taken from the Wales & West pathfinder simulator • Electricity demand is profiled based on Elexon domestic and commercial profiles Bringing this data together is inevitably an approximation of a real energy system.
Flexible demand is not shed	A rule of the model is that smart flexibility (either through a process of “smart” optimisation, or through managed demand side response) can be used to defer or shift demand but that no demand is shed. Within the model parameters set all deferred demand must at some stage be met, i.e. no demand within the system is lost. This has been done in order to preserve the overall demand and therefore generation requirement of the region. The requirement to meet all demand is an artificial constraint within the model. In reality a proportion of demand that is deferred through flexibility would be shed – if a household or commercial consumer turns down demand in response to a price signal, they do not necessarily subsequently turn up demand to the same extent. Exposing consumers to a stronger price and time signal (e.g. by half hourly metering) would be expected to increase energy cost awareness and therefore efficiency.

Table 41 Limitations of modelling simulation

9.3 Reference List

Key documents and sources of data which will support the future energy system vision modelling.

Source	Link
BEIS, 'Clean Growth Strategy' (2017)	https://www.gov.uk/government/publications/clean-growth-strategy
BEIS, 'Regionalised Statistics, 2003-2016: Unchanged Configuration Load Factors' (2017)	https://www.gov.uk/government/statistics/regional-renewable-statistics
BEIS, 'Total final energy consumption at sub-national level' (2017)	https://www.gov.uk/government/collections/total-final-energy-consumption-at-sub-national-level
Cadent, 'Review of Bioenergy Potential: Technical Report' (2017) supports WWU research into bioenergy feedstock potential in Wales	https://cadentgas.com/getattachment/About-us/The-future-role-of-gas/Renewable-gas-potential/Promo-Downloads/Cadent-Bioenergy-Market-Review-TECHNICAL-Report-FINAL.pdf
Citizens advice, 'Living without mains gas' (2017)	https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/Livingwithoutmainsgas.pdf
Committee on Climate Change, 'Meeting Carbon Budgets: Closing the policy gap' (2017)	https://www.theccc.org.uk/wp-content/uploads/2017/06/2017-Report-to-Parliament-Meeting-Carbon-Budgets-Closing-the-policy-gap.pdf
Committee on Climate Change, 'Fifth Carbon Budget' (2015)	https://www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf
Committee on Climate Change, 'Next Steps for the UK Heat Policy' (2016)	https://www.theccc.org.uk/publication/next-steps-for-uk-heat-policy/
DCLG, 'EPC Statistics release – Qtr. 3' (2017)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/655789/EPB_Statistics_Release_-_Qtr_3_2017___final.pdf
DfT, 'All vehicles – veh01' (2017)	https://www.gov.uk/government/statistical-data-sets/all-vehicles-veh01
DfT, 'Traffic volume – miles (TRA01)' (2017)	https://www.gov.uk/government/statistical-data-sets/tra01-traffic-by-road-class-and-region-miles
Element energy for the Committee on Climate Change, 'Pathways to high penetration of electric vehicles' (2013)	https://www.theccc.org.uk/wp-content/uploads/2013/12/CCC-EV-pathways_FINAL-REPORT_17-12-13-Final.pdf
ELEXON, 'Profiling' (2017)	https://www.elexon.co.uk/operations-settlement/profiling/

Imperial College London, Sustainable Gas Institute, 'WP3 – A Greener Gas Grid: What are the options?' (2017)	http://www.sustainablegasinstitute.org/a-greener-gas-grid/
IPCC, 'Annex III: Technology specific Cost and Performance Parameters' (2014)	https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_annex-iii.pdf
KPMG, '2050 Energy Scenarios: The UK Gas Networks role in a 2050 whole energy system' (2016)	http://www.energynetworks.org/assets/files/gas/futures/KPMG%202050%20Energy%20Scenarios%20-%20The%20UK%20Gas%20Networks%20role%20in%20a%202050%20whole%20en...1.pdf
National Grid, 'Future energy scenarios' (2017)	http://fes.nationalgrid.com/fes-document/fes-2017/
National Grid, 'Future of gas' (2017)	http://futureofgas.uk/documents/future-of-gas/
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