The Second State of Natural Resources Report (SoNaRR2020)

Assessment of the achievement of sustainable management of natural resources: Resource Efficiency Energy

Natural Resources Wales

Final Report

About Natural Resources Wales

Natural Resources Wales's purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales's well-being, and provide a better future for everyone.

Evidence at Natural Resources Wales

Natural Resources Wales is an evidence-informed organisation. We seek to ensure that our strategy, decisions, operations, and advice to Welsh Government and others, are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

Title: **SoNaRR2020** Assessment of the achievement of Sustainable Management of Natural Resources: Resource Efficiency – Energy

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Review process: All content has been reviewed internally and by subject matter experts. Further independent peer review was arranged by the Environment Platform Wales. We would like to thank all academic and other external experts for critically reading the individual chapters and suggesting substantial improvements. We are very grateful for their help and advice.

We would also like to thank other experts who have provided evidence and advice during the chapters' development.

Restrictions: None

The Second State of Natural Resources Report (SoNaRR2020) contents

This document is one of a group of products that make up the second State of Natural Resources Report (SoNaRR2020). The full suite of products are:

Executive Summary. Foreword, Introduction, Summary and Conclusions. Published as a series of webpages and a PDF document in December 2020

The Natural Resource Registers. Drivers, Pressures, Impacts and Opportunities for Action for eight Broad Ecosystems. Published as a series of PDF documents and as an interactive infographic in December 2020

Assessments against the four Aims of SMNR. Published as a series of PDF documents in December 2020:

SoNaRR2020 Aim 1. Stocks of Natural Resources are Safeguarded and Enhanced

SoNaRR2020 Aim 2. Ecosystems are Resilient to Expected and Unforeseen Change

SoNaRR2020 Aim 3. Wales has Healthy Places for People, Protected from Environmental Risks

SoNaRR2020 Aim 4. Contributing to a Regenerative Economy, Achieving Sustainable Levels of Production and Consumption

The SoNaRR2020 Assessment of Biodiversity. Published in March 2021

Assessments by Broad Ecosystem. Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Coastal Margins

Assessment of the Achievement of SMNR: Enclosed Farmland

Assessment of the Achievement of SMNR: Freshwater

Assessment of the Achievement of SMNR: Marine

Assessment of the Achievement of SMNR: Mountains, Moorlands and Heaths

Assessment of the Achievement of SMNR: Woodlands

Assessment of the Achievement of SMNR: Urban

Assessment of the Achievement of SMNR: Semi-Natural Grassland

Assessments by Cross-cutting theme. Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Air Quality

Assessment of the Achievement of SMNR: Climate Change

Assessment of the Achievement of SMNR: Energy Efficiency

Assessment of the Achievement of SMNR: Invasive Non-native Species

Assessment of the Achievement of SMNR: Land use and Soils

Assessment of the Achievement of SMNR: Waste

Assessment of the Achievement of SMNR: Water Efficiency

Updated SoNaRR evidence needs. Published as a data table on web in March 2021

Acronyms and Glossary of terms. Published as a PDF in December 2020 and updated in 2021 as a data table on the web

Recommended citation for this section of the report:

Natural Resources Wales. 2021. State of Natural Resources Report (SoNaRR): Assessment of the achievement of sustainable management of natural resources. Resource Efficiency – Energy. Natural Resources Wales.

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Tables and Figures

1. Headline Messages

Energy is the bedrock of human civilisation. Universal, affordable and clean energy is a prerequisite for economic and social development. In addressing pressing global and national challenges of the 21st century such as poverty eradication, food security, essential healthcare, ecosystem conservation, peace and security, access to clean and affordable energy is of utmost importance. In a modern economy, almost all goods and services have energy implications, from the foods consumed, buildings lived and worked in, vehicles used and day-to-day consumables at home and work.

At the same time, the unsustainable use of resources to generate energy and the way it is used has triggered critical scarcities, caused climate change and widespread environmental degradation. The energy sector is a major contributor to climate change, both globally and in the UK (IEA, 2019a). At the same time, it is also a sector that is impacted by the climate change (University of Cambridge and WEC, 2014). These factors will all have negative impacts on Earth and society's well-being.

In the UK, at 24.5%, the energy supply sector is the second largest contributor of greenhouse gas emission (BEIS, 2019b) while in Wales, at 29%, the energy supply sector was the highest contributor of greenhouse gas emissions in 2018 followed by business, transport, agriculture and residential (NAEI, 2020; Welsh Government, 2020e). Emissions from the other top sectors of transport, business and residential sectors are also intrinsically related to the energy used in that sector. (BEIS, 2020c; Welsh Government, 2020e).

As it stands, UK and Welsh energy policy is often framed as a trilemma of objectives; security of supply, affordability, and sustainability. Thus, decarbonisation of the global and national energy system is of critical importance in safeguarding the natural environment. This will also address the challenge in limiting global temperature increase to between 1.5 and 2.0 °C, which may be achieved by adopting the principles of the energy hierarchy, that is:

- reducing energy consumption
- becoming more energy efficient
- investing in and increasing the proportion of energy produced and used from renewables and low carbon sources
- phasing out fossil fuels

The impact of energy on the natural environment

Energy generation and usage impacts the natural environment and the effects can be of local, regional and global nature. For example:

- Non-renewable resources such as coal and petroleum cause more harm to the environment when compared to renewable resources, in the form of air and water pollution. Refer to Water Efficiency, Freshwater, and Air Pollution chapters.
- Coal burning emits sulphur emissions that harm trees. The mining, processing, burning and waste storage of coal can contaminate rivers and lakes and adversely

affect aquatic ecosystems. Refer to Woodlands and Marine chapters and Ecosystem Resilience assessment.

- Oil production and usage result in the release of greenhouse gas emissions into the air. Refer to the Air Quality chapter.
- The exhausts from natural gas release oxides of nitrogen and methane which adversely affect people and animals that use water from the affected water bodies. Refer to the Freshwater chapter.
- Both non-renewable and renewable energy can generate toxic waste which can be harmful to the natural environment. Refer to the Waste chapter.
- Both renewable and non-renewable generation schemes can lead to direct habitat and biodiversity loss.
- Continued increase in renewable energy can have significant impacts on the use of land. Refer to the Woodlands and Land Use and Soils chapters.

The energy system is also the biggest source of human caused greenhouse gas emissions, which includes electricity and heat generation, transport, buildings, industry, fugitive emissions and other fuel combustion.

According to the Welsh Government's Low Carbon Delivery Plan – sector pathway documents (figures are based on 2016 emissions):

- The power sector accounted for 34% of all emissions in Wales (Welsh Government, 2019b). Wales hosts a number of the UK's gas- fired power stations resulting in a large proportion of emissions from a few point sources (Welsh Government, 2019b).
- Industrial emissions accounted for 29% of Wales emissions in 2016, which was dominated by iron and steel production and petroleum refining (Welsh Government, 2019c). Other energy intensive industry, such as manufacturing, construction, solid fuel production, cement, gas production and distribution were also a significant contributor of industrial emissions (Welsh Government, 2019c).
- Transport including international shipping and international aviation, is the third largest sector in terms of carbon emission in Wales (Welsh Government, 2019d). The transport sector also made the least progress in emission reduction.
- Agriculture accounted for 12% of Welsh greenhouse emissions in 2016 (Welsh Government, 2019g). A proportion of this comes from inefficient mobile machinery, livestock and crop production (Welsh Government, 2019g).

Using the National Atmospheric Emissions Inventory (NAEI) summarised categories, sectoral emission for the UK and Wales in 2018 is shown in Figure 1.

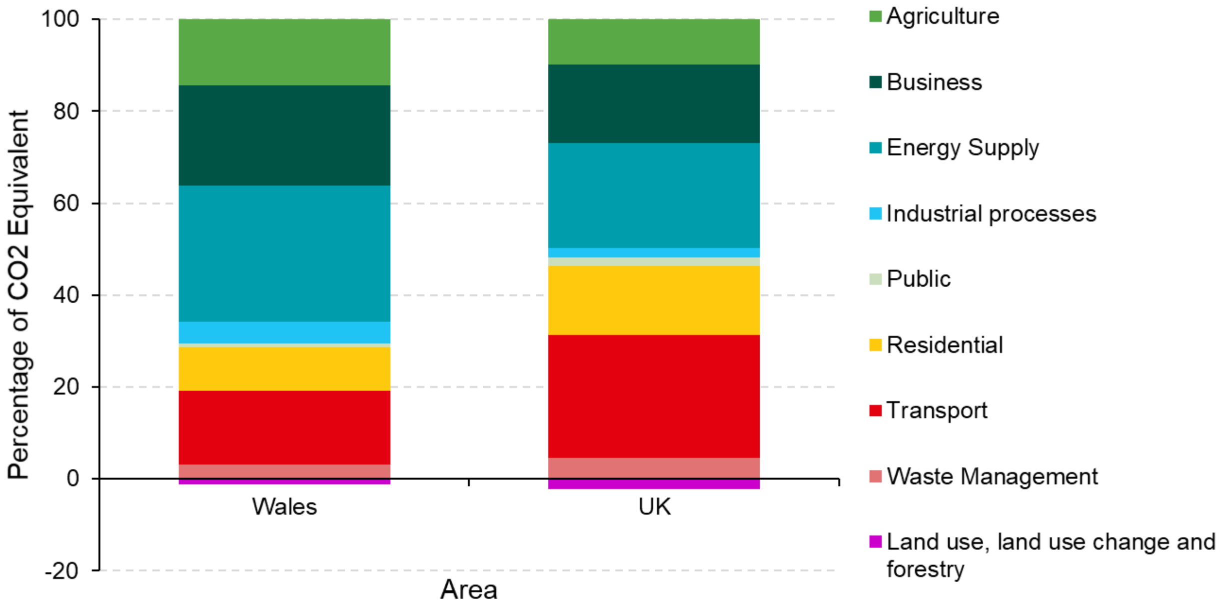

Figure 1 Sectoral share of GHG emissions in Wales and UK in 2018
Data sourced from: NAEI, 2020

Other impacts of energy

Energy is essential in socio-economic development. In Wales,12% or 155,000 of Welsh households lived in fuel poverty in 2018. Of this figure, 2% or 32,000 households live in severe fuel poverty with 19,000 of these recorded as vulnerable households (WAO, 2019). Although the number of households estimated to be in fuel poverty has halved from 332,000 to 155,000 in 2018, this is still not adequate in meeting the Welsh Government’s target (WAO, 2019).

Rising energy bills is a contributing factor to fuel poverty. The annual bill for a typical dual-fuel household in the UK in 2016 was around £1,160; £615 was for gas use and £545 was for electricity (UKCCC, 2017a). Around £105 or 9% of the bill is the result of low-carbon policies, comprising the carbon price, support for renewable electricity generation and costs associated with improving energy efficiency for carbon reduction. Most green levies are added to electricity cost rather than other energy sources such as gas.

Renewable energy is a major part of the energy solution although natural energy sources such as wind and hydro are perceived to have some sensitivity to change due to man-made climatic variation (Cradden et al., 2016; University of Cambridge and WEC, 2014).

In the face of the above trends, reducing energy consumption and improving efficiency of use is by far the most effective way and lowest cost to decarbonise the energy system (UKCCC, 2017a; UKCCC, 2019; IEA, 2019b; GEF, 2020).

Whilst carbon prices and low carbon subsidies raise energy costs for end users, reducing consumption and improving energy efficiency can reduce energy bills, reduce import dependency, and reduce demand at peak times (UKCCC, 2017a). It is also important to recognise the strong relationship between energy efficiency and productivity within industry and how energy efficiency investments can provide a significant boost to overall productivity. Therefore, reducing energy consumption and improving energy efficiency is vital in achieving all aspects of the trilemma and getting to the root of productivity challenges within the Welsh economy.

Reducing energy consumption, increasing energy efficiency and renewable energy development along with decarbonisation is necessary and poses a significant challenge to the energy sector, involving complex dynamics between commercial, policy, and technical landscapes. At the core, the centralised energy system built last century is transforming to become flexible, sustainable and user focused. This transition involves more stakeholders across energy and non-energy specialist sectors.

2. Introduction

Central to the future of Wales is the need for a secure, affordable and sustainable energy system.

Although renewable energy makes significant and increasing contributions, the Welsh energy system remains dominated by fossil fuel, the majority of which are imported (IWA, 2019). Generation of electricity from renewable sources, mainly wind and solar, has been steadily increasing over the past 10 years (Welsh Government, 2017; 2018a; 2019i; 2020c). The use of biofuel for renewable electricity and heat is also increasing (Welsh Government, 2017; 2018a; 2019i; 2020c). Despite increases in renewable generation and use of natural gas to replace coal and other fossil fuels, total emissions from the power sector in Wales has grown by 44% between 1990 and 2016 (Welsh Government, 2019a). Over the same period, overall UK emissions from the sector reduced by 60% (Welsh Government, 2019a).

Energy Generation and Consumption

UK Energy Generation

According to UK Department for Business, Energy and Industrial Strategy (BEIS), fossil fuel, coal, gas and oil, remained the dominant source of energy supply in the UK at 78.3% in 2019, which is also a record low level (BEIS, 2020d). Oil and gas are key to the UK’s current energy mix with oil and gas accounting respectively for 40% and 29% of the UK’s energy production in 2019 (BEIS, 2020d).

Most of the oil is used for transport, mainly road fuels and for air travel, providing 96% of energy used in the sector in 2019 (BEIS, 2020d).

Natural gas is particularly important for electricity generation where it meets around 40% of the fuel required in power stations (BEIS, 2020d). It is also critical nationally for space heating, for both domestic and commercial. In 2019, natural gas met nearly two thirds of UK domestic energy demand. (BEIS, 2020d)

While use of coal has decreased, there has been an increase in renewable electricity generation which was at a record high level of 37.1% of total generation in 2019 (BEIS, 2020d).

Generation of heat from renewable sources continued to increase year on year in the UK between 2015 and 2019, primarily due to increase in generation from wood fuel. (BEIS, 2020d)

Wales Energy Generation

Welsh Government's annual report on Energy Generation in Wales, breaks down Welsh electricity and heat generation by technology, capacity and local authority area for each year. In 2019, 73% of the electricity generated in Wales came from fossil fuel plants with the remainder being generated from renewable sources (Figure 2).

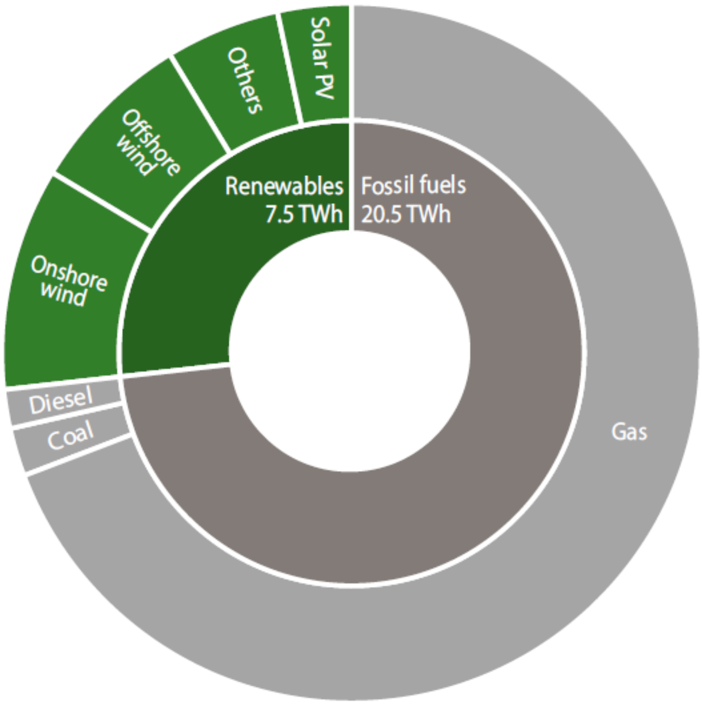

Figure 2: Wales electricity generation mix
Source: Welsh Government, 2020c

Electricity generation in Wales fell by 30% between 2016 and 2019 with annual totals of 40 Terawatt hours (TWh) and 27.9 TWh respectively (Welsh Government, 2017; 2020c).

Consistent with the UK trend, Wales also recorded a 95% decrease in electricity generation from coal but has seen a 32% increase in natural gas between 2006 to 2018 as seen in Figure 3.

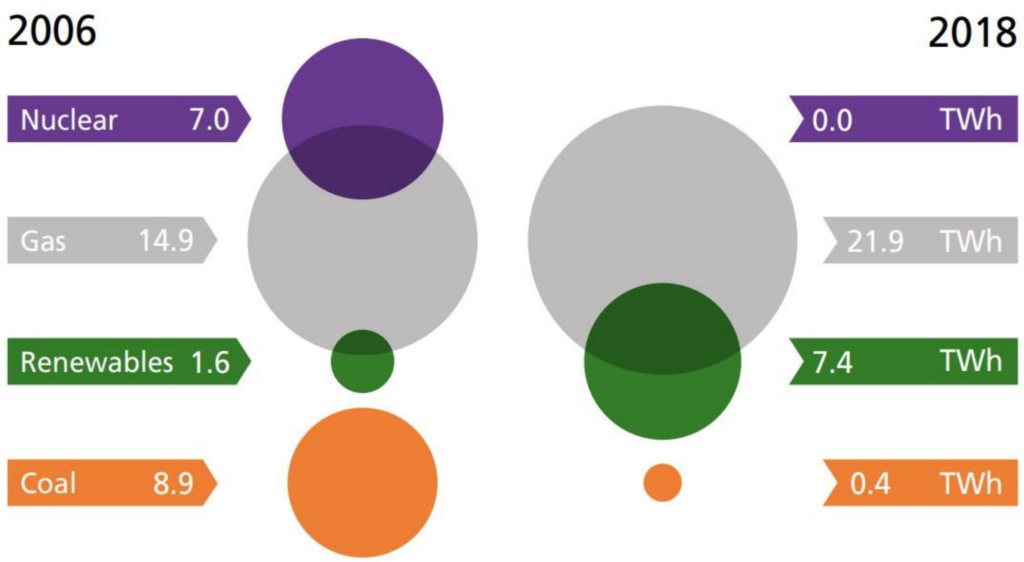

Figure 3 Wales Electricity Generation from 2006 to 2018
Source: Welsh Government, 2019j

As of March 2020, Wales closed its last coal-fired power station. It is likely that coal-fired power stations will not be the part of the electricity mix in the future.

Figure 4 indicates energy generation from renewable sources which has been increasing year on year in Wales. Renewable electricity has increased by over 500% since 2005 (Welsh Government, 2020c) echoing the wider UK trend. In 2019, 7.5 TWh of electricity came from renewables while renewable heat accounted for 2.3 TWh (Welsh Government, 2020c). 825 megawatts (MW) of installed renewable energy capacity was locally owned (Welsh Government, 2019i).

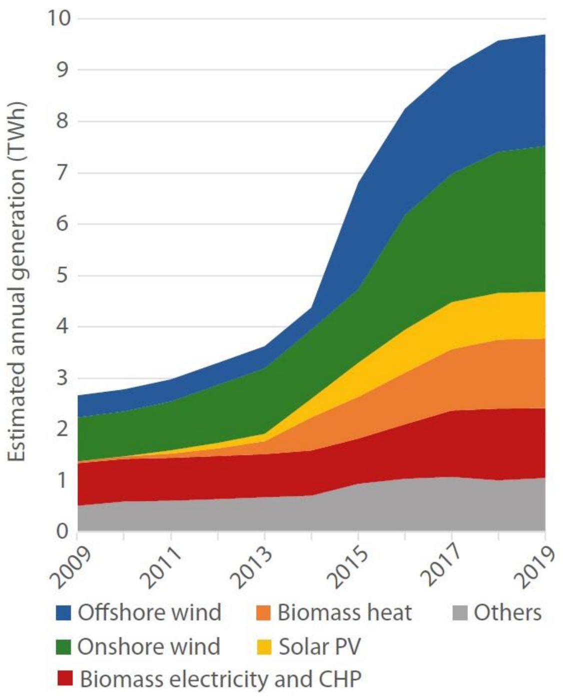

Figure 4 Renewable Energy Generation in Wales
Source: Welsh Government, 2020c

Table 1 outlines the capacity in megawatts (MW) and annual generation of renewable electricity and heat in gigawatt hours (GWh) in Wales by the various technologies.

Table 1 Renewable energy generation by technology in Wales in 2019 (Welsh Government, 2020c)

Renewable energy technologies	Number of projects	Electricity Capacity (MW)	Estimated Electricity generation (GWh)	Heat Capacity (MW)	Estimated heat generation (GWh)
Anaerobic digestion	46	19	103	8	49
Biomass	3450	Not applicable	Not applicable	449	1375
Biomass electricity and CHP	50	132	712	120	662
Energy from Waste	1	30	162	Not applicable	Not applicable
Heat pump	7817	Not applicable	Not applicable	86	165
Hydropower	363	182	347	Not applicable	Not applicable
Landfill gas	24	31	115	Not applicable	Not applicable
Offshore wind	3	726	2200	Not applicable	Not applicable
Onshore wind	748	1255	2874	Not applicable	Not applicable
Sewage gas	5	9	30	10	64
Solar PV	55634	989	924	Not applicable	Not applicable
Solar thermal	4693	Not applicable	Not applicable	13	8
Grand total	**72834**	**3372**	**7469**	**686**	**2323**

In Wales, increases in renewable electricity generation over the last five years has been due to large-scale offshore and onshore wind which accounted for 29% and 38% of generation respectively in 2019 (Welsh Government, 2020c).

While renewable electricity generation is increasing, decarbonisation of heat and transport remains a challenge. Despite increases in renewable energy generation, Wales still relies heavily on natural gas as its primary source of energy as shown in Figure 2 (Welsh Government, 2020c; Welsh Government, 2018a).

Although the renewable capacity has been increasing in Wales, the growth rate has fallen significantly since 2016, as a result of reduction in support including closure of the Feed in Tariffs and Renewables Obligation and the lack of Pot 1 Contracts for Difference (Welsh Government, 2020c). Figure 5 highlights renewable energy installation rate in Wales since 2007.

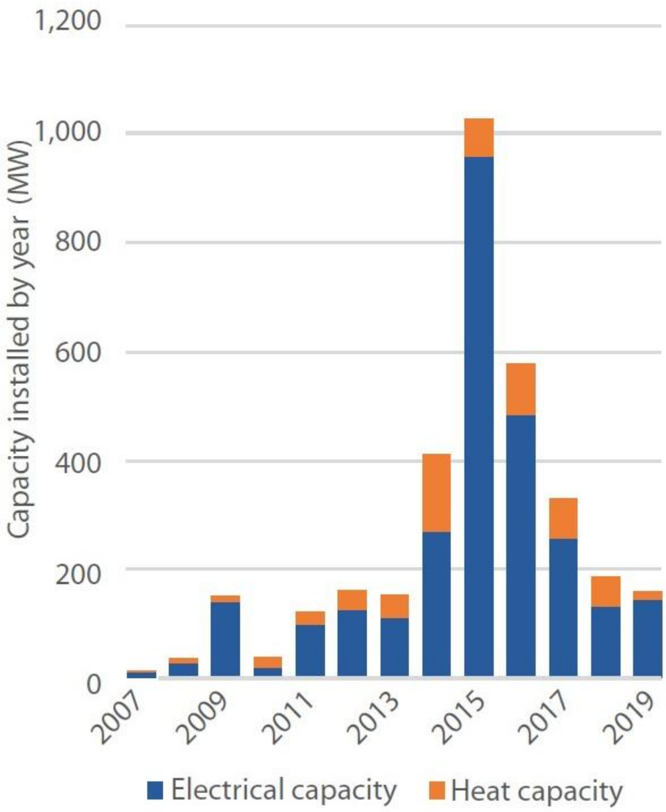

Figure 5 Wales renewable energy capacity installation rate
Source: Welsh Government, 2020c

In 2017, the Welsh Government announced a target of meeting 70% of Wales's electricity demand from Welsh renewable electricity sources by 2030. In 2018, Wales achieved 51% of that target, as shown in Figure 6.

The long-term trend of progress towards this target is due to the combination of both decreasing electricity consumption and increasing renewable energy generation as seen in Figure 7.

However, significant challenges remain in meeting the 70% target by 2030, notably due to lack of available price support for renewable generation, network unavailability and constraints in some areas with significant renewable generation potential (Welsh Government, 2019i; Welsh Government, 2020c).

There are considerable challenges ahead to decarbonise heat. Whilst heat from renewable sources is increasing year on year in Wales (Welsh Government, 2020c) the installation rate for renewable heat are declining as seen in Figure 5 (Welsh Government, 2020c).

Production of renewable heat was approximately 2.3 TWh in 2019 which is equivalent to only 13% of estimated Welsh domestic heat demand. The bulk of heat demand in Wales is met through fossil fuel which is imported natural gas. (Welsh Government, 2020c).

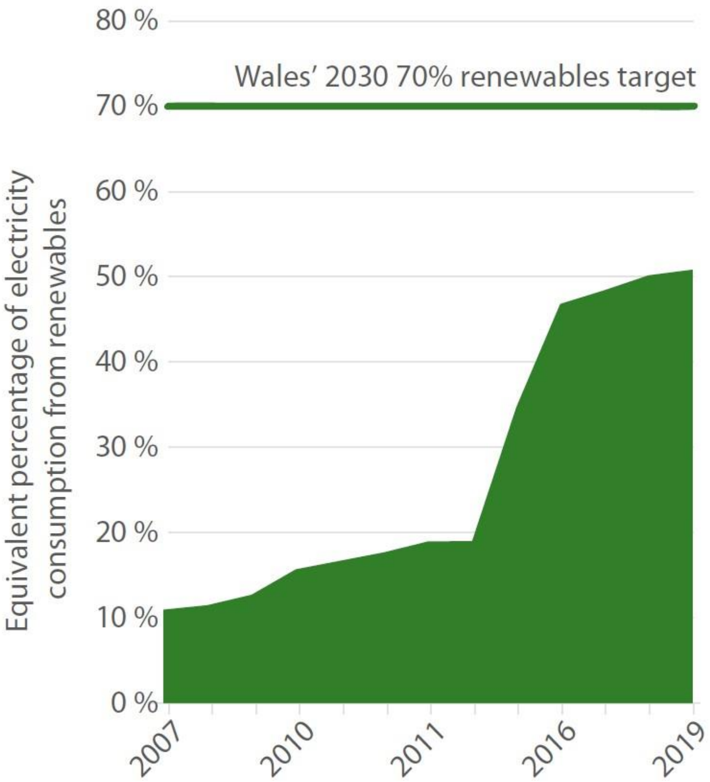

Figure 6 Growth in the percentage of electricity from renewable sources in Wales
Source: Welsh Government, 2020c

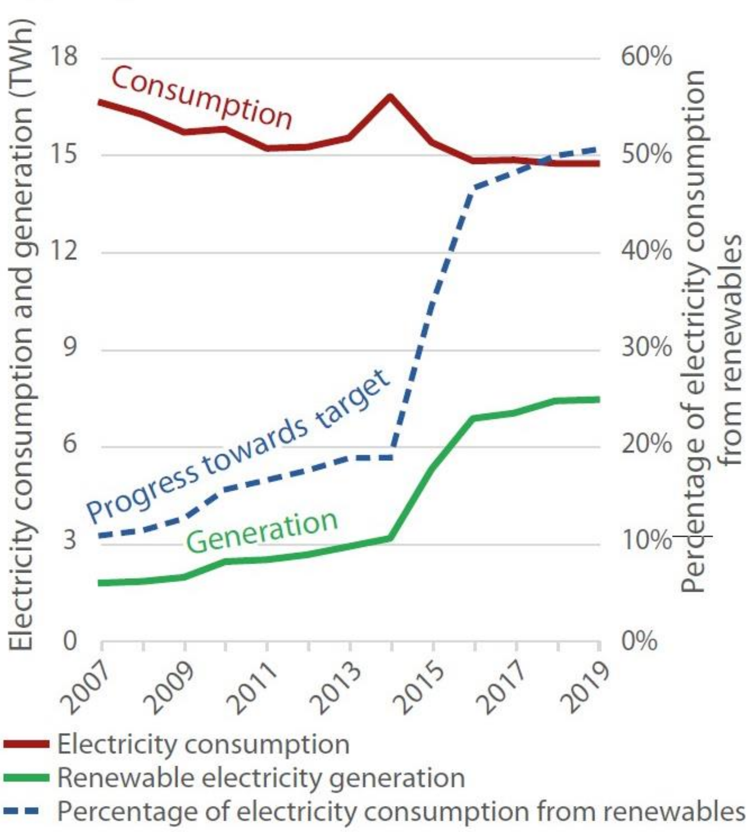

Figure 7 Growth in the percentage of electricity consumption from renewable sources in Wales
Source: Welsh Government, 2020c

Energy Consumption

The UK is consuming less energy than in 1970. While more of the energy consumed is from renewable sources, energy consumption peaked in 2001 at 236,856 kilo tonnes equivalent of oil (ktoe). Since then, primary energy consumption has fallen by 19 per cent to 192,126 ktoe (BEIS, 2019c) with 2019 recording the lowest level consumption of electricity since 1994 (BEIS, 2020e).

This may be explained by:

- the increased use of energy-efficient appliances
- government policies designed to reduce energy consumption
- a decline of UK manufacturing, especially in energy-intensive industries

Figure 8 highlights the long-term trends in consumption by sector and fuel, most notably the growth in energy consumption for transport but decline in industry. Coal use decreased by 96% between 1970 and 2019 and gas consumption more than tripled; although, this has fallen by a quarter since consumption peaked in 2001 (BEIS, 2020b).

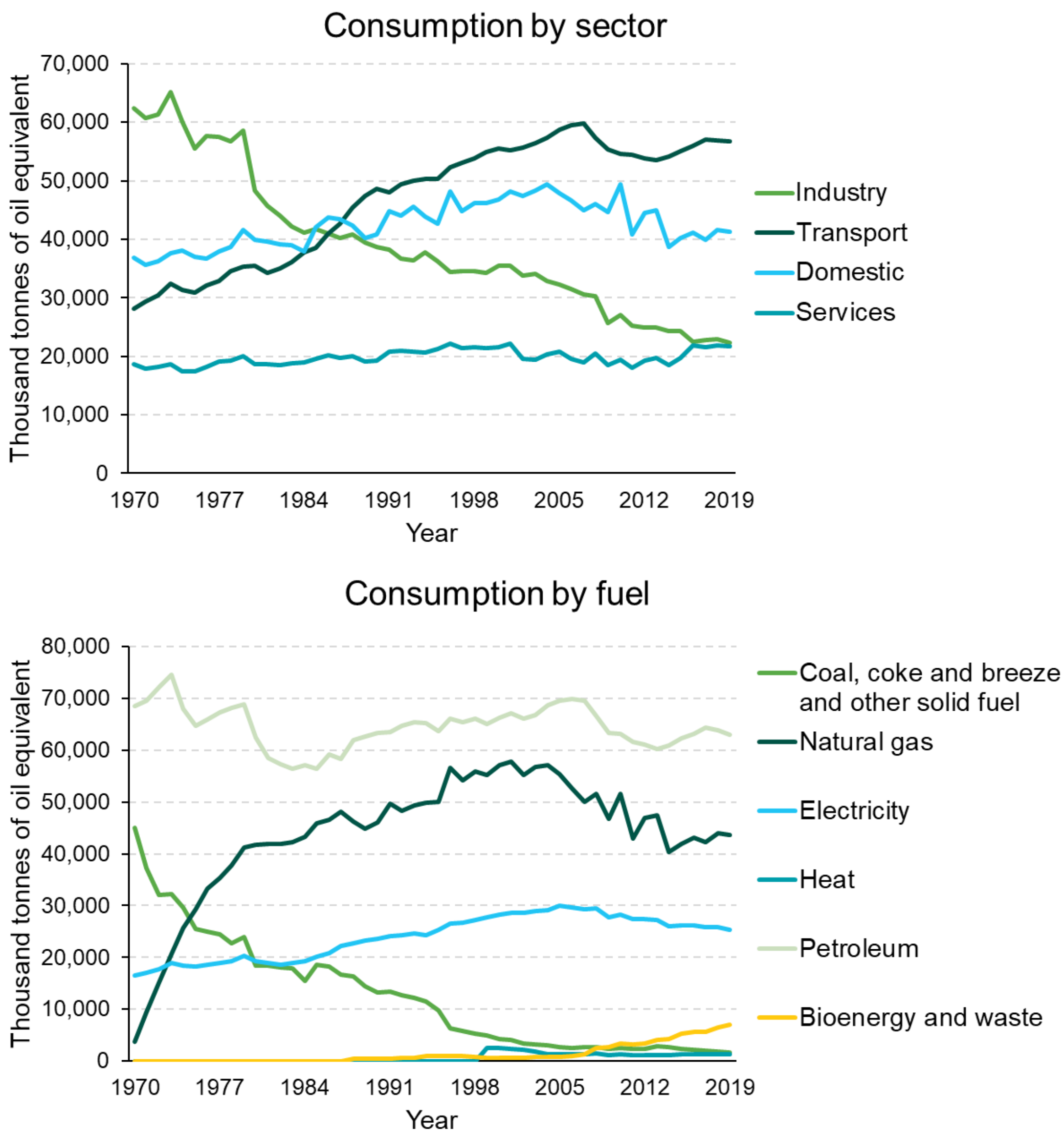

Figure 8 Change in energy consumption by sector and fuel from 1970 to 2019
Data sourced from: BEIS, 2020b; BEIS, 2020f

Consistent with the UK trend, energy consumption in Wales reduced by 19% between 2005 to 2017. During the same period, electricity consumption in Wales fell by 15%, along with 23% reduction in demand for fossil fuels (Welsh Government, 2020d).

The highest reduction in energy consumption was from the industrial sector with a 31% decrease in demand across heat and electricity. This is followed by reduction in building and transport and a minor increase in agriculture as illustrated in Figure 9 and Table 2

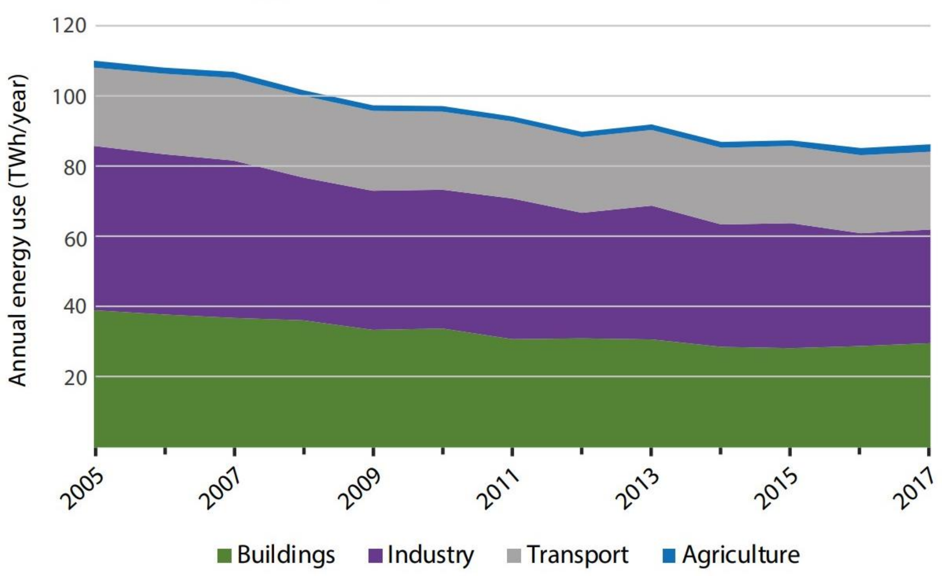

Figure 9 Energy consumption in sector in Wales, 2005 -2017.
Source: Welsh Government, 2020d

Table 2 Wales energy consumption in 2005 and 2017 in TWh per year (Welsh Government, 2020d)

Year	Transport	Buildings	Industry	Agriculture	Total
2005	22.2	39.0	46.7	1.9	109.8
2017	22.1	29.6	32.3	2.1	86.1

The trend continues in 2018, with Wales consuming 91 TWh of energy. Electricity consumption accounted for 14.9 TWh while the remaining 76.1 TWh is used in transport, heating, and industry. (Welsh Government, 2019i).

Most types of fuel have seen a fall in their use in Wales since 2005. The decline seen both in domestic and non-domestic energy consumption is mainly due to a reduction in domestic gas fuel use and non-domestic petroleum products as seen in Figure 10.

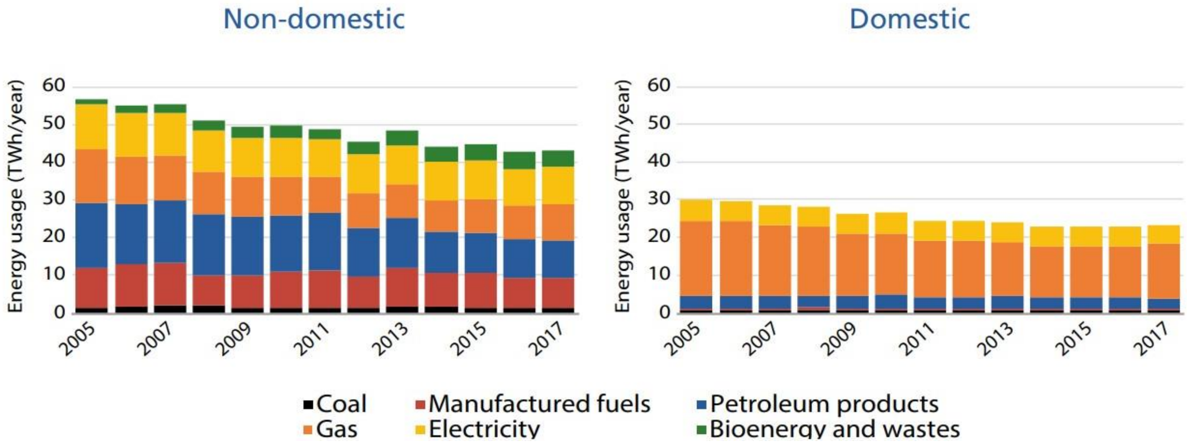

Figure 10 Non-domestic and domestic total energy use in Wales by fuel type, 2005 – 2019
Source: Welsh Government, 2020d

Although annual energy use in buildings decreased steadily by some 24% between 2005 and 2017 (Welsh Government, 2020d), the 1.4 million homes of Wales are still responsible for 27% of the nation's annual energy consumption (BEIS, 2017) and 15% of all demand-side greenhouse gas (GHG) emissions (NAEI, 2016). Note: the building sector includes domestic homes, public buildings and commercial spaces not classed as industrial (Welsh Government, 2019m).

At the time of writing this report, the energy sector was also experiencing unprecedented change in energy consumption due to the Covid-19 pandemic. In 2020, the UK achieved a new record for generating electricity without burning coal (Carbon Brief, 2020) along with a record breaking 18% reduction in energy demand compared to 2019 as the country responded to the national lockdown. (Carbon Brief, 2020)

Energy Efficiency

Improvements in energy efficiency is one of the key strategies to tackle climate change, improve security of energy supply as well as reducing people's energy bills.

According to the International Energy Agency (IEA, 2019b), energy efficiency improvements globally and nationally are slowing down and opportunities to reduce costs and emissions are being lost. Although progress is taking place in relation to technological improvements, slowdown is caused by a mixture of societal and economic trends that are driving more energy use, combined with some recent exceptional factors (IEA, 2019b).

In Wales, the regulation of energy efficiency is a reserved matter and the responsibility of the UK Government, whilst the promotion of energy efficiency is devolved to the Welsh Government. Fuel poverty and social housing standards are also devolved to Wales and these powers have been used to improve the efficiency of heating in private and social housing stock respectively.

Building Regulations are also devolved to Wales, and the Welsh Government is currently consulting on changes to building regulations which has potential to improve the energy efficiency for new homes from 2020. The consultation document also provides detail on the direction of travel for energy efficiency standards for introduction in 2025. The urgent need for energy efficiency is also reflected in the sector emission pathways for building in the low carbon delivery plan (Welsh Government, 2019f). See also Urban chapter.

The Welsh Government Energy Efficiency Strategy also recognises that energy efficiency is a very important element in driving the Well-being of Future Generation Goals (Welsh Government, 2016). Figure 11 illustrates the importance of energy efficiency and how it could help achieve the seven Well-being Goals.

The UKCCC (2018a; 2019) and IEA (2009) concurs that energy efficiency improvements can reduce the need for investment in energy infrastructure, cut fuel costs, increase competitiveness, lessen exposure to fuel price volatility, increase energy affordability for low income households, cut local and global pollutants and improve consumer welfare. Efficiency gains can also boost energy security by decreasing reliance on imported fossil fuels. The IEA (2009) adds that energy-efficiency investments in buildings, industry and transport usually have short pay-back periods and negative abatement costs, as the fuel-cost savings over the lifetime of the capital stock often outweigh the additional capital cost of the efficiency measure.

In 2018, 12% or 155,000 of Welsh households lived in fuel poverty (WAO, 2019). Of this figure, 2% or 32,000 households lived in severe fuel poverty. Many of these homes were built in pre-1919 and have low energy performance rating or lack of central heating (Welsh Government, 2018b).

This shows the scale of the challenge and the need for innovative policies, redirected investment, environmentally sound technologies, domestic and international cooperation, and capacity development to transition towards a green economy.

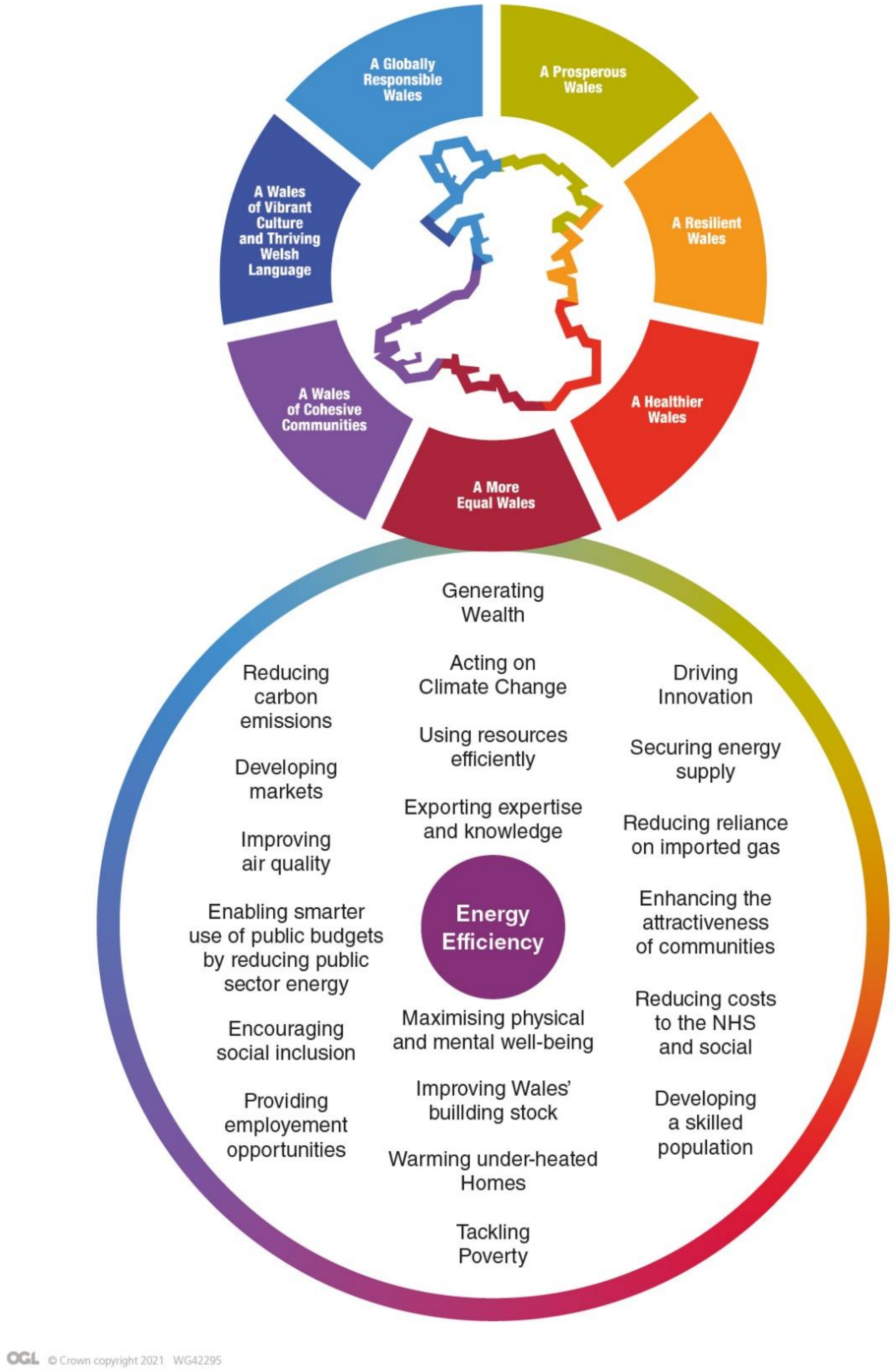

Figure 11 Impact and benefits of Energy Efficiency on Wales's Well-being Goals
Source: Welsh Government

3. State and Trends

Summary Assessment of State and Trends

The following tables give a brief description of the past trends and future prospects for energy generation, consumption, efficiency and emissions. These are assessed to be:

- Improving trends or developments dominate;
- Trends or developments show a mixed picture, or
- Deteriorating trends or developments dominate.

Further information is provided to put this in context.

Table 3 Key Message: Past Trends and Future Prospects of Energy Generation in Wales

Time Period	Indicative Assessment	Description
Past trends (10-15 years)	Improving	In the UK, total electricity generation has been declining. Electricity generated from coal shows a long-term downward trend and an increase in electricity generation from gas. The decline in electricity supplied from fossil fuels coincides with increased generation from renewable sources. Despite yearly increases in renewable energy sources, the UK relies on primary energy from fossil fuel, especially natural gas. In 2018, 36% of energy used in the UK was imported, down from the 2014 level due to increases in indigenous oil and gas output and, more recently, renewables. In Wales, there has been considerable reduction in total electricity generation. The trend shows significant reduction in electricity generation from coal fired power plants but increase in gas fired powered generation. This is coupled with an increase in renewable energy generation for both electricity and heat since 2000. Renewable energy development has been steadily increasing both in the UK and Wales. In Wales, renewable electricity generation increased over 500% between 2005 and 2019 (Welsh Government, 2019i). There is also significant progress in the renewable heat sector both at the UK and Welsh level. However, renewable energy development in Wales has slowed down due to reduction in government support including closure of Feed in Tariff, Renewable Obligation, and supply network constraints. Both Brexit and Covid-19 could have implication on renewable development by hampering investment in it.

Time Period	Indicative Assessment	Description
Outlook to 2030	Mixed Picture	Energy generation indicates a downwards trend for both UK and Wales. Electricity generation in Wales is part of the wider interconnected electricity system of the UK. In 2019, annual generation in Wales was greater than consumption with surplus electricity from Wales exported to the rest of UK through the transmission network. When the generation in Wales is lower than consumption, the deficit will be met by electricity produced elsewhere in the UK. UK government plans to phase out unabated coal fired power stations by 2025. In early 2020, only four coal-fired power plants remained in the UK energy system – Drax, Ratcliffe, West Burton, and Kilroot, with Drax announcing it will close its coal units after September 2022 (Drax, 2020). Reduction in fossil fuel use and generation are to be balanced by increases in renewables, mostly offshore and onshore wind, large scale solar along with emerging technologies such as battery storage and hydrogen. However, there is no clear UK level policy as to how this will happen. Expansion of renewable electricity faces lack of infrastructure and investment support. The renewable sector has had a substantial cut in UK government subsidies and investment, leading to slower growth. Progress is slow in meeting the demand for heat and transport from renewable heat generation and electricity, respectively. Brexit could have a major impact on UK energy system operation and policy across devolved powers - likely effects are still unclear. This is worsened by Covid-19 which is impacting the growth and development of renewable energy sector. However, the situation could also present an opportunity through a green stimulus package with recovery strategy that could help accelerate renewables growth.
Prospect to meet policy objective/ targets by 2050	Mixed Picture	2030 outlook still applies for 2050. The UK must achieve a near total eradication in the use of fossil fuel in its energy system. The transition to zero carbon energy system will involve a considerable amount of fossil fuel as bridging technology. While coal decline is a positive trend, natural gas remains dominant in the UK and Welsh energy sector. Renewables and emerging technologies will continue to play a central role and must be complemented through the optimisation of demand reduction and energy efficiency.

Robustness of data: There is adequate data on electricity generation and production of fuel at the UK level, but data is either not robust or not available or both at the national level to make a thorough Welsh Assessment.

While renewable energy technologies can make significant contributions to decarbonising the UK and Wales's energy supply, they may also be associated with a diverse and complex array of positive and negative social, environmental and economic impacts, which may occur at a range of geographical and temporal scales. In making this assessment we currently do not have adequate evidence across all renewable technologies particularly with regards to impact of energy technologies on ecosystem services.

It is important to consider the full range of potential impacts alongside predicted gains in terms of energy supply, affordability and GHG emission reduction to ensure that the best decisions are made and that associated costs are predicted, minimised and mitigated.

Table 4 Key Message: Past Trends and Future Prospects of Energy Consumption in Wales

Time Period	Indicative Assessment	Description
Past trends (10-15 years)	Mixed Picture	Energy consumption for the UK is a mixed picture. There has been a steady decline in the industrial sector between 1970 and 2019 (BEIS, 2020b) due to significant contraction of the UK manufacturing base, energy efficiency and regulations. Domestic consumption has also reduced. There has been a 23% fall in domestic sector energy intensity use between 2000 and 2019 (BEIS, 2020b), due to improvements in the energy efficiency of homes and regulations (BEIS, 2019d). However, the majority of homes remain far short of the government's aspirational target for higher efficiency and UK properties are among the least-well insulated in Europe (Halden-Pratt, 2020; Timperley, 2019; BPIE, 2019). The service sector recorded a marginal increase between 1970 and 2019 (BEIS, 2020b), with the transport sector dominating the UK's overall energy consumption. Between 2002 and 2014, energy consumption for heat has fallen by 10% due to warmer winters. During this period, actual consumption has varied depending on average temperature changes. There is strong decline in the consumption of coal as an energy source. Coal was a record low in 2019 with significant reduction in use of coal by major power producers and final consumers (BEIS, 2020d). However, natural gas remains dominant. Total energy consumption has decreased in Wales between 2005 and 2018 coinciding with the downward trend on energy generation within the country. Buildings and transport remain significant consumers of energy and little progress has been made in reducing their demand. These sectors require rapid decarbonisation with demand reduction, more efficient use of energy and electrification using low carbon sources. There is currently a lack of strong policy and strategy to achieve this.

Time Period	Indicative Assessment	Description
Outlook to 2030	Mixed Picture	Total consumption of high carbon energy needs to be reduced drastically. Fossil fuel must be substituted for low carbon and renewable generated alternative fuels. Overall priority should be to minimise use of any energy source through demand reduction and energy efficiency. Energy consumption in buildings will need to be reduced through energy efficiency measures, fuel substitutions and use of domestic renewable energy installations. Energy embedded in construction materials and construction waste needs to be significantly reduced. Substituting current levels of travel with low carbon fuels is not a sustainable solution to the transport problem; instead, a systemic change is needed. Ways to reduce demand for transport and technologies must be implemented to decarbonise the energy used to meet the remaining demand. Societal and behaviour changes are crucial elements in achieving the climate and energy aspirations. The coronavirus pandemic has shown that major societal changes can be achieved. Transport policies must be developed to change transport needs and transport systems in response, such as using decarbonised mass transit and freight distribution systems.
Prospect to meet policy objectives / targets by 2050	Mixed picture	Although coal has declined significantly, natural gas still plays a critical role through direct consumption for heating which needs to drastically decline in order to meet net zero targets. Decarbonising heat in buildings will remain one of the biggest challenges. More than 80% of UK dwellings are heated by natural gas. To achieve the Net Zero Target, the UK and Wales need to drastically improve the heat efficiency of homes and buildings and transition to either low carbon electricity or hydrogen or both. The same is required for transport where travel must be reduced and decarbonised. The technical challenges must be addressed along with the behaviour changes.

Robustness of data: There is adequate data on energy consumption by sector and fuel type at the UK level, but data is either not robust or available or both at the Welsh level to make a thorough Welsh Assessment. The Institute for Welsh Affairs (IWA) recently produced data on energy demand for all buildings in Wales. The research provides a clear, data-based picture of the nature, timing and location of half hourly energy demands of buildings in Wales over the period of a year. This research has produced estimates of energy demand for electricity and heating, both space and domestic hot water, of planning and opportunities for demand reduction, demand side response and smart systems Welsh domestic and non-domestic buildings in half-hourly intervals during 2016. This kind of detailed data is most useful in regional energy planning and informing energy system.

Table 5 Key Message: Past Trends and Future Prospects of Energy Efficiency in Wales

Time Period	Indicative Assessment	Description
Past trends (10-15 years)	Deteriorating	The largest fall in energy intensity over the last 30 years has occurred in the industrial sector, mainly due to structural change in the period before 2000, and in the service sector due to general energy efficiency improvements. There has been a general downward trend in domestic consumption since 2005, due to improvements in energy efficiency, largely on appliances. The UK has the oldest and worst housing stock in Europe (BPIE, 2011). There has been a 95 % drop in rates of insulation retrofit since 2012 demonstrating slowed progress on improving the thermal efficiency of homes. Plans for carbon neutral building standards for new homes were dropped by the UK Government in 2015 in a deregulatory move. The total extra cumulative energy costs for new homes built to the lower standard since then has been estimated to be over £2 billion by the end of 2020 (ECIU, 2019). Fuel poverty has been decreasing however improvement in energy efficiency has slowed between 2015 and 2017, stalling potential progress. Wales has the oldest housing stock in the UK with the highest proportion over 100 years old out of the four UK nations at 26% (Piddington et al., 2020). Wales has been making progress in addressing its fuel poverty. Welsh Government set targets to eradicate fuel poverty among all vulnerable groups by 2010, in social housing by 2012, and in the general population by 2018. While there have been significant improvements, such as in the installation of energy efficiency measures in over 45,000 homes between 2011 and 2018, these targets were not met (Welsh Government, 2019r). UK need to quicken the pace in decarbonising the 29 million existing homes in the UK, by ensuring it is low carbon, low energy and resilient to a changing climate. It is also equally important to improve thermal properties and energy efficiency across the whole energy related sector. Although the UK industrial sector has made significant progress in terms of emission reduction over the years, there are still significant opportunities in improving energy efficiency.

Time Period	Indicative Assessment	Description
Outlook to 2030	Deteriorating	The regulation of energy efficiency is not a devolved matter although the promotion of energy efficiency is devolved to Wales. Wales contributes towards the UK's EU target on Energy Efficiency with key dates of 2020 and 2030. There is uncertainty how the EU exit will affect UK implementation and achievement of this Directive. Welsh Government has an Energy Efficiency strategy for the period 2016 to 2026 and an active programme to deliver energy efficiency improvements to fuel poor households. However, a more ambitious programme is required across all housing, building and energy related sectors to meet net zero targets, including zero carbon standards for new build homes. Building regulations have recently seen revised standards to increase the energy performance of new homes. Wales needs to have a comprehensive target and plan with a whole system approach to accompany its strategy on promoting energy efficiency across all sectors to achieve its energy and decarbonisation targets
Prospect to meet policy objectives / targets by 2050	Largely not on track	There is a clear and considerable investment shortfall to meeting the Government's energy efficiency targets. A major upgrade of the energy performance of the UK's entire building stock will be fundamental in reaching net zero emissions to address fuel poverty and cut energy bills. As advised by the UK Climate Change Commission, emissions from buildings need to fall by around 22% between 2015 and 2030, to create options for near-zero emissions by 2050 (Webb, 2016). The UK and Wales could benefit from an integrated policy framework for energy efficient buildings and low carbon heat supply along with a renewed governance process to achieve the necessary significant changes. The UK and Welsh efforts to decarbonise will require increased investment across the energy system with more focus on behaviour change and innovation to help ensure minimisation of costs in investment, and further improvements in energy efficiency. Wales needs to have a comprehensive target and plan with a whole system approach to accompany its strategy on promoting energy efficiency across all sectors to achieve its energy and decarbonisation targets.

Robustness of data: There is adequate data in relation to energy efficiency at the UK and Wales level with regards to housing and fuel poverty. However, there is a lack of data in relation to energy efficiency on transport, industry and other energy related sectors, and on how Wales could maximise its power on the promotion of energy efficiency.

Table 6 Key Message: Past Trends and Future Prospects of Emissions from Energy Sector

Time Period	Indicative Assessment	Description
Past trends (10-15 years)	Mixed Picture	The UK has decarbonised its electricity mix faster than any other major world economy and now receives half of its electricity from low carbon resources. Some 54% of UK electricity generation in 2019 came from low-carbon sources, including 37% from renewables and 20% from wind alone. A record-low 43% was from fossil fuels, with 41% from gas and just 2% from coal, also a record low. The UK power generators also supplied less electricity in 2018 than at any time since 1994 as energy demand from homes and industry continues to fall. However, Wales has had a slower emissions reduction in the power sector compared to the wider UK. This is mainly due to emissions from Aberthaw, a coal-fired power station which emitted 7.3 MtCO2 in 2015, and five gas Combine Cycle Gas Turbine (CCGT) plants which emitted 5.7 MtCO2 (UKCCC, 2017b). Aberthaw was closed in March 2020, which marks the last coal-fired power station in Wales. Both the UK and Wales have made very little progress in reducing emissions from transport and the residential sector. Decarbonising heat and transport remain a considerable challenge and very limited progress is being made towards net zero targets in these sectors.
Outlook to 2030	Mixed Picture	Both the UK and Wales are still in the process of meeting their respective targets in reducing emissions from the heat, transport and industry sector.

Time Period	Indicative Assessment	Description
Prospect to meet policy objectives/ targets by 2050	Mixed picture	Heating is one of the most challenging areas to decarbonise. More than 80% of UK dwellings are heated by natural gas, a major contributor to UK greenhouse emissions from homes. In line with the UK Government, Welsh Government has proposed, through their Future Homes Standards building regulations, that from 2025 gas boilers can no longer be fitted in new homes. Instead, low carbon heating technology will be used. Low carbon retrofit for existing buildings both on and off-gas grid would require a transition to heat pumps, low carbon gas. or district heating networks with renewable low carbon energy sources. There is currently no clear strategy in place to achieve this and a regulatory approach will be needed to drive this change. Transport remains the largest emitting sector of greenhouse gases in 2017, having overtaken the energy sector in 2016. Around a fifth (21%) of UK greenhouse gas emissions came from road transport in 2017. Since 1990, emissions from rail, buses and domestic shipping decreased, whereas van emissions increased by 67%. Van traffic has doubled since the early 1990s. (DfT, 2019). This coincides with 28% increase in road traffic during the same period, although GHG emissions from road transport increased by only 6%. This is likely to have been due to improvements in the fuel efficiency and emissions from newer vehicles (ONS, 2019). The UK Government has committed to ban sale of new diesel, petrol, and hybrid vehicles by 2035 to help the transition to zero emission vehicles. The transition to electric vehicles is predicted to require a large increase in UK electricity generation to meet this demand due to the need for large scale charging infrastructure. Industries such as steel, petrochemicals and cement manufacturing will still produce large amounts of CO_2, leaving hydrogen and carbon capture, utilisation, and storage as some of the methods for reducing emissions from the sector.

Robustness of data: Data is probably adequate in helping to assess the sectoral emission.

4. The impact of resource use from energy on ecosystem services and the 4 aims of SMNR

Ecosystems provide a range of goods and services that contribute towards human well-being through environmental, economic, and cultural benefits. The supporting, provisioning and regulating services provided by the ecosystems underpin most of the energy services used daily as described in Table 7, Table 8 and Table 9.

The way in which energy is harnessed and employed makes it a critical environmental issue, as often its sourcing, production, transmission, distribution, and consumption has an impact on the ecosystems.

The generation of energy, both from fossil fuel and renewable sources, generate a number of local and global impacts such as consumption of natural resources, production of atmospheric emissions, consumption of water, generation of conventional and nuclear waste, increase in land use and the installation of infrastructure which have effects on habitats, flora and fauna (UNEP, 2007).

According to IUCN (2008), most factors leading to the accelerating loss of biodiversity are linked to the development and increasing use of energy by society. These links are both direct, such as fuel use, and indirect, such as support for food production and consumption, and that all energy sources have impact on biodiversity one way or the other.

Energy technologies have local impacts where energy is generated, and global impacts where energy feedstock or raw materials for energy infrastructure are sourced (Nerini et al., 2017; Hastik et. al, 2015). Assessing these impacts in both local and remote locations is important but challenging (Hastik et.al, 2015).

Ecosystems are also key in meeting the growing energy demand especially if the aim is to meet that demand through renewable sources. The quality and integrity of ecosystems need to be well-managed and enhanced to ensure the sustainability of future supplies (Svadlenak-Gomez et al., 2013).

The importance of ecosystem services is increasingly being recognised by governments and while there is considerable research undertaken in understanding the impact of energy on ecology, little has been done to translate these impacts in understanding their effects on human well-being (Ekins et al., 2015; Hastik et al., 2015)

Stocks of natural resources are safeguarded and enhanced (Aim 1)

The transition to renewable energy sources is both vital and inevitable for sustainable development (UN, 2015). The consistent availability of renewable energy is a central goal of sustainable energy concepts, alongside energy efficiency and sufficiency.

Renewable energy sources, such as wind, water, solar, biomass, wave, is a natural resource and must be sustainably managed for its continued sustainable use and role in addressing the climate crisis and energy trilemma.

For instance, water provision is a key ecosystem service and underpins many energy production options, such as supporting biomass production and its use in hydropower installations. More modern applications of ecosystem services for energy production include the harnessing of energy contained within ocean currents to generate electricity. See also the water efficiency chapter and marine chapter.

In recent years the expansion of renewable energy has been controversial in terms of land use competition, social acceptance, and trade-offs with nature and biodiversity conservation (Jackson, 2011; Tilman et al., 2009) which has negative consequences on the quality of the provision of ecosystem services (Svadlenak-Gomez et al., 2013). For example, some renewable energy pathways can have major impacts on biodiversity by disrupting ecosystem processes and thus, potentially taking a toll on the provision of the ecosystem services (Gasparatos et al., 2017). See Table 7, Table 8 and Table 9for some examples. Therefore, it is important to systematically analyse the benefits and disadvantages of renewable energy technologies in order to find the best possible solution for a specific location and help safeguard the natural resource for its continued ability to support ecosystem services (Hastik et al., 2015).

The town and country planning system help to ensure the delivery of development whilst mitigating any potential adverse environmental effects by steering the right development to the right locations.

For example, Future Wales; National Plan 2040 identifies pre-assessments areas where significant onshore wind farms can be located, giving greater certainty to developers, planning authorities and the public where such forms of development are more likely to be considered acceptable. In essence it provides strategic principle of steering the right, large scale, renewable technology to the right place.

However, whilst the planning system has the ability to direct development to fewer sensitive areas for mature technologies, its ability to do likewise for emerging renewable technologies is limited due to limited evidence and understanding of potential effects.

Ecosystems are resilient to expected and unforeseen change (Aim 2)

All sources of energy, both conventional and renewable sources, have an impact on the natural environment and its ecosystems. The key to sustainable energy systems is to ensure that the right technology is developed in the right place.

For example, many big dam hydropower sites have dire ecosystem consequences in terms of direct impact on habitats and species and long term impacts due to changes in hydrology, geomorphology, barrier effects and ecosystem continuity (Abbasi and Abbasi, 2011). These impacts can be avoided by using run-of river schemes, rather than dam type schemes, located in less sensitive areas which would retain ecosystem integrity and resilience. (Abbasi and Abbasi, 2011)

In the case of biomass, sustainable forest management could help avoid over-exploitation of forests, woodlands, rivers and make the physical environment in which these systems exist sustainable. For example, it will ensure the river system or forest system, as they are more stable, will retain the biodiversity of their natural ecosystem and the natural processes within them. As a result, they will continue to protect the provision of wider ecosystem services and increase their resilience to climatic change.

Table 7 Ecosystem impact on provisioning services from renewables technology. (Source: Hastik et al., 2015)

Renewable technology type	Threats	Benefits
Hydropower	• Reduced water availability when diverted from water course • Loss of productive land • Land use conflicts	• Water retention at reservoirs in case of drought
Wind power	None	None
Ground mounted photo-voltaic	• Solar fields compete with food production	• Solar fields used as grazing for sheep • Alternative to reforestation of steep slopes
Deep geothermal	None	None

Table 8 Ecosystem impact on regulating and supporting services from renewables technology. (Source: Hastik et al., 2015)

Renewable technology type	Threats	Benefits
Hydropower	• Physical and hydrological alterations resulting in habitat loss and reduced ecosystem resilience	• Water retention by hydro power schemes in case of extreme weather events
Wind power	• Habitat destruction and disturbance to air routes for birds and bats	None
Ground mounted photo-voltaic	• Plant community changes due to shading • Alteration of green corridors	None
Deep geothermal	• Near surface: impact on groundwater invertebrates possible • Deep geothermal: modification of habitats in conservation areas	None

Table 9 Ecosystem impact on cultural services from renewables technology. (Source: Hastik et al., 2015)

Renewable technology type	Threats	Benefits
Hydropower	• Destruction of landscapes	• Positive connotation of water areas, dams and reservoirs as “landmark”
Wind power	• Visual impact on landscapes	• Positive connotation as “landmark”
Ground mounted photo-voltaic	• Visual impact on landscapes	None
Deep geothermal	None	None

Therefore, it is important to maintain the integrity of the ecosystem while pursuing energy security in the face of anticipated climate change.

The challenge will be meeting this demand in a way that does not undermine ecosystems. Improving energy efficiency, energy intensity and conservation must be central to any approach as will be managing the overall impacts of energy use on biodiversity (IUCN, 2008).

Wales has healthy places for people that are protected from environmental risk (Aim 3)

In Wales, the Well-being of Future Generations Act 2015 bestows a remit on public bodies to improve the social, economic, environmental and cultural well-being of Wales through delivery of its seven well-being goals as outlined above in Figure 11.

Given that energy is a fundamental requirement for supporting development and economic growth which contributes to well-being, the challenge lies in providing energy services sustainably and ensuring energy security without driving further loss of species and ecosystems. This is in addition to mitigating the impacts of climate change, which is caused partly by both energy production and consumption and has the most significant indirect impact on ecosystems services and biodiversity.

The solution lies in parallel, mutually reinforcing approaches:

1. ensuring a diversified and distributed sustainable energy mix combined with increased energy efficiency and conservation
2. restoring and sustainably managing ecosystems
3. adopting adaptation measures (IUCN, 2008).

Priority must be given to national scale improvements on energy efficiency and reduction in energy demand.

Other key focus areas should include:

- Improving ecosystem management, for example biomass source, that promotes more moderate harvest levels of forest products or other vegetation so that the ecosystem can retain its overall integrity.
- Managing forest resources in a sustainable manner also increases resilience and adaptive capacity to climate change by providing a resource base as well as a physical buffer against flooding (IEA, 2013).

An integrated water management approach that assesses river basin resources from a broad perspective and includes planning and multiple stakeholder involvement (Williamson and McCormick, 2008) must be implemented. Such an integrated approach can help protect water flows and ecosystem services in the long term by providing a life supporting resource and an energy source for small hydropower systems (Abbasi and Abbasi, 2011), thereby increasing resilience and adaptive capacity of the community.

Contribution to a regenerative economy (Aim 4)

A regenerative economy is an alternative to a traditional linear economy, of make, use, dispose, in which resources are kept in use for as long as possible, the maximum value is extracted from them whilst in use, and the products and materials are recovered and regenerated at the end of each service life (WRAP, 2020; Welsh Government, 2019q). See the Waste chapter for more information.

It is a systems-level approach to economic development designed to benefit businesses, society, and the environment. Circular economy in the energy system consists of design, processes and solutions that maximise the efficient use of natural resources for energy production, end use of energy, and excess energy and side streams (Deloitte, 2018). It offers an approach that is not only powered by efficiency solutions and low carbon energy, but also transforms the way products are designed and used.

Deloitte (2018) highlights that the energy system can be optimised through three key tactics:

1. Circular economy of energy production, this includes renewable energy and waste-to-energy
2. Industrial symbiosis and municipal-level circular economy cooperation, this includes the use of excess energy and side streams for industries and municipal and industrial cooperation
3. Circular economy in the customer interface, this includes demand response, two-way district heat, energy-as-a-service and energy efficiency of the end user

A good example of this tactic is illustrated in Figure 12, which outlines the circular economy concept for the wind energy sector. Wind turbines already have a recyclability rate of 85% to 90% (Wind Europe, 2020). Making turbines 100% recyclable is an important task for the wind industry as Wales heads towards a circular economy.

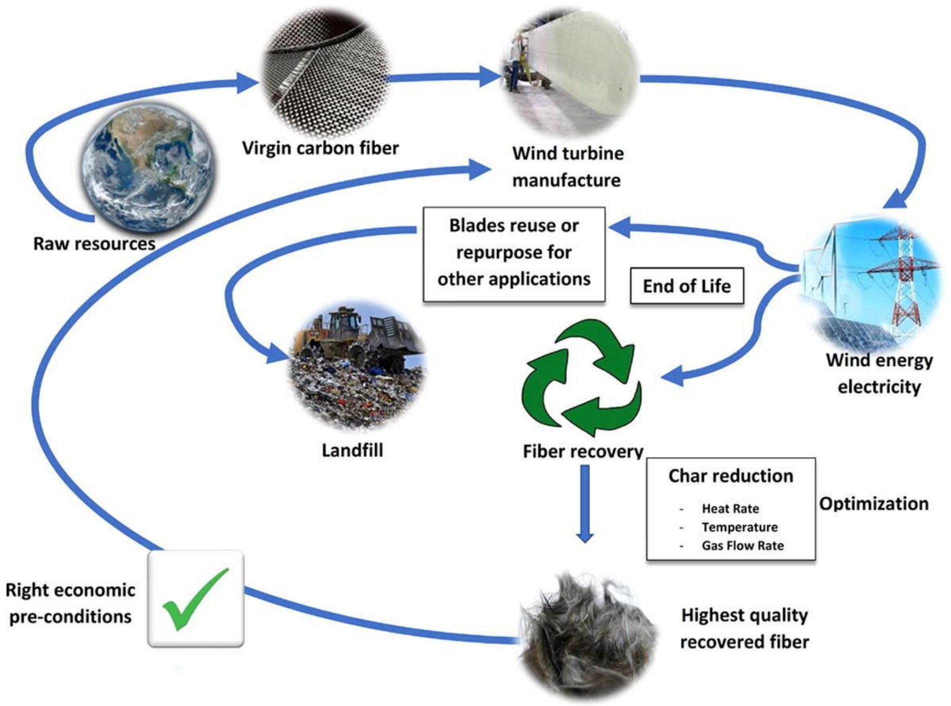

Figure 12 Circular economy of wind energy sector
Source: Reprinted from Hao et al., 2020. © 2021 with permission from Elsevier

The concept of energy from waste (EfW) has potential to deliver environmental and economic benefits to Wales while keeping costs down for local authorities. It is key in the transition to achieving zero waste by 2050 (Welsh Government, 2010). The waste hierarchy helps illustrate the role of EfW of separating recyclable materials for recycling and reprocessing as a priority over energy recovery where there are markets for those materials, followed by energy recovery, which is preferred over landfill for non-recyclable, combustible material. In short, to effectively manage all waste, all levels in the waste hierarchy need to be addressed. See the Waste chapter for more information.

5. Impact of energy on key themes

Impact of energy on climate change

A typical global consequence is the 6 greenhouse gases regulated in the Kyoto Protocol; five are emitted during different activities within the energy production process which affects the climate. During the generation of electricity in thermal plants, the combustion of fossil fuels produces carbon dioxide (CO_2) and nitrous oxide (NO_x) emissions.

Impact of energy on land use and soils

The rise of renewable energy and the management of energy demand are identified as two areas in which new dimensions and tensions are being added to the relationship between energy and land use (IEA, 2013). For example, current and future energy demand is expected to be addressed to some extent by using bioenergy to generate electricity, heat, and power transport. (Welsh Government, 2019a; 2019h) Converting large areas of land for biomass production will have major implications for food production, water use, biodiversity, recreation, and carbon sequestration (see Land use and soils chapter).

Sustainably done, bioenergy is known to provide opportunities to mitigate water pollution impact in addition to its role in decarbonisation especially in heat, which is one of the biggest challenges for Wales.

Impact of energy on woodlands and biodiversity

Energy generation and distribution activities impacts biodiversity through the modification or loss of natural habitat, such as woodlands, due to changes in land use or changes in ecosystems as a result of development of energy facilities (Luderer et al., 2019).

Even the renewable energy sector, which is considered the backbone of the Green Economy, is known to affect the ecosystem and biodiversity (Gasparatos et al., 2017).

This also extends to energy intensive sectors such as transport, industry, and buildings. For example, transport requires energy mainly for vehicle operation and to some extent, for manufacturing of the vehicle, all of which impacts the natural environment and its habitat.

Impact of energy on marine

Hydrokinetic/marine energy, which includes wave and tidal power, encompasses an array of energy technologies, many of which are still in the experimental stages or in the early stages of deployment. While actual impacts of large-scale operations have not been observed, a range of potential impacts can be projected (Gasparatos et al., 2017).

Such perceived impacts include disturbances of coastal ecosystems at or near the seabed, which are known to be important habitats for many species (Frid et al., 2012; Bonar et al., 2015). The limited deployment of modern ocean energy means that there is little empirical evidence to quantify the actual effects on ecosystem change and biodiversity, with many of these effects being essentially speculative (Frid et al., 2012; Bonar et al., 2015). See the Marine chapter for more details.

Impact of energy on water resources

Energy and water systems are intricately interdependent and are directly influenced by factors such as population, climate and economic growth. Water is required in the energy delivery value-chain, particularly for the extraction of fossil fuels, fuel production, thermal power plant cooling and heat transfer in domestic and district heating. See also Water efficiency chapter.

It is also perceived that there could be significant impacts from the onshore hydrocarbon and exploitation on the UK water systems, particularly groundwater, should the sector develop into commercialisation (Konadu et al., 2017).

Even fuels or technologies used to achieve the clean energy transition could, if not properly managed, increase water stress or be limited by it. Some low-carbon technologies, such as wind and solar PV require very little water, others, such as biofuels, concentrating solar power, carbon capture, utilisation and storage of nuclear power are relatively water-intensive (IEA, 2020).

Impact of energy on air quality

Energy generation, distribution and consumption activities has significant impact on air quality. The two energy intensive sectors which has significant impact on air quality is transport and industry.

In the UK, energy consumption in the transport sector has been steadily increasing as illustrated in Figure 13 and more than 90% of transport energy use depends on oil products. Since most transport emissions are discharged at street level, often within densely populated cities, improvements in transport efficiency can therefore have a significant impact on air pollution and on human health.

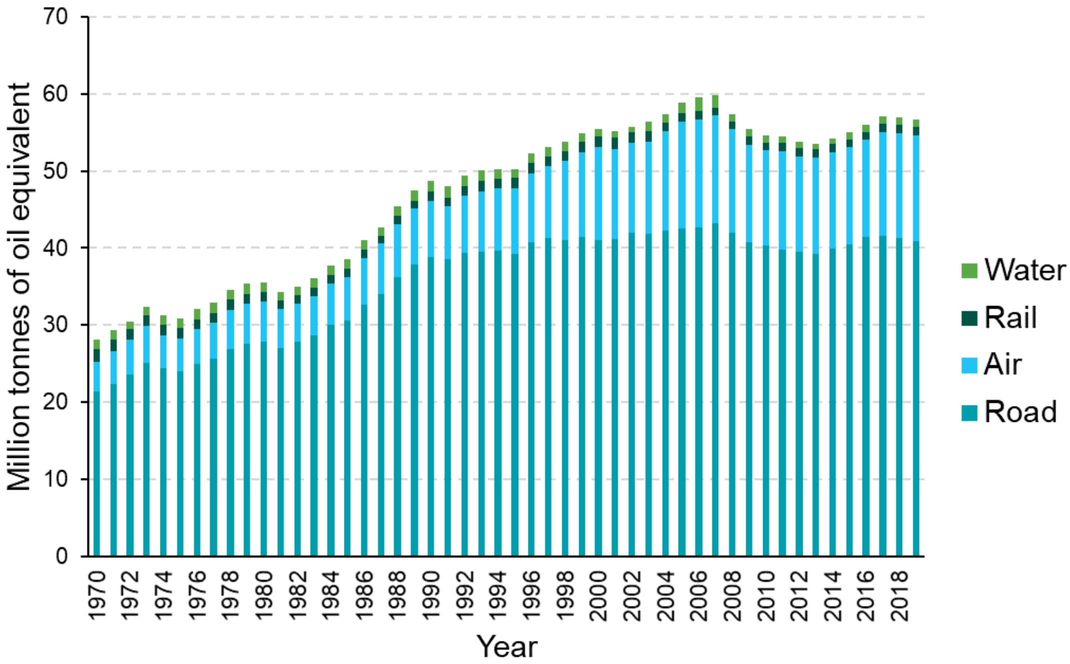

Figure 13 Trends in transport consumption from 1970 to 2018
Data sourced from: BEIS, 2020f

6. Synergies and Trade-offs

Energy underpins economic and social development; thus, it lies at the heart of both the UN's 2030 Agenda for Sustainable Development and the Paris Agreement on Climate Change (UN, 2015).

Ensuring access to affordable, reliable and sustainable energy is also key for Wales in achieving both the SMNR objective and Well-being Goals as outlined in the Environment (Wales) Act 2016 and Well-being of Future Generations (Wales) Act 2015.

The role and importance of a sustainable energy system required in managing Wales's natural resources and improving the social, economic, environmental and cultural well-being of Wales, can be seen through the examples outlined in the linkages between the 17 United Nations Sustainable Development Goals.

The interconnectedness between various goals and sectors, for example water-energy-and food, implies the potential for synergies but also the risk of trade-offs (Nerini et al., 2017; Fader et al., 2018). Synergies are understood as positive effects of a target achievement that would, in turn, allow reaching other targets or mutually beneficial development of infrastructure and policies, which can facilitate sustainable development.

A good example of a synergy is energy from waste (EfW), which is not limited to waste management. The energy it produces is a valuable domestic energy source contributing to energy security. It can also contribute to renewable energy targets which are aimed at decarbonising energy generation whilst improving the environment. EfW also has the added advantage that it is non-intermittent, so it can complement other renewable energy sources such as wind or solar.

Trade-offs are created where one target intensively uses resources necessary for the achievement of another target, or when environmental degradation caused by the achievement of one target limits the chance of achievement of another target. For example, the paths taken by individual nations to achieve energy targets could affect their ability to achieve the water and food targets in either a positive or negative way.

An example of a trade-off is bioenergy which is the most contested renewable technology in relation to land use (Trainor et al., 2016). Bioenergy is also known for its implication on water resource and food prices (Gheewala et al., 2011). Bioenergy can provide opportunities to mitigate water pollution impact (Gheewala et al., 2011) in addition to its role in decarbonisation especially in heat (UKCCC, 2018b), which is one of the biggest challenges for Wales.

In a recent study looking at the synergies and trade-offs between efforts to achieve Sustainable Development Goal (SDG) 7, Affordable and Clean Energy, and delivery of the 2030 agenda, it was recognised that out of the 169 targets featured through the 17 goals, 113 targets required actions to change the energy system (Nerini et al., 2017). This is illustrated in detail in Figure 14 which indicates targets highlighted in black, and indicated with black lines, call for action in relation to the energy system.

The study also identified evidence of synergies and trade-offs between at least 143 targets and actions in pursuits of SDG7. At 143 synergies, as shown in Figure 15, there are more than twice as many synergies between SDG7 and other targets than there are trade-offs, of which there are 65 as shown in Figure 16 (Nerini et al., 2017).

Nearly all trade-offs relate to the tension between the need for rapid action to address key issues for human well-being, for example, poverty eradication, access to clean water, food and the careful planning needed to achieve efficient energy systems with a high integration of renewable energy (Nerini et al., 2017).

From an environment and natural resources perspective, which the energy system underpins and profoundly impacts on, the study indicates 46 environmentally-related targets with synergies and 31 trade-offs with SDG7 (Nerini et al., 2017). Interestingly, the study also concluded that it was not possible to deliver SDG7 without understanding how the energy system affects and depends on well-being, infrastructure and environment.

Figure 17 highlights a diagram by the European Environment Agency outlining energy, mobility, and food system as the core of societal and economic development. This has been modified to reflect how the mobility, energy and food system also encompasses other key themes informing the SoNaRR. Much of the impacts and potential benefits of the energy system with other key theme areas of SoNaRR has been discussed in earlier sections. However, mapping the synergies and trade-offs between energy and the Well-being goals may provide further insights on how the natural environment can be managed more sustainably as required by the Environment (Wales) Act.

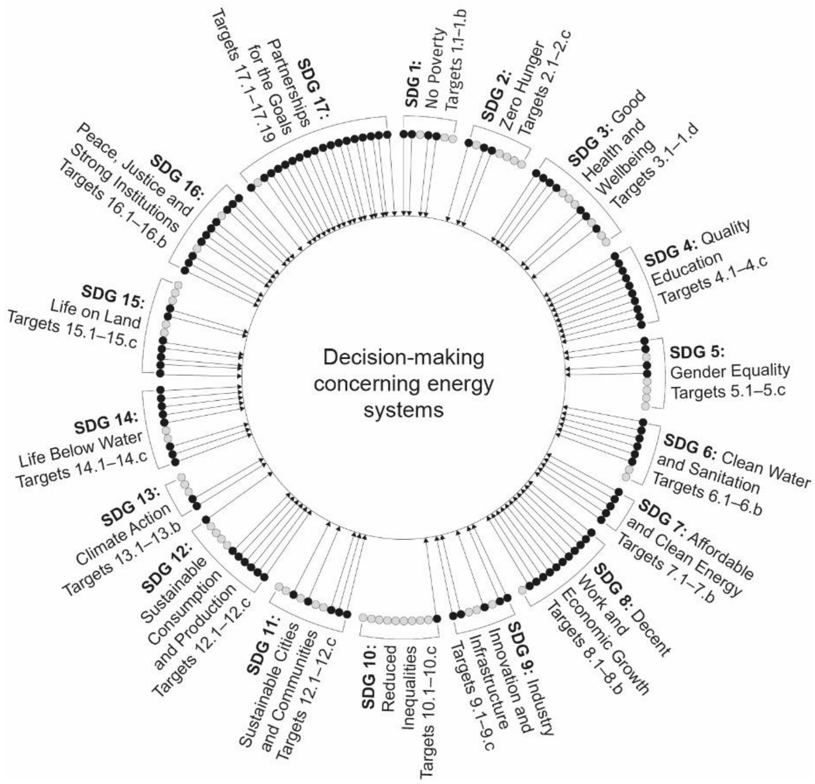

Figure 14 Interlinkages between energy system, the SDGs and targets (Reprinted from Nerini et al., 2017. © 18 March 2021 with permission from Nature Springer)

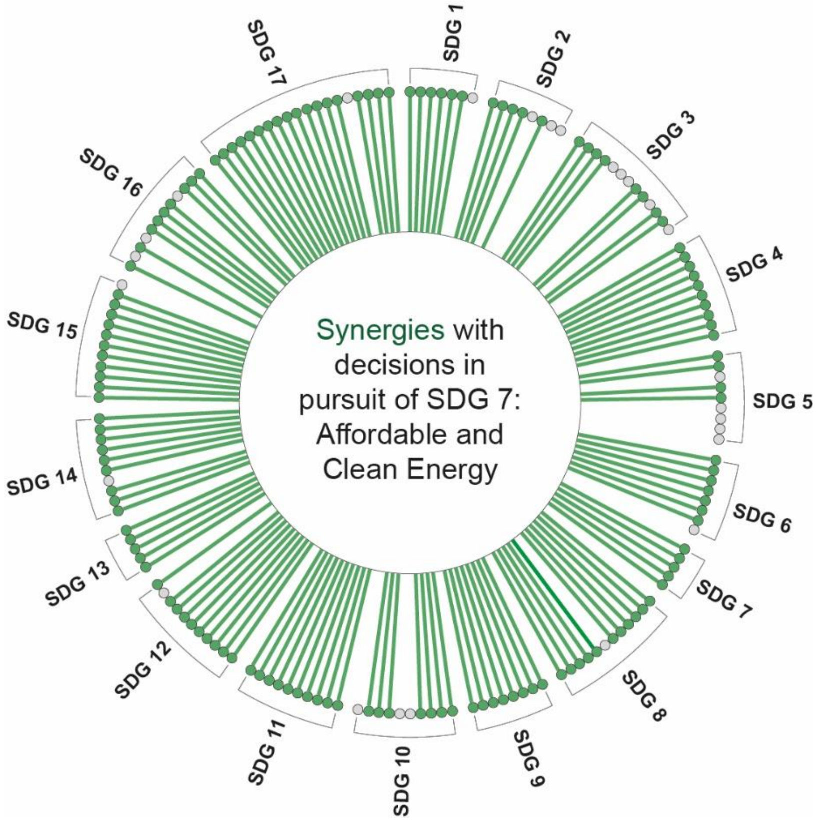

Figure 15 Interlinkages between energy system, the SDGs and targets – synergies (Reprinted from Nerini et al., 2017. © 18 March 2021 with permission from Nature Springer)

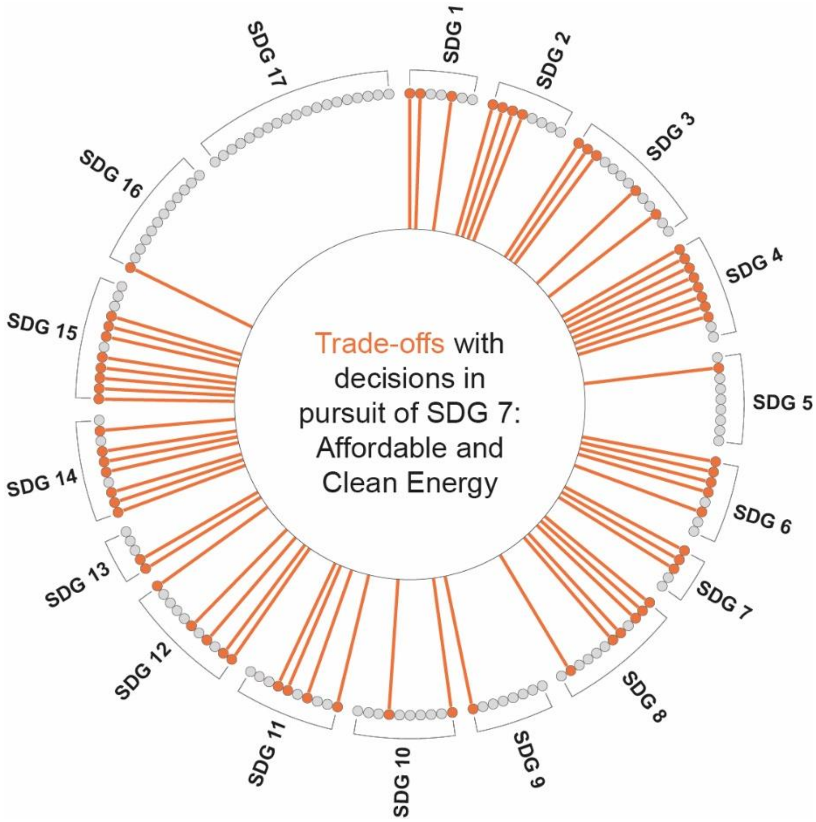

Figure 16 Interlinkages between energy system, the SDGs and targets – trade offs (Reprinted from Nerini et al., 2017. © 18 March 2021 with permission from Nature Springer)

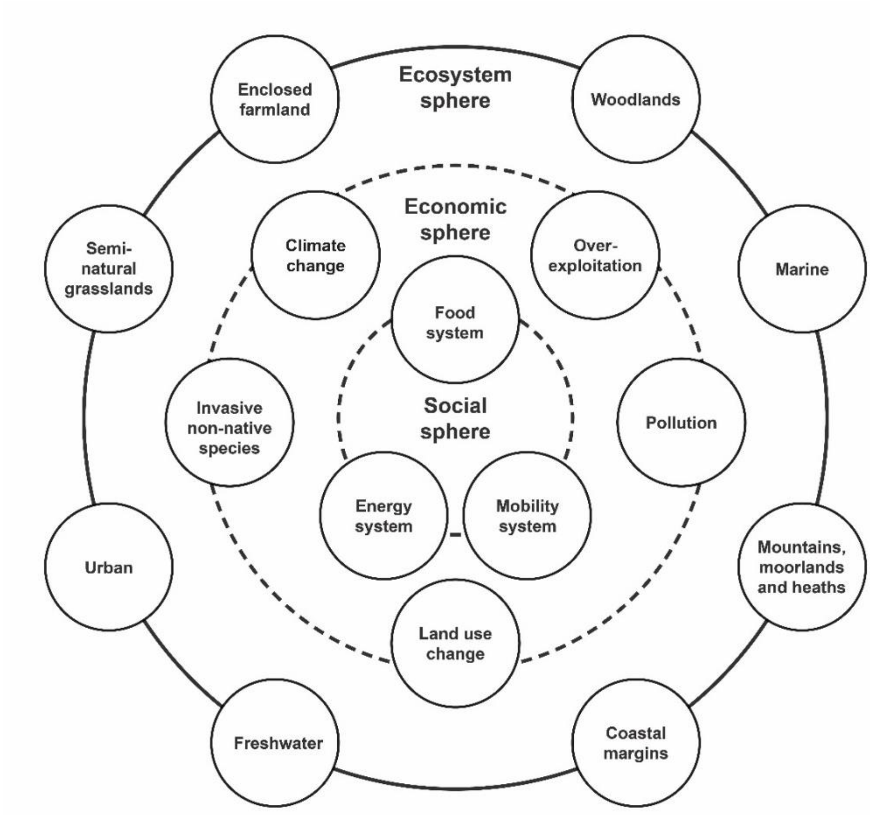

Figure 17 Interlinkages of energy, mobility and food systems and SoNaRR theme areas Adapted from: European Environmental Agency, 2019

7. Opportunities for action to achieve the sustainable management of natural resources

Achieving the sustainable management and efficient use of natural resources will require changes to how energy systems use natural resources to minimise impacts.

Adopt the principles of energy hierarchy

The UK and Wales need more vigorous energy management that considers and embeds the energy hierarchy in the transition of the energy system which is applied across electricity, heat, and transport. It should be made the cornerstone of the energy transition. There is enough evidence to support that this can be done with desired economic growth.

The concept of the 'Energy Hierarchy' (IME, 2020) is simple, but has profound implications for the energy sector. It is a principle for prioritising solutions which states that a coherent energy policy must start with energy demand reduction and continue with improving energy efficiency before different types of energy supply are considered (Welsh Government, 2011). It has five tiers of priorities as illustrated in Figure 18.

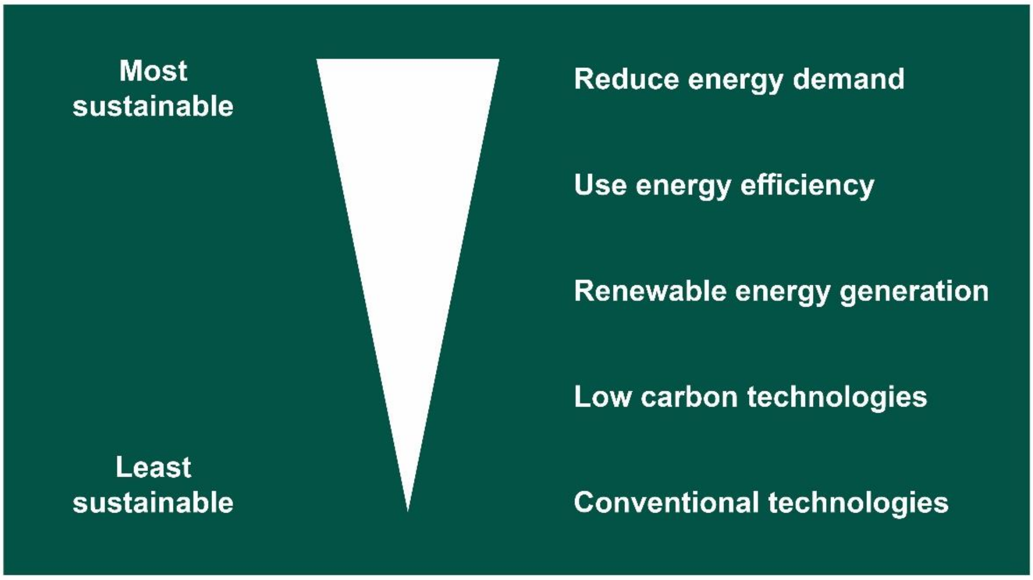

Figure 18 : Energy Hierarchy
Adapted from: IEM, 2020

Tier 5, conventional technology, provides no benefits in addressing the environmental or climate change issue but captures the short to medium term energy security, known as the 'bridging technology' as regarded by the UN's

Intergovernmental Panel on Climate Change report (IPCC, 2014), and should be phased out.

It is vital for the energy sector to adopt and implement the energy hierarchy as has been the case with the waste hierarchy. The concept of a 'Waste Hierarchy' (Welsh Government, 2019n) has been very influential in advancing the debate about ways of controlling waste and reducing the emissions from the waste sector (Welsh Government, 2019e). A similar approach can help the prioritisation of new solutions for energy management.

The energy hierarchy provides an effective framework to guide energy policy and decision making. The hierarchy does not require that one tier be completed before moving on to the other. Instead, it would be beneficial to practice all tiers at the same time.

Whole systems approach to energy transition

A whole systems approach in developing a portfolio of options for clean energy, through various ways must be adopted, from:

i) macro: the interaction between the power, heat and transport sectors;
ii) sectoral: the interaction between and cost effectiveness of supply, demand and storage measures
iii) technological: valuing the associated network and system costs of different generation options.

The whole system approach should also apply across vectors and process stages, and between the energy sector and other sectors, for example water, land and waste, which can present significant opportunity for new technologies, methods and services that are bundled across vectors and sectors.

Lifecycle analysis for all energy technologies

A life cycle assessment (LCA) is a method of study used to estimate the environmental impact caused by all stages of the life of a product, or in this case, energy source, from production to end-use. In decarbonising the energy system, all energy technology should be considered on its LCA. Even renewable energy comes with some environmental impacts which makes LCA valuable. This will also aid in ensuring that the right development is in the right place.

8. Barriers to achieving the Sustainable Management of Natural Resources and how they could be resolved

Behaviour

Behavioural issues need to be considered in all aspects of the energy transition, from improving awareness of the benefits of energy efficiency and renewable energies, to ensuring that technologies are easy to use, and that financial decisions can be made in a well-informed manner. The challenge is to consider how citizens react to everyday decisions and situations, how they plan in the long-term and how they, therefore, make investment decisions.

While new technologies and materials are widely available, encouraging uptake and proper use requires individuals to be provided with adequate information to enable them to make choices which are in the long-term societal interest. For many, this may clash with their own interests, or their perceived interests, or they may simply be unaware of the options available to them.

Long-term planning and investment decisions, such as building insulation and installation of new technologies, require conscious decisions with an awareness of benefits and available financial means.

However, even once investments have been made, retrofitting buildings with energy efficient technologies can sometimes trigger ‘rebound effects’, where lower energy bills simply encourage users to use more energy or where cost savings are directed towards purchasing other energy intensive goods and services (IEA, 2019b). The resulting energy efficiency gap is the difference between expected and actual impact and is related to the behaviour of its users.

Therefore, it is important to consider the role of behaviour in energy transition, from when to make investments in building renovations, to when to use and operate electrical equipment, and the settings and modes in which to use them. Behaviour change therefore includes change in both long-term direction and thought, as well as in day-to-day behaviour.

Infrastructure

The lack of infrastructure

The transition of the UK/Welsh energy system is both deep and rapid, driven by changes in technology, economics, policy constraints and consumer choice. Yet some aspects of energy networks evolve more slowly as infrastructure investments are often capital-intensive, time-consuming to plan and construct and, once built, have a lifetime of multiple decades.

New political commitments, such as the UK's Net Zero Target and the ratification of the Paris Climate Change Agreement, will accelerate energy system change and impose stronger constraints on emissions which has wide-ranging consequences for energy infrastructures. (See Climate change chapter). A failure to fully incorporate these aims into UK energy infrastructure policy would increase risks for network developers and market actors and raise the overall costs for the transition. This is outlined in the Welsh Government's Energy Generation Report (Welsh Government, 2019i) on the lack of infrastructure such as grid capacity that hinders Wales meeting its renewable electricity target.

There is also the need to consider how future infrastructures will sit within the new norm of the energy networks which will integrate heat and transport along with electricity. The integrated nature of modern energy networks is blurring the boundaries between infrastructure types. Increasingly interconnected transport, heat, digital and energy systems offer considerable opportunities but stretch the limits of the current regulatory framework.

A modern approach to energy infrastructure needs to go beyond the traditional categories of pipes and wires. This includes recognising demand-side resources such as infrastructure; integrating planning and operation of gas and electricity networks; tapping into the demand flexibility potential from electrified heat and transport; and enabling multipurpose projects such as offshore grids.

The infrastructure policy framework needs to be fully aligned with the transitions of the future. The challenges to the UK/Welsh energy infrastructure are increasingly recognised by individuals across the system. Finding appropriate solutions will require reshaping the UK's approaches to infrastructure planning, financing, and institutional governance.

The vulnerability of infrastructure to climate change

Infrastructure in the UK and Wales is experiencing significant impacts as a result of the natural variability of the climate. This is currently worsened by the increasing effects of climate change (Welsh Government, 2019m). Transportation of energy sources and electricity infrastructure systems will feel these effects in particular. For example, severe storms such as the recent "Beast from the East", Storm Ciara and Storm Dennis that produce high winds, ice, snow and lightning can damage electricity lines, particularly where the majority of electricity transmission and distribution is above ground. The climate emergency means events like these will become more frequent and will increase in severity. In the face of such a crisis, coping effectively with their effects can also tackle the root of the problem, for example insulating homes against heat loss means more energy efficiency, less CO_2 emissions and slower climate change. (Welsh Government, 2019p). See Climate change chapter.

Technology

Technology and innovation are key components of a successful whole system energy network. The lack of it will hinder both progress and uptake of technologies vital for the decarbonisation of energy networks. For instance, under current pricing structures, many households spend a significant proportion of their income on energy bills which has been a challenge in providing affordable, reliable and clean energy to consumers. Innovative technological solutions have helped solve a large aspect of this problem by helping to optimise energy use. These technologies help to generate clean and renewable energy and, with innovative ways to store it, have automated its use in the most efficient and affordable way.

Solar panels, for example, are becoming cheaper and more widely used. Such energy optimisation technologies will make the system more reliable and secure and will improve power quality, lower costs and reduce emissions. Optimisation does this by balancing energy price, individual and collective demand requirements, weather forecasts and battery charging times.

There are also concerns that innovation in technology and system are not developing fast enough to promote investor confidence or to keep up with the progress needed. The slow progress in scaling up and demonstrating new technologies may limit the extent in which innovation within the UK energy system develops.

Political

Geopolitical issues are a well-known barrier in optimising the energy hierarchy. For instance, political instability, between and within nations, poses a risk to the security of energy supply materials and resources. Geopolitical instability may manifest in price volatility, such as leading to higher generation costs, disruption of supply chains or degradation of international relationships which could disrupt the chain of energy hierarchy.

Political disagreement within the UK may also pose a risk to the delivery of certain cross border projects while political dispute may disrupt electricity delivery from neighbouring countries via interconnectors, leaving the UK vulnerable to supply and demand inequalities.

Policy

There are also concerns that a general lack of consensus about energy policy may limit its overall effectiveness of maximising energy hierarchy and hinder the progress of transition. This is obvious in the case of energy efficiency which is well known for its benefits in decarbonising the energy system but lagging behind due to ineffective polices and political will to maximise its benefits.

9. Main pressures affecting resource use

Drivers of Change

This section provides a brief overview of the main and changing environmental, social, technological and economic drivers of the energy system that continue to impact the natural environment.

Demographic Drivers

Population growth

Energy is a pre-condition to population growth. At the same time, a growing population consumes more energy which exerts a demand on energy resources, challenging supply and impacting the natural environment.

The long-term resilience of a wide range of environmental systems is now being tested by the requirements of a rapidly growing global population and the demand for higher living standards. This includes meeting the energy and food needs of the estimated 9 billion people in 2050. As population grows, competition for energy resources grow. Energy security concerns emerge as more consumers require ever more energy resources which has taken a toll on the energy systems where unsustainable practices have dominated. Continuing deterioration of natural resources could stress the ability to meet the needs of the growing population and undermine economic activity (Luderer et al., 2019).

In Wales, the population grew by 150,000 between 2005 and 2017 (Welsh Government, 2020d) with 31% growth in average productivity per head. In the same period energy consumption decreased by 19% (Welsh Government, 2020d), particularly electricity consumption (Welsh Government, 2019i). This is partly due to increasing efficiency but also because Wales imports many of its manufactured goods from overseas. This contributes indirectly to impacts on ecosystems in other parts of the world through the energy used in the material production, manufacture and transport of the imported goods that are consumed.

Green growth could meet the challenge of increasing energy demand as population grows (OECD, 2011; Welsh Government, 2015). Green growth is about fostering economic growth and development while ensuring that natural assets continue to provide the ecosystem services on which the well-being relies. See SoNaRR Aim 4: A Regenerative Economy for more information.

Sweden has successfully decoupled economic and population growth while successfully reducing the CO_2 emissions of its energy system by reducing fossil fuel dependency, carbon intensity, conversion loss and energy intensity (Kerr, 2014; UNEP, 2011). In contrast, during the same period Canadian emissions have continued to rise in the context of rapid demographic and economic growth without the same success for all four technology terms (Kerr, 2014; UNEP 2011).

Increased urbanisation

Increasing urbanisation is significantly related to energy use. Urbanisation has increased energy consumption through three pathways:

1. increased energy consumption in new buildings and transport sector
2. urban motorisation, which induces energy-intensive transportation
3. the rising quality of energy-intensive lifestyles. (Zhao and Zhang, 2018).

Urbanisation is also one of the reasons for increased energy consumption, especially fossil fuel, which creates the challenge of mitigating air and noise pollution and controlling waste (Minh et al., 2017). See also Urban chapter.

Decentralisation of urban areas which encourages decentralised energy supply through a renewable energy supply network could help address some of these issues, coupled with urban policies designed to encourage compact urban growth. Green buildings and new energy vehicles could play a vital role in saving energy.

The changes in lifestyle and growth of a global consumption society and e-Society will bring new challenges to energy-saving policies and climate change mitigation.

Policy Drivers

The Climate Change Act 2008 provides a guide for the UK's transition to a low carbon economy. It also provides a long-term framework for the UK's energy and climate policy.

The UK Energy Act 2013 has been instrumental through the implementation of the Electricity Market Reform (EMR) by aiding investment to the UK's ageing energy infrastructure with a more diverse and low-carbon energy mix. This ensures that the UK has future security of electricity supply and meets its climate and renewables targets in a way that minimises costs to consumers. Some key tools of the EMR are Contracts of Difference, Emissions Performance Standards, Carbon Floor Price and Capacity Market.

The Environment (Wales) Act 2016 requires Welsh Ministers to reduce emissions in Wales by at least 80% by 2050. This Act also requires Ministers to set interim emissions reduction targets for the years 2020, 2030 and 2040, and establish a system of carbon budgeting that together create an emissions reduction pathway to the 2050 target. See the Climate change chapter for more information.

In 2019, the UK government raised the level of ambition, legislating for a net-zero target for all greenhouse gas emissions by 2050. Wales has also accepted this challenge with a target of reducing its greenhouse gas by 95% by 2050 as recommended by the UK Climate Change Committee (Welsh Government, 2019k). The Welsh target will be strengthened and guided by the Environment (Wales) Act 2016 which provides a statutory framework for action on climate change.

The power sector is one of many pathways that has been identified by Welsh Government in its Low Carbon Wales Delivery Plan for specific emission reductions through ambitions to reduce the use of fossil fuels, accelerate the deployment of renewable energy and increase the support for innovation in the power sector (Welsh Government, 2019a). This was strengthened by the 2017 targets which were amended in 2020 with improved targets on renewable energy to be achieved by 2030 (Welsh Government, 2020a).

The systemic change required by the UK and Welsh Government to embrace the commitments of Climate Change will fundamentally change the energy sector.

However, decarbonisation of electricity is only part of the solution to reducing the impact of climate change (UKCCC, 2019). Other elements of note include the reduction in emissions through the reduction in, and decarbonisation of, heat demand for buildings and the replacement of diesel and petrol cars by either electric vehicles or hydrogen fuel cells or both (UKCCC, 2019; Watson et al., 2019).

Economic Drivers

Energy is an input to nearly every product and service in the economy and underpins economic activity across a variety of sectors.

Major shifts in the sector can have strong positive and negative ripple effects throughout the economy as evidenced in Iceland where the geothermal energy business has served to offset the effects of economic crisis. This has made Iceland one of the most prosperous welfare economies in the world, while negative impact can be observed by the recent volatility in oil prices. Energy supply that is more cost effective, reliable, secure and environmentally sustainable contributes to long-term resilience of economic development.

In the UK, as illustrated in Figure 19, the UK economy grew while energy-related emissions did not, a trend also observed by the International Energy Agency in 2015. This concurs with the UK economy which reduced emissions by over 40% whilst growing the economy by over two thirds (BEIS, 2019a).

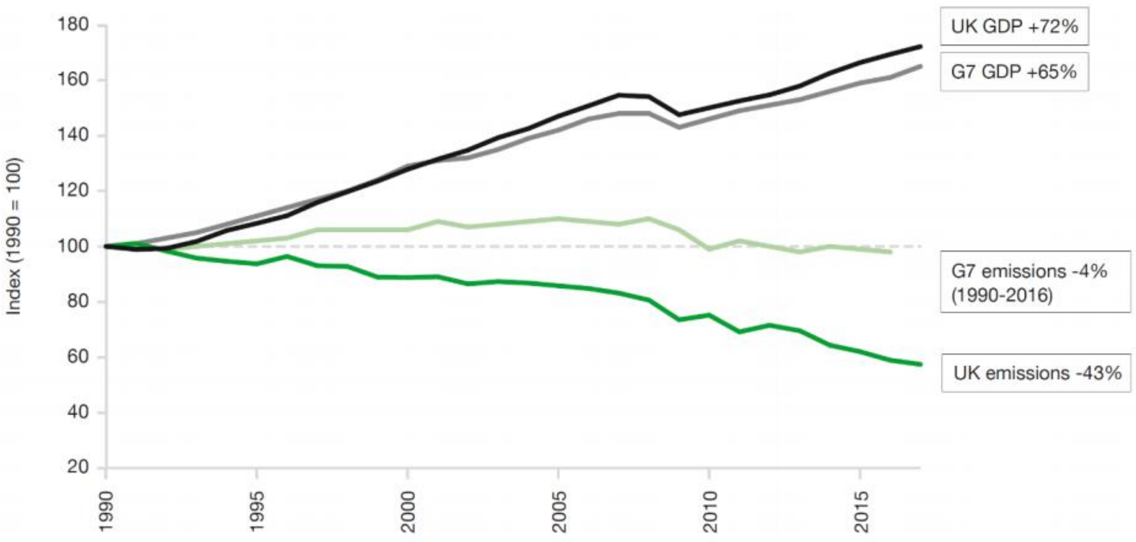

Figure 19 GDP and emissions for the UK and G7
Source: BEIS, 2019a

The UK Government analysis also suggests that the low carbon economy already supports over 430,000 jobs and is predicted to grow by around 11% per year to 2030, four times faster than the average growth rate for the UK economy as a whole (Welsh Government, 2019a) This was affirmed by the UK Climate Change Commission in its Sixth Carbon Budget estimating the creation of over 200,000 jobs within the building retrofit sector between 2030 to 2050 while the Policy Exchange estimates 40,000 direct jobs, plus more across the wider supply chain as new offshore wind, hydrogen and carbon capture and storage industries grow (Nicolle et al., 2020)

It is estimated that exports of low carbon goods and services could be worth between £60 billion and £170 billion by 2030 for the UK (Ricardo Energy and Environment, 2017).

Improved economy of renewable energy

The costs of generating electricity from large scale solar and wind energy are now equal or below the cost of generation from gas or nuclear plants.

According to a new estimate from the Department of Business, Energy and Industrial Strategy (BEIS) electricity from onshore wind or solar could be supplied in 2025 at half the cost of gas-fired power (BEIS, 2020a).

Social Drivers

Fuel Poverty

The Welsh Government recognises that clean growth has a strong social dimension, and that poor building energy performance is not only costly, financially and to the environment, but can cause poor health for householders. Such conditions are preventable through simple measures such as installing insulation and efficient low carbon heating systems

In Wales, fuel poverty is defined as the need to spend over 10% of household income on fuel costs to maintain adequate warmth for health and comfort. The latest estimated figures show that 155,000 households are still in fuel poverty (Welsh Government, 2018b; Welsh Government, 2020b).

Prosumer

The rise of prosumers highlights one of the most exciting trends in energy transition and renewable energy. Prosumers are energy users who produce energy through, for example, solar panels installed on or around their houses and using innovative equipment such as heat pumps, energy storage devices, in other words batteries, and electric vehicles that will interact with the energy market through different pricing mechanisms such as time variable tariffs.

Prosumers are both individuals and businesses who may not always be able to produce all the energy they need, so are still connected to the grid to supplement their usage. However, as solar panels, solar inverters and battery storage units become more effective and affordable, energy prosumers can become less reliant on the grid.

Decentralisation

On the demand side, the way energy is used, and the interactions energy users have with the energy system is constantly evolving. Customers are moving away from the linear process and towards a more direct interaction with suppliers through energy generation and managing their usage.

Rapid falls in the costs of solar panels and battery storage, combined with the roll out of smart meters and the continued development of demand side response technologies provide the basis of a very different way of producing and consuming energy with greater emphasis on self and local energy generation.

This is supported by Welsh Government through three key ambitious targets, two of which emphasises on local ownership:

- Wales to generate 70% of its electricity consumption from renewable energy by 2030.
- A target of 1 GW of renewable electricity and heat in Wales to be locally owned by 2030.
- New energy projects to have at least an element of local ownership from 2020.

Technological Drivers

Innovation

Improvements in technology continue to modify the outlook for the energy sector, driving changes in business models, energy demand and supply patterns as well as regulatory approaches. Clean energy technologies could move the energy sector towards higher climate change ambitions if technological innovations were pushed to their maximum practical limits.

Technological advancements are set to make energy systems around the world more connected, intelligent, efficient, reliable, and sustainable. Rapid advances in data, analytics and connectivity are enabling a range of new digital applications such as smart appliances, shared mobility and 3D printing. Technological advancements in energy systems in the future may be able to identify who needs energy and deliver it at the right time, in the right place and at the lowest cost.

Technological advancement are also empowering end users and increasing their knowledge and awareness of energy resulting in positive behavioural change. For example, new tools such as blockchain could help to facilitate peer-to-peer electricity trade within local energy communities.

Energy Technology Perspectives 2017 (IEA, 2017) highlights how energy innovation, in other words scaled-up deployment of available technologies and further development of technologies in the innovation pipeline, can support multiple policy objectives while ensuring secure, reliable and affordable energy. The analysis also indicates that regardless of the pathway chosen for the energy sector transformation, policy action is needed to ensure that multiple economic, security and other benefits to the accelerated deployment of clean energy technologies are realised through a systematic and co-ordinated approach (IEA, 2017).

According to the IEA (2017) over the long term, under a best-case scenario of improved efficiency through automation and ridesharing, energy use could halve compared with current levels. Conversely, if efficiency improvements do not materialise and rebound effects from automation result in substantially more travel, energy use could more than double.

Digitalisation

Digital technologies are everywhere, affecting the way people live, work, travel and play. Digitalisation is helping improve the safety, productivity, accessibility and sustainability of energy systems around the world. It is also raising new security and privacy risks, while disrupting markets, businesses and workers.

The energy sector has been an early adopter of technologies. In the 1970s, power utilities were digital pioneers, using emerging technologies to facilitate grid management and operation. Oil and gas companies have long used digital technologies to improve decision making for exploration and production assets, including reservoirs and pipelines.

The industrial sector has used process controls and automation for decades, particularly in heavy industry, to maximise quality and yields while minimising energy use. Intelligent transport systems are using digital technologies in all modes of transport to improve safety, reliability and efficiency.

Digital technologies are already widely used in energy end-use sectors, with the widespread deployment of potentially transformative technologies on the horizon, such as autonomous cars, intelligent home systems and additive manufacturing, such as 3D printing. While these technologies could reduce the energy intensity of providing goods and services, some could also induce rebound effects that increase overall energy use.

Across all transport modes, digital technologies are helping to improve energy efficiency and reduce maintenance costs. The most revolutionary changes from digitalisation could come in road transport, where global connectivity and automation technologies could fundamentally transform how people and goods are moved. The interactions among potential disruptions in road transport including the uptake of automated, connected, electric and shared mobility will play a key role in shaping the future energy and emissions trajectory of the overall transport sector.

Digitalisation, including smart thermostats and smart lighting, also helps to reduce total energy use in residential and commercial buildings and has been instrumental in reducing energy demand and behavioural change.

Political Drivers

The energy transformation will be one of the major elements that reshape geopolitics in the 21st century, alongside trends in demography, inequality, urbanisation, technology, environmental sustainability, military capability and domestic politics in major states (IRENA, 2019). The energy sector is also highly affected by geopolitics (Prpich et al., 2014), especially for an energy system that remains largely dependent upon fossil fuel and thus susceptible to market volatility and global unrest (Prpich et al., 2014)

On 29 April 2019, the Welsh Parliament declared a climate emergency at the national level (Welsh Government, 2019s). It is now part of 31 countries around the world that have declared climate emergency and are working towards achieving new targets of reaching net zero emission before 2050.

Additionally, Brexit and the current COVID-19 pandemic are likely to impact and change the energy sector and its transformation. In some ways, the pandemic provides the preview of the kind of disruptions that climate change will bring, but it also offers a chance to rebuild a cleaner, more sustainable world.

10. Evidence Needs

Energy data tracking

Understanding the energy consumption trends and habits of individuals, households and businesses is the first and most important step in reducing energy demand and achieving energy efficiency. It could also help understand and compare renewable energy supply profiles with likely demand for different users and geographical area.

Although a wealth of energy information and data are available on the internet at the UK level, the range of data is often limited at the national level for devolved nations. It is also often a challenge sifting through the vast data to find comprehensive, relevant and high-quality material required for end users.

As such accurate, accessible and easy to interpret data on a range of energy related issues such as property characteristics, energy use, sources of energy and income, could help drive a more targeted approach in helping to reduce energy demand and delivering energy efficiency measures through various plans, policies and programmes.

Since 2017 Welsh Government has been producing a Welsh Energy Generation report annually and, as of 2020, a Welsh Energy Use report which provide data on Welsh electricity and heat generation and use, by technology, capacity and local authority area.

In 2017, the Institute of Welsh Affairs produced a concise data-base for a sub sector of energy: buildings. The report, which provides estimates of half hourly energy demand for the Welsh domestic and non-domestic buildings for a year provides useful insights on when, where and why the energy currently consumed in that sector is used (Knight et al. 2017).

The challenge is to provide the energy data in actionable information for end users that could help reduce their energy demand and increase efficiency.

Improvements in tracking energy data and producing the right level of reports will help improve the reliability and monitoring of future SoNaRR assessments. It is anticipated that this will provide a regular and reliable dataset for energy generated and used along with the progress in decarbonisation in Wales.

Lifecycle analysis of renewable and low carbon technologies

The generation and consumption of sustainable energy based on renewable sources is a challenging task for replacing the fossil-based fuels to address the energy trilemma for affordable and secure clean energy. All energy technologies, renewable and non- renewable, have implications on the natural environment. Thus, it is important to consider the Life Cycle Assessment (LCA) of a renewable and low carbon technology in the pursuit of sustainable energy.

Although a number of LCA analyses of renewable energy technologies are available, there is still significant gap in evidence and knowledge on renewable technologies. This is more so for emerging renewable energy technologies such as storage and hydrogen. Additionally, there is a lack of consistency in the conclusion about the life cycle impacts of different technologies, according to the size and the technology of the considered development. This limits the utility of LCA to inform policy makers and constitutes a barrier to the deployment of a full awareness on sustainable energies.

Synergies and trade-off between Well-being Goals and SoNaRR themes

Energy transition started with decarbonising electricity supply and generation and the UK has made tremendous progress in that sector. In recent years, the transition extended to energy consumption and demand through a whole system approach considering two other energy intensive sectors, heat and transport, which is challenging but beneficial. This begs the questions if the transition needs to be considered in a more holistic way with deeper integration to other sectors such as agriculture and health.

In doing so, it may be beneficial in understanding the synergies and trade-offs between the well-being goals and key themes highlighted in SoNaRR. This could help provide a complete picture about the intersection of energy with each key theme in contributing to the well-being goals. This approach is similar to how energy was considered within the UN Sustainable Development Goals.

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