UK Decarbonisation Strategy

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Abstract

We discuss the most viable processes to achieve a decarbonised future and the impacts of transitioning from the current state to net-zero emissions by 2050. With a broad variety of renewable and nuclear systems we show how the UK can maintain flexibility to meet intense and unforeseen demands as sectors become interlinked. Using smart systems in energy, heating/cooling and transport sectors we can invest in low-cost and low carbon systems dominated by renewable energy.

1 Introduction

On 12 December 2015 the UK set a legally binding target of achieving net zero emissions by 2050 under the Paris Agreement [1]. While the decarbonisation of the power sector is already visible, removing carbon emissions from all sectors of society is a challenge - figure 1 shows current emissions. Any remaining emissions from hard-to-decarbonise sectors of society will have to be offset by carbon neutralising alternatives in other sectors to reach net zero targets. The foundation of the transition to net zero in the UK is the transformation of the energy system from an inflexible, centralised, high carbon system to a smart, flexible, low carbon system dominated by renewable energy.

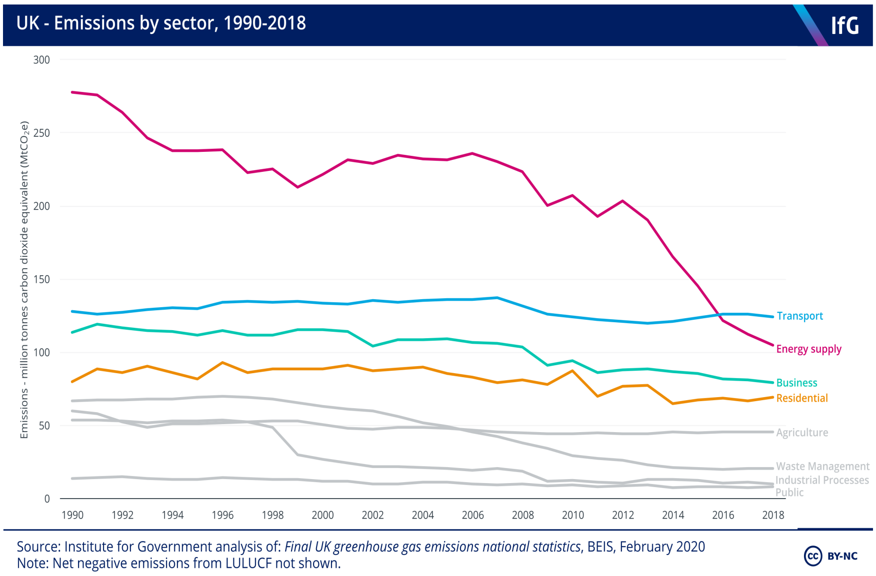

Figure 1: Total emissions from different sectors in the UK since 1990 [2]

The growing investment in zero-carbon solutions proves that decarbonisation also holds great economic value [3]. Renewable energy sources will penetrate global energy markets faster than any other source in history, completely changing the way the energy system operates. Accelerating deployment will also drive costs down and make established and new technologies cheaper to introduce by providing competition; a spur in innovation can provide jobs and economic benefits for the UK both nationally and internationally.

As there is inevitable uncertainty in the future we must ensure that a broad variety of systems is established. To meet our net zero target we must provide:

- **Flexibility**, to meet intense and unforeseen demands.
- **Decentralisation**, bringing stability that merges the electricity grid, transport and domestic demands as they become more interwoven.
- **Accessibility** to the population, with lower costs, and smarter more efficient use of energy.

In the following sections we will discuss the most viable processes in the Energy, Transport and Home and Industrial Heating and Cooling sectors, which hold the key sources of emissions [4] (figure 1), to achieve a decarbonised future and the impacts of transitioning from the current state.

2 Energy Sector

The energy sector is vital to the success of completely decarbonising all sectors as society becomes increasingly dependant on electricity. Reaching net-zero in the energy sector will mean virtually ending emissions and relying entirely on renewable and nuclear technology. Currently National Grid predicts that the country will need at least a further 263GW of installed capacity to reach its 2050 net-zero emissions target and there will need to be a doubling to 700TWh in generation [5]. The government has already committed to ending coal in the electricity mix no later than 2025 [6]; however, a coordinated approach to entirely decarbonising the energy sector is paramount. The increase in demand not only requires a robust replacement but also an increase in capacity where new sources of demand and millions of electric vehicles (EVs) and heat pumps connect to the system.

We advise renewable technology to be the backbone of the power sector but due to the instability of renewables in providing consistent electricity, battery and nuclear technology must also be used. With very rapid falls in the costs of renewables over the last 5 years [7], maintaining such market conditions will further stimulate these cost reductions - an ambitious and well-designed energy innovation strategy could generate £54 billion/year of business opportunities for the UK by 2050. Figure 2 outlines a possible composition for an expected 700TWh system.

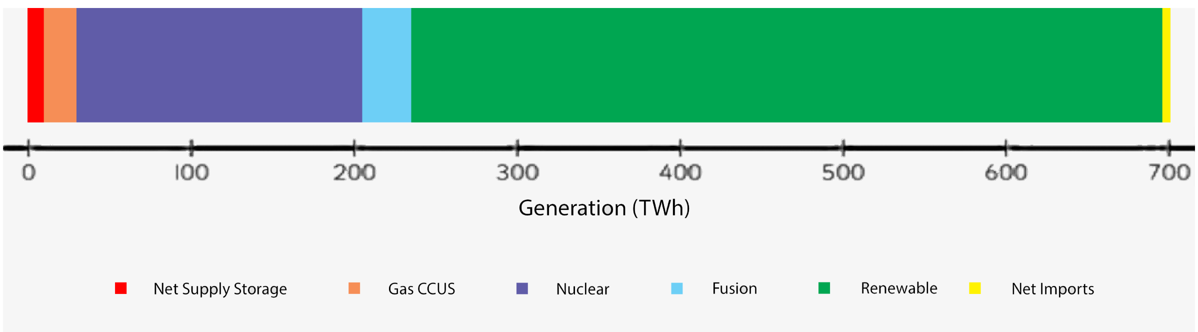

Figure 2: Energy composition in 2050

The transformation of the electricity system is an opportunity to exploit new forms of system flexibility. There will be more numerous and smaller sites of generation across the country, not just the large, centralised power stations with which we are familiar. Through local energy system modelling and flexibility in how energy is generated and consumed, supply and demand can be shifted in time or location so they are matched efficiently, keeping costs down for consumers [8]. Responding more quickly and shifting electricity around more easily also means less generation and network needs to be built. Already the government has seen that privatisation spurs competition [9] leading to innovation and stability and by ensuring consumers are in control and have the choice to use different providers the energy sector can continue to thrive with a net-zero electricity system. A previously one-directional system is transforming into something more dynamic.

2.1 Wind turbines

In 2019, wind generation provided 64 TWh of power becoming the UK's second largest source of electricity [10]. Figure 3 shows the development of offshore and onshore wind generation between 2010 and 2019 - a total wind generation increase of 19GW. With a single floating/conventional wind turbine generating 7MW of power, around 8,600 onshore wind turbines are currently in operation across the UK with an additional 2,300 offshore. This amounts to a total maximum capacity of over 24.1GW of electricity and equated to 20% of Britain's total electricity generation in 2019 and 54% of our renewable electricity [11].

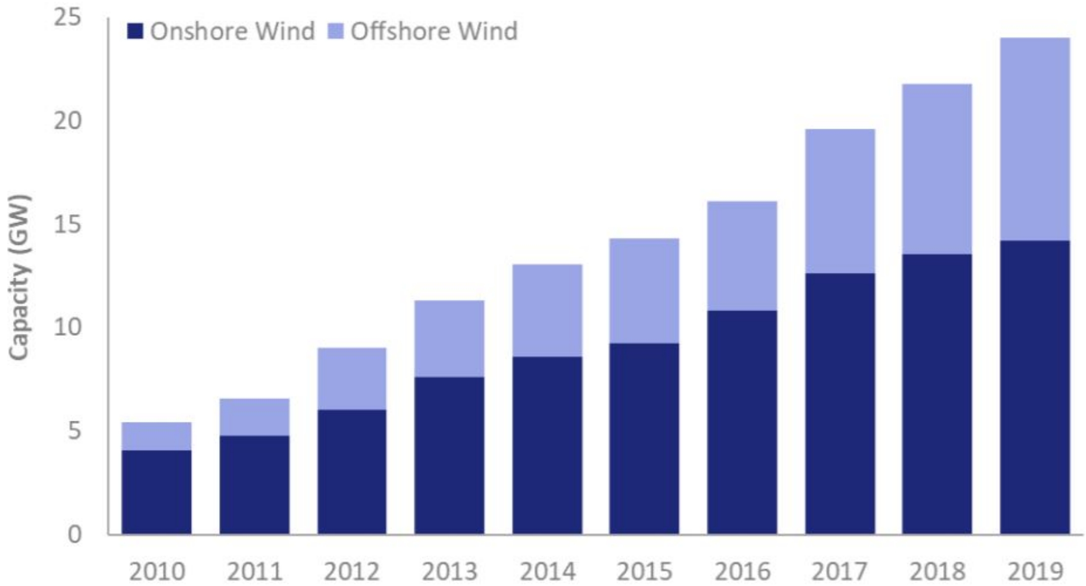

Figure 3: UK offshore/onshore wind capacity 2010 to 2019 [12].

With wind turbines currently only being second to gas turbines in the electricity mix, they are clearly the most viable in the decarbonisation of the UK. With an established system we can see that consistent wind speeds and directions are vital, so further investment into offshore wind is required to generate electricity and maintain efficiency [12]. To reach net-zero by 2050, wind capacity must be increased to 22-29GW via onshore and 40GW via offshore by 2030 [13]; a total of 45,000 wind turbines are required by 2050 to form the backbone of the power grid. In achieving these targets 60,000 jobs in ports, factories, supply chains and manufacturing can be generated by 2030 [14] amounting to £50bn in investments [15].

2.2 Solar Energy

The most recent data suggests that solar accounts for around 4% of Britain's total electricity generation with the Solar Trade Association estimating that 900,000 British homes have solar photovoltaic (PV) panels installed [16]. In fact the UK currently has a combined capacity of 13.26 GW of solar PV power - enough to power around 3 million British households [16]. However, with a $1m^2$ surface area currently producing only 150 Watts in sunny conditions, photovoltaics would not be effective on a large scale in the UK due to geological and meteorological factors [17]. They are clearly more valuable for individual homes which would alleviate pressure on the national grid and allow consumers to sell any excess electricity back to the grid. Therefore the promotion of solar panels for private use is important especially for new buildings.

2.3 Biomass

Biomass is unique amongst renewable technologies as it can be used as a substitute for fossil-fuel based products and activities, from power generation to hydrogen production and even new forms of plastics [18]. At the end of 2020 biomass supplied 6.7% of Britain's electricity which is

16% of our renewable electricity supply [18].

The Committee on Climate Change believes sustainably sourced bioenergy could provide up to 15% of the UK's primary energy by 2050 [18]. Along with its ability to deliver negative emissions, the delivery of alternative fuels and products makes biomass a valuable tool for reaching net zero emissions within all sectors of society.

2.4 Energy Storage

Renewables do not have consistent power (both above and below the required amount) and so storing excess low-carbon generation over longer periods of time could enable us to use this electricity more effectively and decarbonise the energy system more deeply at lower costs. Already the 75MWh energy storage system, located in Thurcroft, is being optimised by Flexitricity for revenue generation while helping National Grid ESO to balance supply and demand [19]; a project at DP World London Gateway is also expected to deliver up to 640MWh [20].

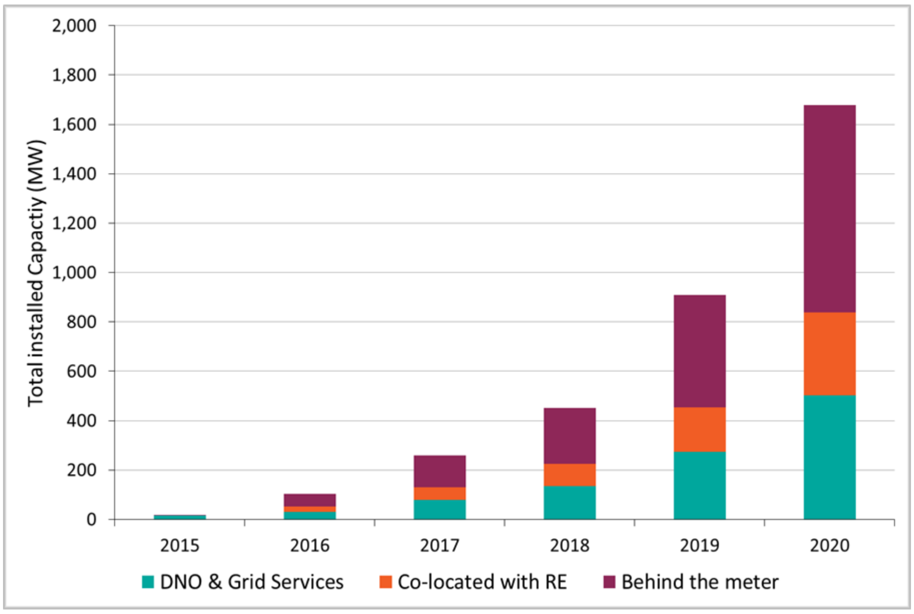

Figure 4: Energy storage increase by sector from 2015 - 2020 [21]

Figure 4 demonstrates the exponential increase in the total installed energy capacity in the UK, with increasing contributions from both the National Grid and also domestic and industrial contributions, as denoted by 'behind the meter'. We can also see an increasing contribution from Renewable Energy sources, referring to hydropower and pumped storage facilities [21]. Energy storage can greatly reduce costs and so promoting energy storage innovation and investment in the commercialisation both for private and grid use is important [22]. Currently hydrogen storage is being researched as an evolution to current lithium ion batteries [23] - they can provide much more efficient long term storage and so are vital to maintain stability of the future grid and consequently a carbon free future.

2.5 Carbon capture - CCUS

Carbon capture, utilisation and storage (CCUS) will form a key pillar of efforts to put the UK on the path to net-zero emissions. It is the only group of technologies that contributes both to reducing emissions in key sectors directly and to removing CO2 to balance emissions that cannot be avoided – a critical part of net zero goals [24]. Tackling emissions from existing and future energy infrastructure, CCUS should be retrofitted to existing power and industrial plants - a cost-effective pathway for low-carbon hydrogen and synthetic fuel production to meet current and future demand in transport, industry and buildings.

2.6 Small modular reactors

Nuclear power continues to be an important source of reliable clean electricity, currently supplying around 16% of our needs and with a £7 billion contribution to the nuclear sector for the UK economy in 2016 [25], it is an important source of stable electricity to complement renewables. However, with the exception of Sizewell B and Hinkley Point C, which is under construction, all of the existing nuclear power plants are due to have ceased generating by the end of 2030; to make a flexible and decentralised power grid Small Modular Reactors (SMRs) are necessary in their replacement.

SMRs are based on proven water-cooled reactors, but on a smaller scale using nuclear fission to generate low-carbon electricity. Their components can be manufactured in factories using innovative techniques and then transported to site to be assembled making them cheaper to manufacture and maintain, important for a futuristic and stable grid.

Rolls-Royce have already announced their success in developing a SMR that can be ready for delivery by 2030. One UK SMR will be able to: produce 170 tonnes of H_2 or 280 tonnes of net-zero synthetic fuel per day; heat or cool a city the size of Sheffield; desalinate to produce 500 million cubic metres of potable water per year. Each UK SMR will cost £1.8 billion, which is also in the territory of private equity being able to buy and run a reactor [26].

Advanced modular reactor (AMR) usually refers to a variety of Generation IV reactor technologies which are at an earlier stage of development but are ideologically similar to SMRs. Though they are not commercially ready, they will offer new functionalities such as industrial process heating and could operate at over 800°C unlocking more efficient production of hydrogen and synthetic fuels. Investment into their development is necessary as they are an evolution of SMRs [27]. With just 4 years to construct a single SMR, somewhere between 10 and 16 units by 2050 would be required to replace electricity on the grid. For hydrogen and synthetic fuels, particularly for transport (including aviation) and home heating, a market for a few 10s of units could be created [26]. Keeping prices low and forming a decentralised system, small modular reactors (including AMRs) are a flexible investment for the energy sector - they can complement renewables, bring stability, and greatly accelerate the decarbonisation of transport and domestic and industrial heating/cooling.

2.7 Fusion

The UK is a world leader in the most promising fusion technologies and so is uniquely well-placed to lead the future commercialisation of this technology. JET has already produced a world record 16 megawatts of fusion power using deuterium and tritium fuel [28], around 70% of the heating power put into the plasma itself. The government has already committed over £400 million towards new UK fusion programmes notably to develop a concept design for the Spherical Tokamak for Energy Production (STEP) – expected to be the world's first compact fusion power plant, to be built in the UK by 2040. Large continued investment and support can not only meet emission targets but also provide the UK with a strong foundation in energy and economically beyond 2050.

2.8 Smart meters

The efficiency of a smart grid is not only dictated by the technology used to produce electricity but also its consumption. Based on data gathered from smart meters, appliances can turn on when the rate of electricity is cheapest or only when required (e.g. setting washing machines to turn on when the rate of electricity is cheapest); the provider can selectively provide electricity [29]. In addition, smart meter data combined with weather forecasts can allow grid operators to plan the integration of renewable energy into the grid [30] - the technology can predict how much energy will be needed, where and when, matching demand with supply and lowering costs for both private companies and consumers as energy use can be tracked [31].

Research conducted by Delta-EE on behalf of Smart Energy GB shows that: smart meters will contribute to a 25% CO2 reduction by 2035 from households (from 2015 levels) [32]; in transport, smart meters will enable high levels of electrification delivering 54% CO2 reduction by 2035 (from 2015 levels); smart meters will allow for flexible networks which allow for greater generation using renewable systems and will contribute to a 77% CO2 reduction in the energy sector by 2035. The smart grid infrastructure is also expected to deliver huge economic benefits to the UK. Estimations include a potential of £13 billion of gross value added and £5 billion of potential exports by 2050.

As the foundation of a smart grid, smart meters also provide economic benefits to the consumer market. Households with medium to high energy consumption could save £50 to £100+ and the technology will create over 9,000 jobs with high demand in electrical engineering specializations [33]. For off-grid cases, users can also feed back to the grid and sell it at a profit.

As of 30 September 2020, there are 22.2 million smart meters in homes and small businesses in the UK [34]; however, there are concerns about cybersecurity, customer service, health and safety which should not be neglected. Therefore, most of the budget should be invested in these factors so that adoption can be accelerated and landlords should implement smart meters as a policy for all homes. Figure 5 shows the resulting future roll-out expectations.

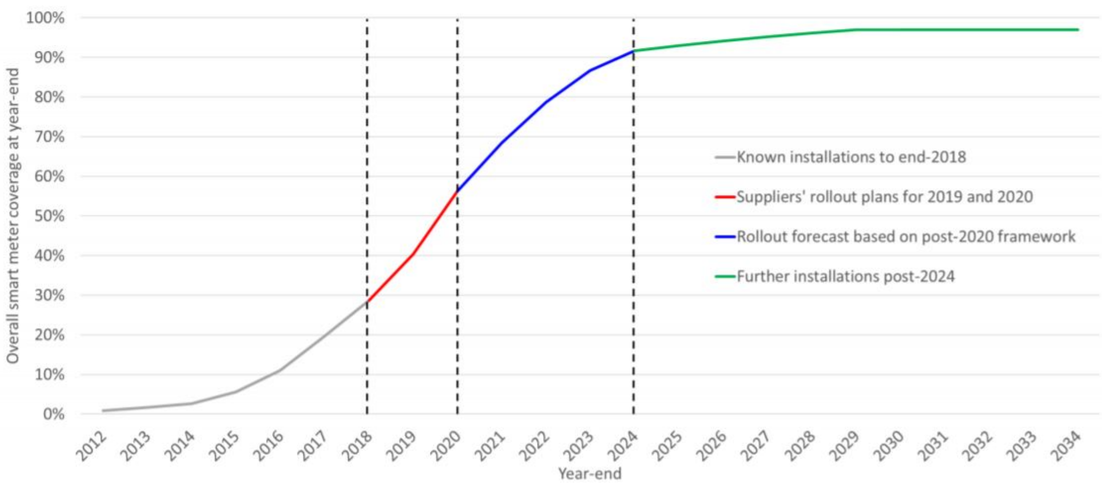

Figure 5: Future smart meters in operation by the end of each year [35].

A smarter grid with a balanced demand can contribute to a decentralised and decarbonised energy system with 11% of the 2050 net-zero target achieved using smart meters [36].

3 Transport

In the UK transportation is one of the biggest contributors of CO2 emissions out of all sectors (Figure 1). In 2019, transportation contributed to around 34% of all emissions in the UK with road travel being the biggest contributor [37]; emissions from air and rail travel were the next big contributors. The total emissions from this sector have been around 130 million tonnes a year on average since 1990 and have hardly seen any decrease.

Travelling is a key part of an interconnected world and through the use of alternative fuels and electricity, an infrastructure for a net-zero emission transport sector is paramount to reaching a decarbonised UK by 2050.

3.1 Electric Vehicles

Currently, 97.6% of passenger vehicles run on petrol and diesel [38] and with fossil fuels being a limited resource, alternative engines must take centre stage in UK decarbonisation. With over 10% of new cars in 2020 being electric (figure 6), electric and hybrid vehicles are a viable replacement and have seen an increase in their numbers - in 2010 there were just over 1300 and currently they number over 240,000 [39].

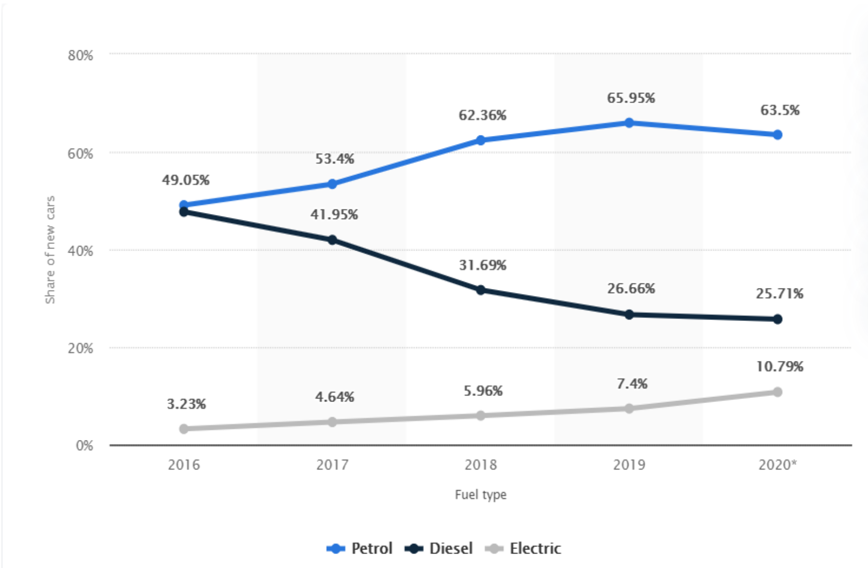

Figure 6: Market share of new car sales [40]

The challenge lies in making people switch - this must be a gradual but steady change to allow further reductions in price for consumers and allow the National Grid to cope. A nationwide survey by the UK's automotive trade body found that 44% of motorists don't think they'll be ready to run a battery vehicle in 2035, 1/4 saying they can't see themselves ever owning one [41]. A survey of 10,000 Britons [42] named their demands for EV ownership: £24k price; 30-min charging; 282 mile range. Furthermore a report by the ICCT found that the UK currently has just 5% of its 2030 target public charger network [43].

With government plans to stop the sale of new petrol and diesel cars by 2035 [39], the only viable and available options would then be electric, hybrid and hydrogen powered vehicles. Already in April 2020 petrol and diesel cars have seen an increase in tax [44] and further tax increases could promote the uptake of electric vehicles. These changes must be met with investment in an infrastructure to recharge any electric vehicle, which can help improve consumer confidence. Allowing people to charge their vehicles to around 80% in 40 minutes at rapid charge points [45] and completing fast charging stations in parking spots and at homes is paramount.

The National grid already has the capacity to meet the increase in demand of energy, even if every vehicle switched into an electric vehicle overnight [46]. However, this does not mean it has the capacity to charge all of them at the same time, such as during the regular peak between 6pm to 8pm. Therefore, this load must be distributed with the use of smart chargers. Smart chargers can charge your vehicle when demand is low and overnight to reduce stress on the National Grid. This system could also be used in reverse to provide energy for the National grid in times of peak demand. Until the infrastructure is established, hybrid vehicles are a good stepping stone to allow for a change to electrification.

The industry has already improved the development of electric cars which has greatly decreased costs - the cheapest electric vehicle currently on the market is the Skoda CITIGOe iV which costs £15000 [47]. With a strong charging infrastructure there can be greater consumer confidence, increasing company investment. This can drive development of better performing and cheaper technology (also reducing insurance costs), ultimately leading to a net-zero emissions future.

3.2 Hydrogen Fuel Cells

Hydrogen fuel cells only produce water vapour as a byproduct and use the most abundant element in the universe (Hydrogen). This is still a developing sector with many of the costs in implementation derived from safely storing the very volatile hydrogen fuel. Currently only 2 hydrogen powered vehicles are on the market and they cost more than £60,000 [48] making it very difficult to rely on them for carbon neutrality in their current state.

Although high costs may prevent immediate uptake, hydrogen is a byproduct of many systems in the future energy sector and so is an opportunity for government investment to create future growth as an alternative to electric vehicles. This can also create jobs in fields of manufacturing and fuel production. Currently there are only 13 hydrogen fuel stations in the entirety of the UK [49] but by implementing storage into existing petrol stations we could provide healthy growth to the market. In the near term it would be wise to focus on the use of hydrogen fuel cells in public transport, such as buses to promote private investment opportunities to drive costs down and so allow the possibility of hydrogen powered vehicles to thrive.

3.3 Rail Travel

Rail travel contributes very little in emissions relative to other modes of transport [39]. The main focus on rail travel has been electrification, which helped reduce emissions by 195,000 tonnes in 2018 [39], highlighting how effective this method is. With £4 million funding into rail projects, hydrogen and battery solutions may help to further decarbonise rail travel. A direct result of this funding has produced the Riding Sunbeams project which aims to power trains directly using solar energy.

As rail travel continues to decarbonise and expand, it could reduce the number of road vehicles, helping to meet net-zero targets. As electricity is also set to become cheaper decreasing ticket prices can bring convenience for long journeys, resulting in further use of rail networks over road vehicles. We should continue to focus on electrifying the rail network and invest in expanding it to allow more people to choose public transport over cars.

3.4 Aviation

Just like rail travel, aviation is a relatively low contributor to emissions with around 39Mt in 2018 [39]. International aviation makes the bulk of emissions as so it is generally agreed upon to treat it as an international issue, leading to international policies which affect all participating members and not just the UK individually. The UK is a member of the UN International Civil Aviation Organisation (ICAO), which takes the responsibility of reducing carbon emissions in aviation. The CORSIA policy, which currently 82 states are a part of, states that aeroplane operators are required to offset the growth in international emissions to around 2.5Gt of carbon dioxide by 2035 [39].

Therefore investment in aviation should lie in developing technologies such as electric engines, hydrogen power and the use of efficient synthetic fuels. Currently, the government has the Future Flight challenge in place, with a total investment of around £300 million supporting the development of novel aircraft and their supporting infrastructure [50]. With synthetic fuels being a byproduct of the energy sector, investment into their development could also spur innovation. Fundamentally further investment into research projects and their infrastructure can not only decarbonise the UK but also provide a strong economic and technological advantage as the World transitions to new systems.

4 Domestic and Industrial Heating

Whilst Electricity and Transport are already making leaps this sector is the most difficult to decarbonise due to the UK's reliance on gas and coal for heating: domestic emissions account for 17%; industrial for 14%; and 5% comes from cooking and hot water [51]. 23 million households in the UK, accounting for 85% of the total number [52], are currently heated by natural gas with the remaining 15% opting for oil, liquid petroleum gas, or electricity as alternatives [51]. Furthermore many industrial processes also rely on heating. Current solutions to reducing carbon emissions in this sector involve improving gas boiler efficiency and imposing tighter regulations on boiler manufacture. However, in order to achieve carbon neutrality by 2050, more viable solutions to domestic and industrial heating will be imperative for the UK's sustainability goals.

4.1 Passive Solutions

Double glazing and proper insulation in new and old homes can alleviate the need for heating and cooling especially in rural areas. Nearly 20% of homes in rural areas are in the very energy inefficient F and G categories, compared to just 2.4% in urban areas; 91.1% of urban households have a gas connection, and are able to use gas boilers compared to only 40% of homes in rural areas. With proper insulation consumers could save £20 in heating costs and 150kg of carbon dioxide emissions per year, per household [53]. With the advent of more efficient and less-polluting boilers, investment to insulate homes throughout the UK is a simple and effective solution to both reduce pressure on the power grid and heating/cooling systems.

4.2 Ground and Air source heat pumps

Already, under the Future Homes Standard act, all newly built homes from 2025 will not allow the installation of gas fired boilers [54]. One of the leading alternatives to Boilers are ground, or air, source heat pumps that heat homes using a mixture of electricity and natural heat from the surrounding air or ground [55].

The upfront cost of a Heat pump is a large deterrent to consumers, with air and ground source heat pumps averaging between £6,000-£8,000 and £10,000-£18,000 respectively in comparison to the competitive price of £2300 for a gas boiler installation [56]. Clearly, due to heat pumps using electricity, if generation becomes dominated by renewable energy, prices will likely fall and greatly promote heat pumps [57]. Furthermore, the average lifespan of a heat pump (20 years) can reach twice that of a boiler (10 years) [57]; in figure 7 we can see that the running costs per KWh for gas boilers (coefficient of efficiency CoP of 0.93) are larger compared to a heat pump (CoP of 3.6). [58].

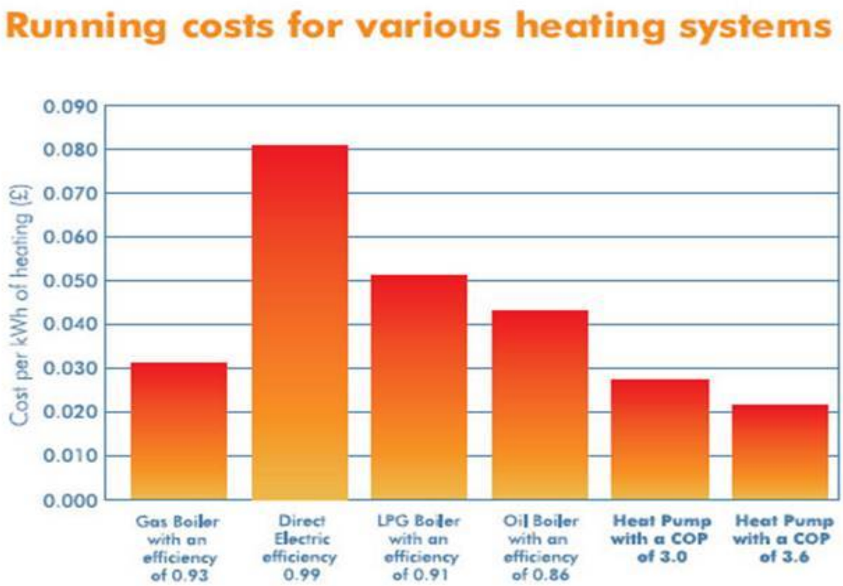

Figure 7: Mitsubishi Electric air conditioning heating system cost comparison [58]

There are alternative financial incentives for investment into Heat pumps with the governments Renewable Heat Incentive (RHI), where consumers opting for air/ground source heat pumps, biomass boilers and solar thermal panels are subsidised by the government for using renewable sources of domestic heat [59]. This scheme is due to expire on the 31 March 2022, so future programs similar to this should be encouraged as the RHI has seen much success.

However, heat pumps can take up to 5 times as long as boilers to heat up [60], and rely greatly on suitable insulation in the house to retain heat in order to compare to gas boilers. We would recommend using heat pumps in conjunction with alternate renewable heat sources such as hydrogen boilers (as discussed below), in order to achieve competitive heat output against gas boilers, and to promote innovation.

4.3 Hydrogen boilers

An alternative solution, and arguably more viable, would be the transition to an era of hydrogen fueled boilers. Using hydrogen as an alternate to natural gases for heating has been an initiative for manufacturers over the last few years [61], primarily because the by products of combustion by hydrogen is H_20 and heat (a carbon free process). Furthermore the current infrastructure, such as the gas network and the 'wet' heating system dominated households, are already equipped to make this transition as many operating boilers are capable of burning a hydrogen blended mix without alteration [62]. Companies such as Worcester Bosch have already created and tested the first 100% Hydrogen powered boilers, with zero change to the users experience and matching heat output to conventional gas boilers [61].

Ironically, Hydrogen production is currently responsible for 830Mt of CO_2 per year, making it a huge global contributor to carbon emissions. This can be fixed by building hydrogen electrolysis stations near renewable generators, providing a low-cost and zero emission hydrogen supply [63]. Figure 8 shows future predictions of the cost of hydrogen electrolysis if geological renewable potential is harnessed; it is competitive with the Methane reformation market [64] showing the additional economic benefits. Furthermore with hydrogen being produced in Biomass power stations we can easily harness hydrogen for use in industry and domestic scenarios.

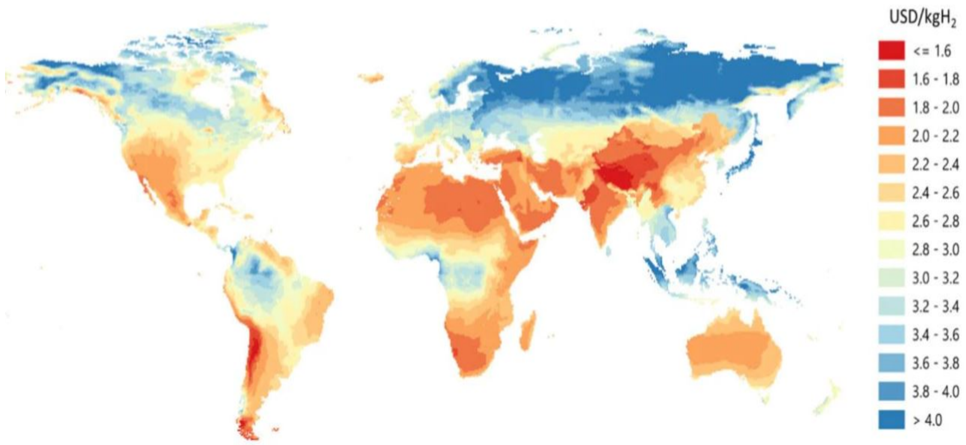

Figure 8: Hydrogen costs from solar PV and onshore wind systems in the long term [64].

4.4 Industrial processes

Industrial heating is vital to the production of many materials and chemicals. In 2012, Industrial heating processes contributed 81.3Mt of CO_2 to annual emissions, with the largest contribution being Iron and Steel as seen in figure 9.

SECTOR	TOTAL ANNUAL CARBON EMISSIONS 2012 (MILLION TONNES CO_2)
Iron and Steel[1]	**22.8**
Chemicals	18.4
Oil Refining	16.3
Food and Drink	9.5
Cement[2]	7.5
Pulp and Paper	3.3
Glass	2.2
Ceramic	1.3

Figure 9: Energy-intensive industry total direct and indirect carbon emissions in 2012 [65]

In order to reduce these emissions by 40-60%, by 2050, large scale CCUS (a.k.a CCS) and increased efficiency of flue gas recycling should be implemented, distributed as seen in figure 10.

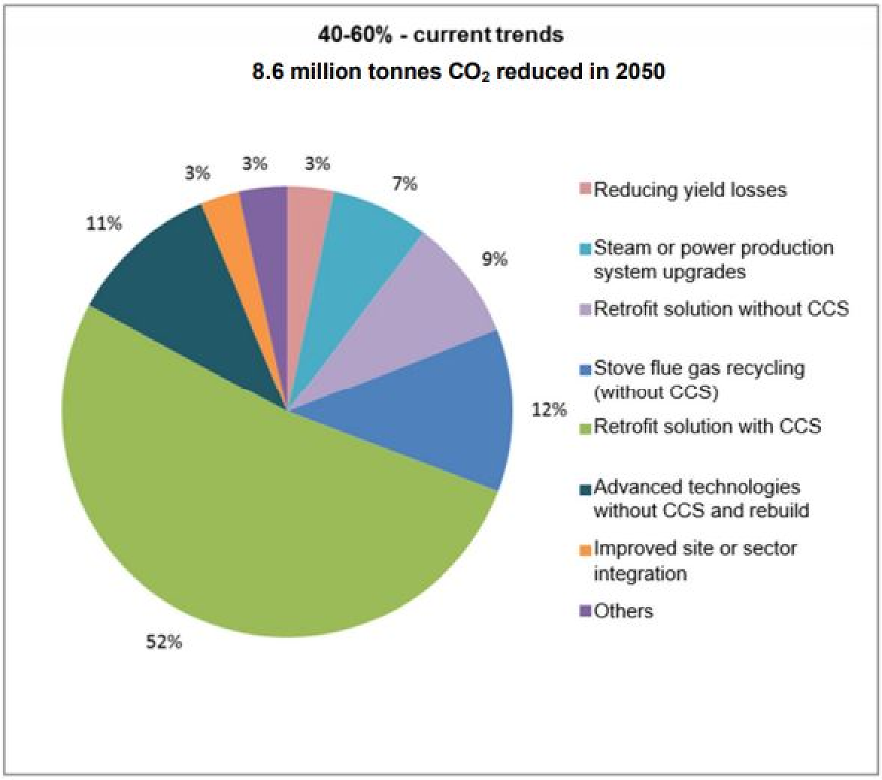

Figure 10: Breakdown of 2050 emissions savings, for the 40-60% CO2 reduction pathway for the Iron and Steel sector [65]

The second biggest contributor is Chemicals, specifically Ammonia for the agricultural sector. We suggest using synthetic fuel in this industry as it is a low carbon, industrial by-product being produced in Biomass generators and could amount to greater decarbonisation (figure 11). The further possibility of producing alternative materials with Biomass makes it incredibly valuable.

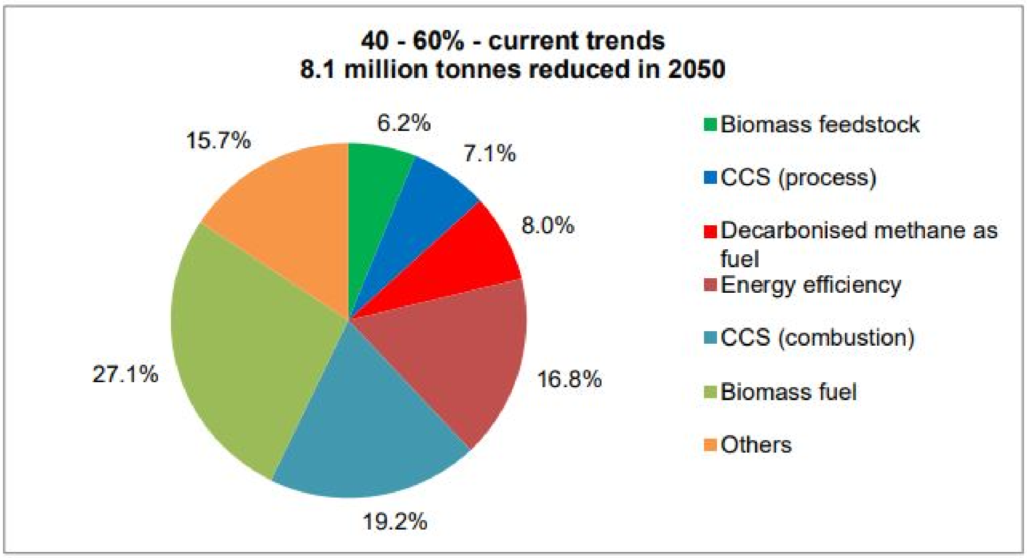

Figure 11: Breakdown of 2050 total emissions reduction for the 40-60% CO2 reduction pathway for the Chemical sector

Both of these sectors could also be fuelled by AMRs (section 2.6), with 800 degree heating and capability to refine goods, and so investment into SMRs (to develop the technology) and AMR commercialisation is incredibly useful in order to reduce carbon at both ends of industrial energy usage.

5 Conclusion

With our strategy decarbonising the UK will meet the Paris Agreement and also provide jobs, innovation and a more stable economy. Localising power generation will accommodate greater flexibility forming a strong foundation for accessible, low cost, smarter and more efficient use of energy; a broad variety of net-zero and nuclear systems can maintain flexibility, to meet intense and unforeseen demands. A government that evolves can bring further incentives to private consumers and businesses to decarbonise their systems. As the electricity grid, transport and domestic/industrial demands become more tightly dependant on each other a smart, flexible, low carbon system, dominated by renewable energy can ensure that net-zero systems flourish beyond 2050.

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