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THE UK POWER AND ENERGY CHALLENGES TOWARDS NET ZERO — A BRIEF TECHNOLOGICAL OUTLOOK

Abstract: The report aims to present an overview of the key challenges and possible solutions for the growing needs of the UK power and energy sectors and their ongoing decarbonisation. The material explores how the UK electricity demand and electrification of services challenges may be satisfied and the 2050 Net Zero target achieved, including some of the considered energy system and power device changes associated with achieving Net Zero.

1. INTRODUCTION

The United Kingdom's (UK's) energy system is today one of the fastest growing globally in terms of the diversity and the composition of the utilised energy sources. This inevitably raises a number of considerable technical challenges on successful and stable integration of new sources into an increasingly decarbonised power grid. The advent of large scale renewable power generation is particularly demanding in this respect, as the intermittent availability of renewables is disruptive to conventional techniques of operating the electric grid and could lead to power shortages if not addressed adequately.

The UK's legal commitment to delivering Net Zero by 2050 imposes further demands to provide what needs to be an intrinsically flexible and resilient energy system of the future. Its structure will fundamentally need to allow reliable real-time manipulation and matching of new and emerging demand sources to renewable generation, and will be particularly challenged

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by the balance of, on one side, the changing peak demands and uncertainty in their prediction, and on the other a peak system capacity increasingly compromised by decarbonised generation. To deliver this capability a number of technological breakthroughs and solutions are required that have hitherto not been conceived or proven on this scale. Furthermore, the energy system must enable the economy to decarbonise including negative emissions provision to offset those sectors that are difficult and more time demanding to fully or partially decarbonise. As carbon neutral and renewable resources are expected to play a key role in this decarbonisation it will be vital for the feasibility of the future Net Zero network to identify new reliable sources of ancillary services, which are essential to effective functioning of the power network and are today largely delivered from sources such as gas and/or nuclear generation.

This study looks to provide a brief overarching review of the current state of the UK energy system and the general requirements for its successful decarbonisation going forward. Different possible scenarios put forward by the UK's electricity system operator to achieve the national Net Zero targets for the electricity system are then overviewed. Finally, some of the key underlying electrification technology challenges to do with electrification of transportation are reviewed to provide an insight into how some of the wider energy system decarbonisation targets translate into those to do with device design and utilisation.

2. PATHWAYS TO A FULLY DECARBONISED POWER SYSTEM

The UK energy power system has traditionally been dominated by conventional carbon rich energy sources, much like those of most developed countries. However in the past few decades an initially slow but a now rapidly accelerating transition towards integration of large scale renewables has been taking place. The current state of the system in 2022 is of an approximate total installed capacity of 105 GW out of which almost 50 GW is renewables, made up mostly of wind power generation but also of a rising percentage of solar and some marine generation [1]. The current peak demand is approximately 50–55GW, and has moderately varied in the past decade driven by a nationwide push for a switch to higher energy efficient appliances and lighting and some reduction in industrial activity [2]; this is widely expect to considerably increase going forward.

The variability of renewables and the challenges this imposes in exploiting the renewables installed capacity was illustrated in 2021 during which, despite an overall increase in installed renewables capacity, the generation from renewables was reported to decrease by close to 9% caused by the reported less favourable conditions for wind, solar and hydro generation [3]. This was most prominently observed for wind generation, whose contribution reduced by 14% compared to 2020, due to unusually low average winds during 2021. Despite this reduction however, the proportion of electricity generation from renewables in the UK in 2021 was second only to that originating from fossil fuels, fully illustrating the importance and the sizeable contribution renewables make to the modern UK electricity network. The 2022 status of the UK's installed electricity generation capacity composition and its corresponding generation output contributions are illustrated in Fig. 1, clearly highlighting the large renewables input in the power generation mix.

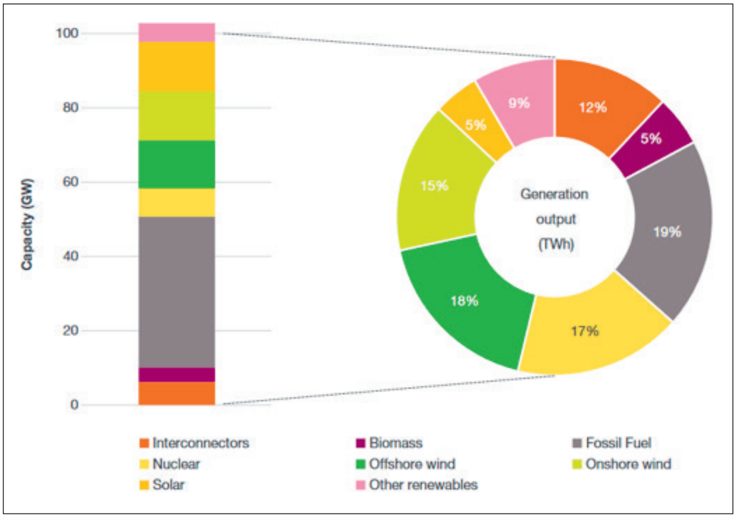

Fig. 1 UK electricity generation capacity (GW) and output (TWh, approx. 333.2 TWh in total in 2021), 2021 [4]

2.1 *The aim: a fully decarbonised network*

The UK has committed its energy future to elimination of emissions and a carbon free economy with the ultimate goal of achieving Net Zero by 2050, and on the road to this a decarbonised power system as early as 2035. The national statistics on emissions by source, shown in Fig. 2, present a growing reduction trend in the past two decades, that is picking up pace in recent years with the increased proliferation of renewables. Perhaps unsurprisingly the biggest net emissions contributor in 2020 was transport

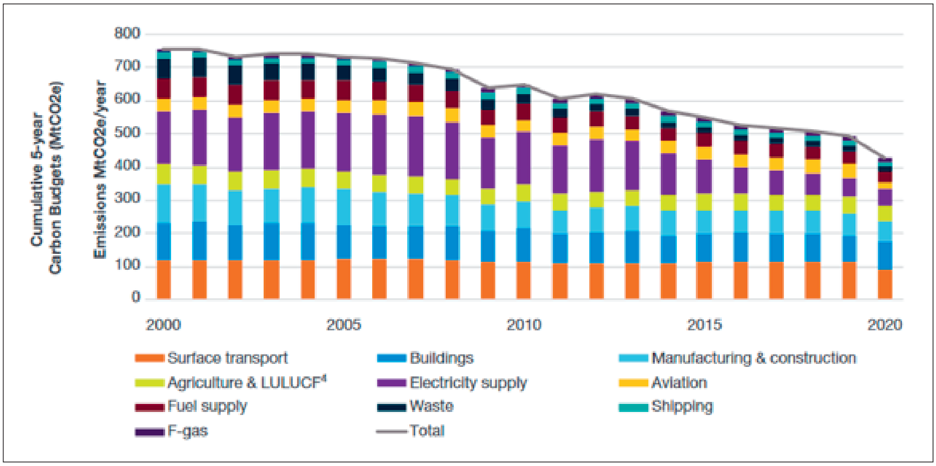

Fig. 2 UK historic emissions by sector [5]

which contributed to almost a quarter of all emissions. The transportation sector is consequently set to undergo a large scale decarbonisation through full and/or partial electrification of ground and eventually of marine and air transport. Similar solutions are being sought for decarbonising the buildings and manufacturing sectors whose carbon footprint is also significant.

The UK desires to significantly accelerate the transition to a carbon free energy system, including the delivery of a reliable, secure and low (ideally zero) carbon power system. To achieve this a number of technological advances will need to be developed and adopted [4] as identified by the national electricity network operator. Some of the key strategic aspects of the required innovation in the electricity and energy system are listed below:

— *Advanced demand side strategy* will be needed to incentivise the consumers to adopt a more flexible energy consumption and thus alleviate the pressures in balancing what is expected to be a challenging to predict and intermittent renewables contribution and a very flexible demand.

— *Large scale energy storage* will be key to success of the future low carbon electricity network and its ability to balance the supply and demand with variable and intermittent generation input. This will be vital to increasing system resilience and also the avoidance of potentially having to waste large amounts of renewable generation output due to it coinciding with low demand/oversupply periods. This will include the provision of large scale storage solutions, either electrical assuming the technology can be delivered in time, or by exploring alternatives such as hydrogen uptake.

— *Improved energy efficiency* can provide rapid benefits on the energy cost and security fronts through demand reduction. This can be achieved through usage of more efficient devices on the network (e. g. lighting, heating, home appliances etc.) but also on a more fundamental level through, e. g. better building insulation to reduce heating related energy consumption.

— *Decarbonisation of heat* is highly pertinent to the UK system which is highly reliant on natural gas for heating, and needs to be undertaken urgently with consideration of regional differences in the UK, and in particular the differences in proximity to energy infrastructure between these.

— *Digitalisation and innovation* will be needed to enable the customer demand and consumption profiles to be better aligned with the changing energy cost and availability profiles. Consumer data availability will be key to enabling developments in smart technology on this front that can facilitate automated or quasi automated adjustment of consumption with cost of energy. This would be beneficial to both the customers and the grid operator/provider and would enable the consumers to take advantage of low cost energy in the period of high renewable output which does not necessarily coincide with conventional peak demand timing. Ensuring both the consumer data security and cyber security would be crucial and integral to this process.

— *Flexibilty*, to securely, effectively and stably operate the future low carbon energy system with high renewables penetration will require a much higher level of flexible capacity than is the case today. This will be needed to offset the loss of traditional ancillary service provided by e. g. natural gas, which is essential to grid stability, but also to allow the optimal contribution from flexible assets in the grid to ensure supply security.

2.2 Possible pathways to Net Zero energy future

The UK national electricity system operator has outlined a number of different possible pathways toward the Net Zero energy future and the UK 2050 target, naming these the future energy scenarios [6]. Four different energy scenarios are identified which follow different trajectories and are all deemed to be potentially credible predictions of future developments in the UK energy sector. The explored scenarios aim to consider the future energy needs, how these may be met and which solutions they may require to realise. The underlying aim of the analysis is to provide an advisory framework for the UK energy industry stakeholders that can be used to guide and underpin the energy network development, support investment decisions and guide policy development.

Four different scenarios for 2050 were defined, exploring different possibilities for how the power system could evolve between now and 2050 through changes in infrastructure innovation, technology and behaviour.

The purpose is to look at different possibilities in decarbonising the energy network (e. g. societal change or energy system technological transformation) and attempt to predict what implications and impact this may have and what future routes it may create. The scenarios are defined as:

1. *Falling short / Steady Progression:* which assumes the slowest possible decarbonisation progression rate scenario that does not meet the 2050 Net Zero target.

2. *Consumer Transformation:* looks at ways of reaching Net Zero by 2050 through changing the consumer behavioural patterns, i. e. the way energy is used and consumed.

3. *System Transformation:* looks at reaching the 2050 target through changing the way we generate and supply energy.

4. *Leading the Way:* looks at the fastest credible way of reaching Net Zero through a combination of consumer engagement and the assuming availability of world leading technology.

Each of the defined scenarios is presented with a corresponding predicted annual energy flow diagram as shown in Fig. 3. The diagrams show the linkage between energy source (diagram left hand side, in TWh) and energy consumption (diagram right hand side, in TWh) per primary energy type. They are conceived to enable the understanding of the annual supply and demand and its different composition possibilities based on the growth scenario adopted.

The Falling Short scenario depicted in Fig. 3a assumes the minimum amount of difference with respect to the current state of the power network and fails to reach decarbonisation targets. This scenario assumes that domestic heating decarbonisation has been very limited and by 2050 still relies heavily on fossil fuel usage (i. e. largely natural gas). It also assumes limited progress with energy efficiency and usage of hydrogen, but does assume

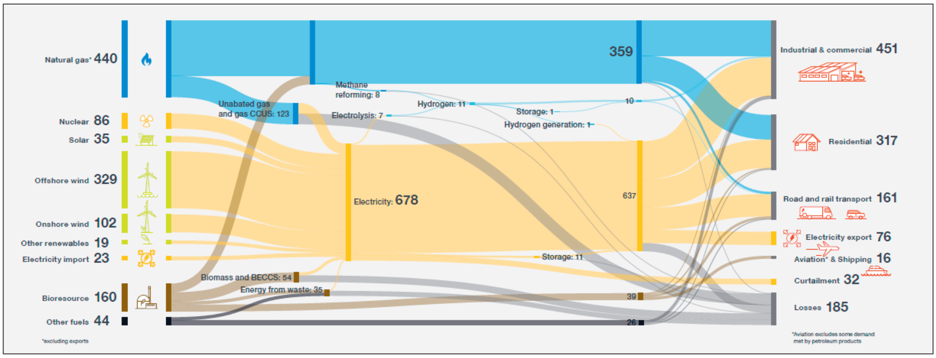

Fig. 3. a Falling Short scenario energy flows, 1237 TWh total

progress has been made with fully electrifying small passenger vehicles, while large transportation vehicles remain fossil fuel powered.

The Consumer Transformation scenario in Fig. 3. b assumes the transport, industry and heating are largely electrified and high levels of renewables are available in the system with some integration of hydrogen. High adoption of energy efficiency is assumed and combined with successful large scale electrification predicted to lead to the lowest end user energy demand out of the four scenarios. The System Transformation scenario, Fig. 3 c, maintains a high natural gas intake but however assumes the highest proportion of hydrogen integration and use for powering the industry, heating homes and operating high girth transportation vehicles. This is assumed to be followed by moderate progress with electrification.

Finally, the Leading the Way scenario assumes that industrial and heating needs are largely met by 2050 through a combination of usage of hydrogen and electricity. A high grid flexibility is attained through hydrogen manipulation and direct air carbon capture and storage systems used for

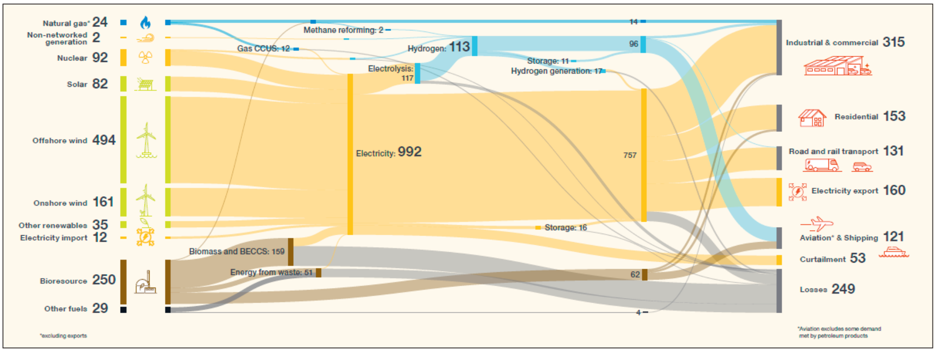

Fig. 3. b Consumer Transformation scenario energy flows, 1182 TWh total

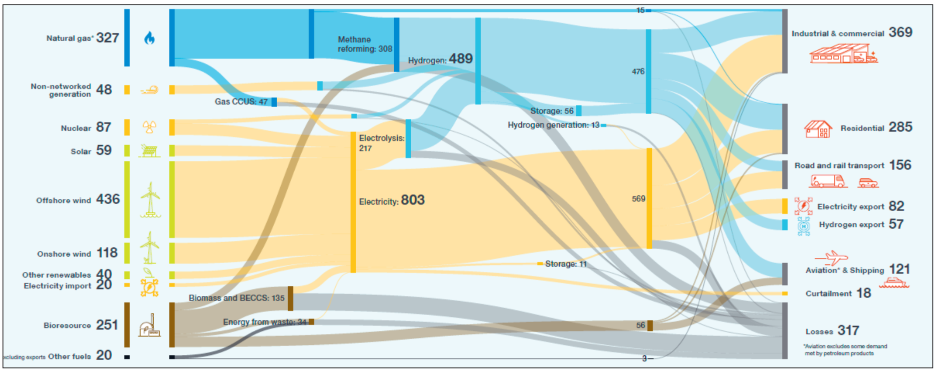

Fig. 3. c System Transformation scenario energy flows, 1406 TWh total

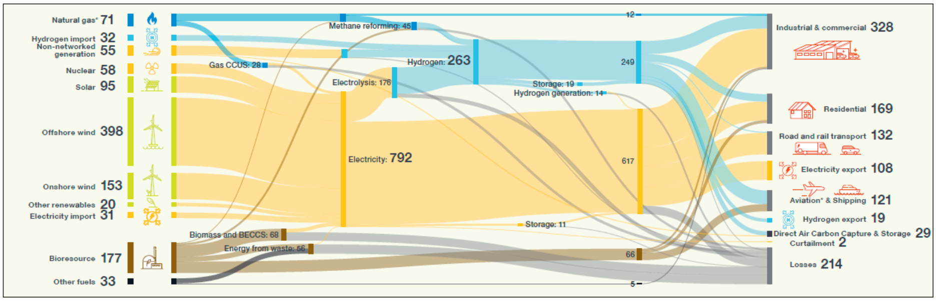

Fig. 3. d Leading the Way scenario energy flows, 1123 TWh total

Fig. 3 The UK National Grid's future energy scenarios energy flow [4, 6]

negative emissions, i. e. to offset the emissions from the remaining reduced amount of fossil fuel used in generation.

All four scenarios are deemed to be realistic and possible, and detail the implications of different decisions in the process of power network decarbonisation. Their findings indicate that there are different potential paths that could deliver Net Zero, but also that the viability of this delivery is vitally dependent on the adoption and success of large scale electrification of predominantly the transportation and heating sectors, and reduction of any leftover fossil fuel usage related emissions.

3. TRANSPORT ELECTRIFICATION: ONE OF KEY INGREDIENTS TO NET ZERO

Transport electrification remains one of essential barriers to wider Net Zero adoption in the UK and one that requires imminent and extended duration action to be addressed. The UK is strongly committed to changing this landscape and moving towards full road electrification at a reasonably rapid pace. As part of this push the UK has decided to end the sales of all diesel and petrol cars in the country by 2030 and to focus on use of electric vehicles (EVs) exclusively beyond [7].

There has already been steady progress on facilitating increased usage of EVs with the energy infrastructure, however this is still at relative infancy. Fig. 4 illustrates the growth in EV charging infrastructure in the UK over the past few years, which is seen to be rapidly accelerating with the early uptake of EVs. However while the pace of charging infrastructure rollout is increasing it is currently deemed too slow to cater for fast rising EV users needs, and requires further intensification [8].

The large scale transport electrification targets on the national level translate into targets for advances in the underpinning technology needed to

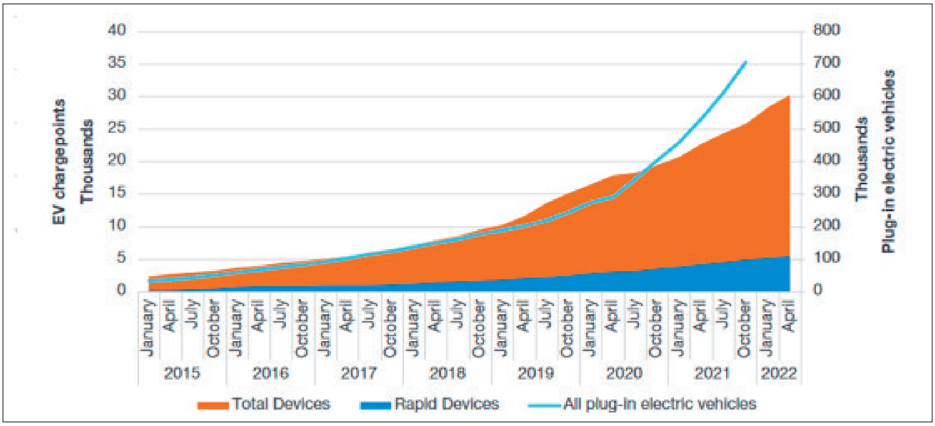

Fig. 4. EV public charge point installed in the UK [1]

deliver the technically and economically viable EVs in required numbers. The relevant automotive technology roadmaps look at mapping the future developments of specific enabling technologies and set out performance target that align with target performance desired from EVs [APC, US ev everywhere]. At the core of these is the electromechanical power conversion system of the vehicles making up their powertrain and containing the propulsion electric motor, the power electronics to drive it and the energy source to supply it from.

The electrical energy storage system remains the main challenge to large scale commercialisation of EVs. This is pertinent to both the battery power/energy density and its cost, as while these are continuously improving neither are still not quite at the levels required to ensure the desired mass adoption of EVs. The targets set out by the UK Automotive propulsion council stipulate that, to ensure long term EV viability, by 2035 the power and energy density of EV batteries need to rise from the current 3kW/kg and 280Wh/l, to 12kW/kg and 100Wh/l, respectively, while at the same time the cost is expected to reduce by more than 50%. The battery technology is largely expected to remain dominated by the traditional Lithium-ion solutions however alternative chemistries are researched. To attain the desired improvement in energy/power density and cost, improved cell chemistry, battery management and manufacturing processes will need to be developed.

Another key element of the EV powertrain is the power electronic converter, whose performance is essential for ensuring optimised power flows between the propulsion motor and the battery, and hence the delivery of desired traction. EV power electronics will continue to heavily utilise traditional silicone based semiconductor devices. However it is widely expected that the emerging class of wide band gap semiconductor devices will be increasingly finding implementation in EV traction drives as they can offer improved electrical and thermal performance. For the potential of these devices to be utilised fully new solutions will be needed around their manufacturing, integration and cost, but also around conceiving new circuit topologies that can best utilise their performance potential. In addition, the thermal management of power electronics is widely expected to remain one of key challenges in their improved utilisation in this area. The set targets for EV power electronics power density is to reach 50kW/kg by 2035 rising from the current 15kW/kg, while also achieving around 40% cost reduction at the same time.

The electric motor is at the heart of the EV system and its key propulsion enabler. The EV e-motors performance is also the subject to mandatory improvements, and in particular where power density and efficiency is concerned. Their manufacturing also remains a challenge with the mass market maturity in this sector being fairly low still, and needing advances for the mass market application costs to be brought down. The e-motor performance improvements are expected to be delivered through exploring the application of new materials and closer integration with the power electronics elements of the power train and to an extent through exploration of increased speed designs. The targets for e-motor power density are to increase to 9kW/kg by 2035 from the current average of around 3 kW/kg.

4. CONCLUSIONS

This paper has presented a brief overview summarising the key challenges in decarbonising the UK energy network. Viable means for network decarbonisation were reviewed in various network growth scenarios, as put forward by the UK national electricity network operator. The success of UK decarbonisation by 2050 is found to depend on a complex combination of a range of technologies: it fundamentally revolves around electrification of heating and industry as well as electrification of transport, and around large scale integration and exploitation of renewable power generation. If further requires the currently unavailable large scale energy storage technology, as well as a host of additional advances to maintain the Net Zero power network stable, flexible and resilient. Finally the delivery of set decarbonisation targets is underpinned by requirements for improvements in the underlying enabling technology. This is perhaps best illustrated in the set electrification of ground transportation targets, which effectively translate in requirementt for considerable technological advances in the underpinning powertrain technology, ranging from much better small scale energy storage, to high power density power electronics and traction e-motors. To deliver these will need not only significant investment but also a range of innovative engineering techniques that remain to be conceived and proven.

REFERENCES

[1] 'UK Energy in brief 2022 'The UK Gov. Department for Business, Energy & Industrial Strategy, Aug 2022.
[2] A Vaughan, 'UK electricity use falls–as rest of EU rises 'The Guardian, 2018.
[3] 'Digest of UK Energy Statistics 'The UK Gov. Department for Business, Energy & Industrial Strategy, Aug 2022.
[4] 'Future Energy Scenarios 2022 Report 'UK National Grid, 2022.
[5] 'Final UK greenhouse gas emissions national statistics: 1990 to 2020', The UK Gov. Department for Business, Energy & Industrial Strategy, June 2022.
[6] 'FES in Five 'UK National Grid, 2022.
[7] 'Government takes historic step towards net-zero with end of sale of new petrol and diesel cars by 2030 'The UK Gov. Department for Transport, Office for Low Emission Vehicles, Department for Business, Energy & Industrial Strategy, Nov 2020.
[8] 'Taking charge: the electric vehicle infrastructure strategy 'The UK Gov. Department for Transport, March 2022.