The Future of Nuclear Power as a Low Carbon Energy Source

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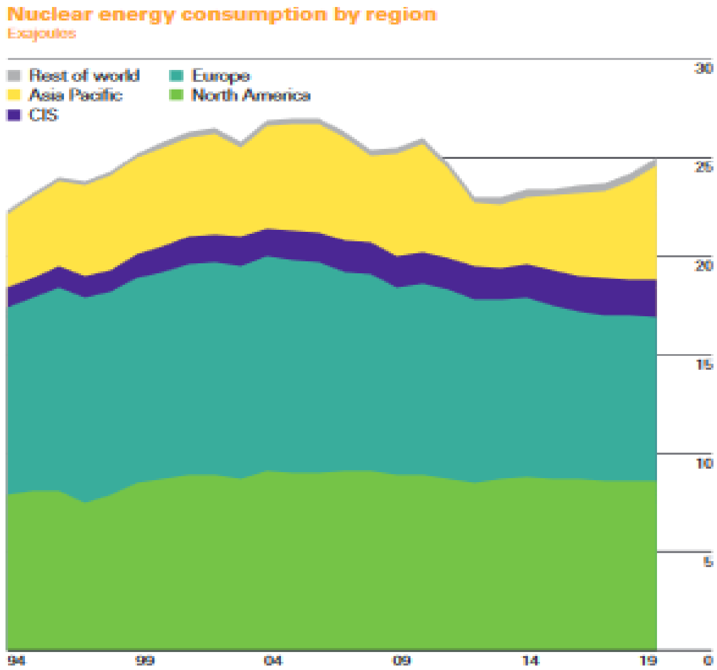
1.Introduction

Since the 1950’s nuclear fission reactors have been used to generate power in a number of advanced countries, after the development of atomic weapons showed the enormous potential of harnessing the heat released in nuclear reactions for the generation of electrical power. This paper will analyse the future of nuclear power as an energy source, taking into consideration current and future technologies, comparing with alternative sources of energy, and looking at the political and strategic dilemmas faced by countries as they attempt to shape energy policy while meeting their emission reduction targets set by the 2015 Paris Agreement.

In 1953 amid growing concern of the possibility of a nuclear conflict between the United States (US) and the Soviet Union, President Eisenhower delivered a speech at the UN titled ‘Atoms for Peace’. Looking to avoid a global arms race the speech outlined a policy of sharing sensitive commercial nuclear technology with other countries. Public approval for nuclear power generation however was high, and its potential to generate significant quantities of power meant it was viewed as the energy source of the future. Since this time however public support - particularly in Western Europe - has declined, accelerated by high profile accidents at Three Mile Island in 1979, Chernobyl in 1986 and at Fukushima in 2011.

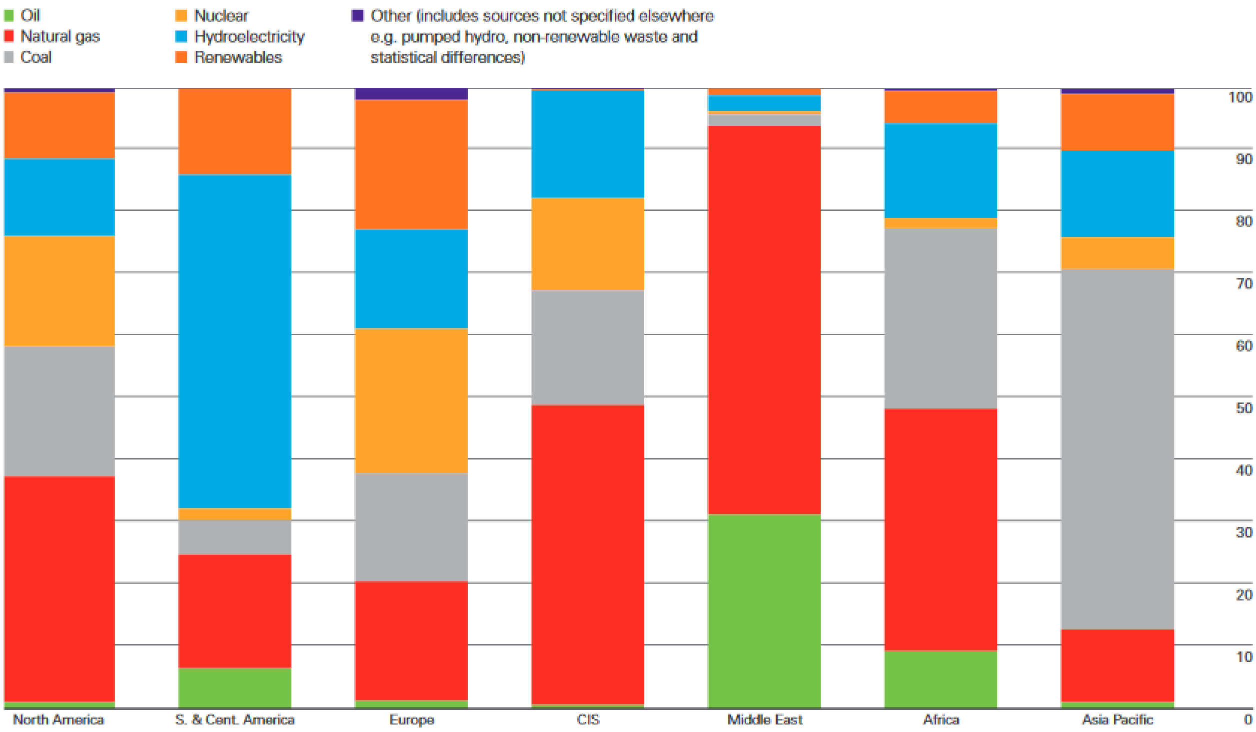
After the Fukushima accident, global generation of nuclear energy fell as Japan and other countries began taking nuclear capacity offline. After this decline there has been a steady increase, until a historic high was reached in 2019 when a total of 2796 TWh was generated globally, surpassing the previous high in 2006. The share of nuclear in the electricity mix in 2019 represents only around 10% of total production, a fall from a high of 17.5% in 1996. North America and Europe represent the biggest share of consumption with a lower share in Asia Pacific, CIS (Russia and former Soviet states) and the rest of the world (Fig.1), the latter three regions is where most of the growth is expected to take place in the future.

Fig.1: Nuclear energy consumption by region - Exajoules



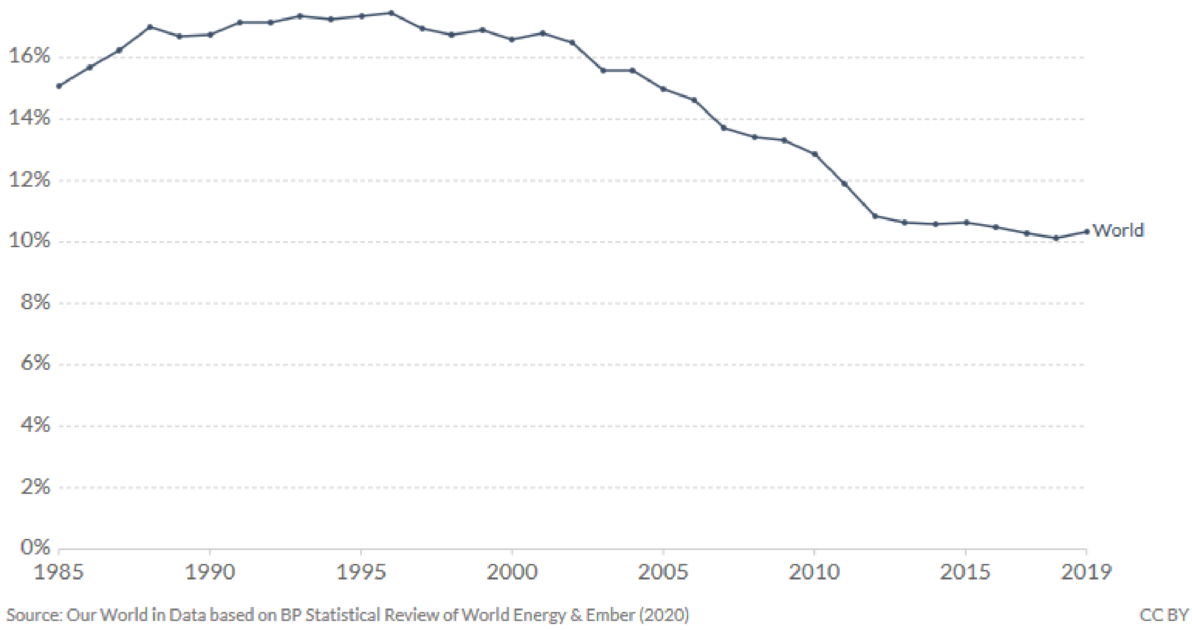
(BP Statistical Review of World Energy, 2020a)

Fig.2: Regional electricity generation by fuel 2019 - Percentage



Source: (BP Statistical Review of World Energy, 2020a)

Fig.3: Share of electricity production from nuclear



Source: (BP Statistical Review of World Energy, 2020,)

2.Developments in new regions

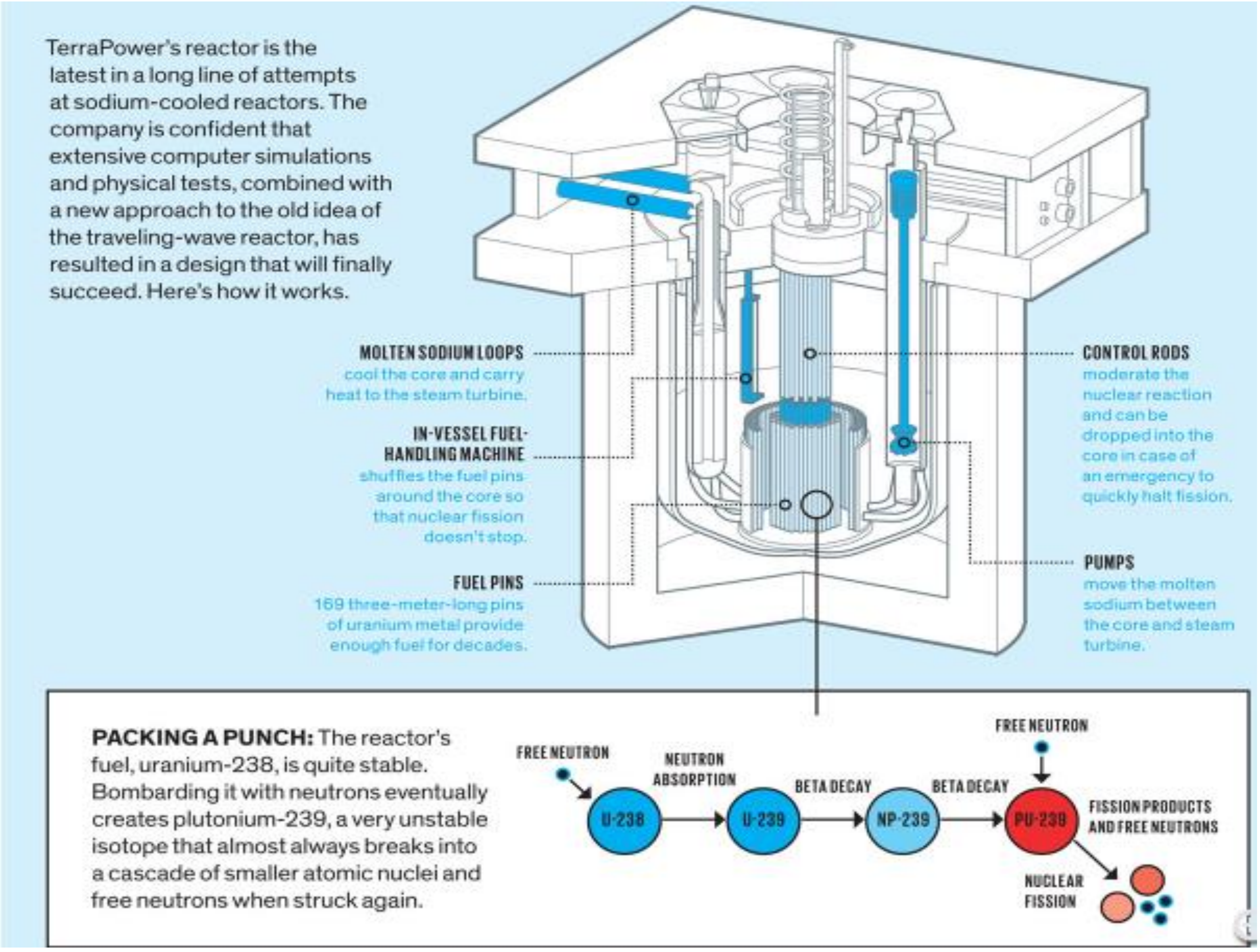
With a key area for reducing greenhouse gas (GHG) emissions being the decarbonisation of the energy sector, the shortfall resulting from the phase out of fossil fuels has to be met with alternative low carbon energy sources, a motivating factor for some to build new nuclear power plants. One region where this is apparent is in the Middle East; despite accounting for one-third of global oil production and some of the lowest production costs, major oil producers such as Saudi Arabia, Iran and the United Arab Emirates (UAE) are investing in new nuclear power facilities. In relation to the nuclear programme in Iran concerns have been raised from the US, as well as opponents in the region. To address these concerns the 2015 Iran Nuclear Deal aimed to reduce the country's stockpile, as well as redesigning the Arak heavy water reactor from running on natural uranium (producing plutonium for two bombs per year) to low-enriched fuel (producing traces of plutonium). A new president in Washington may give hope that the deal may be resurrected with Biden saying that it would be the, "best way avoid an arms race in the region" (Al Jazeera, 2020).

3.Fast breeder and Generation IV reactors

Using enriched uranium with conventional reactors, there is roughly 230 years supply at today's current consumption rate (Fetter, 2009). For low-enriched reactor fuel the enrichment process seeks to increase the level of the fissile isotope uranium-235 from 0.7% to around 5%. The main isotope uranium-238 cannot undergo fission directly, but through neutron capture can be transmuted to plutonium-239 which then subsequently undergoes fission. At the end of the cycle this spent fuel needs to be safely stored in underground repositories at an ever increasing rate and cost (Feldman, 2018). Although many have been plagued with technical difficulties in the past, fast breeder reactors (FBRs) are designed to generate fuel at the same time as producing energy, the advantage of which is the ability to convert 60 times more energy from the original fertile material. There is also the possibility of producing fissile uranium-233 from thorium-232 (International Atomic Energy Agency, 2005) with the same concept, which has the added benefit of thorium being more abundant and having less proliferation risk than the plutonium waste from the uranium-plutonium cycle. Another example of research in this area is the travelling wave reactor (TWR) being developed by a company founded by Bill Gates – TerraPower. The main advantage of the TWR is that it has the ability to sustain a fission reaction when fuelled with natural uranium or spent fuel. If realised commercially it is claimed it could reduce energy costs, proliferation risk and waste, as well as a better standard of safety than conventional reactors (Dipesh et al., 2014).

This type of sodium fast reactor is one type of ‘Generation IV’ reactor currently in the research phase which it is hoped will allow for sustainable fuel cycles and also operate at very high temperatures. The advantages of these designs operating at much higher temperatures is the possibility of high temperature electrolysis, ultimately enabling the production of green hydrogen; the generation of which is seen as a key driver in the energy transition by allowing for alternative fuels in hard-to-abate sectors such as shipping, aviation and steel production.

Fig.4: Surfing the Sodium Wave



Source: (IEEE Spectrum, 2018)

4. EROI

The energy return on investment (EROI) for traditional fossil fuels is declining and will continue to fall as future reserves become more difficult to extract. Despite the growth in power generation from renewables in recent years the world is still highly dependent on fossil fuels, with the continual use of coal power generation in developing countries highlighted as a particular problem. As Richard Heinberg predicted in his 2005 book *The Party's Over*, the global transition to alternative energy sources will result in less cheap energy as countries are forced to look to seek replacements for fossil fuels. The concept of EROI may be considered a useful tool for deciding how energy policy should be shaped, but the estimated values for the different energy sources vary considerably, especially for nuclear. Due to the trend of EROI for fossil fuels continuing to decline though, the economics of nuclear power generation should be becoming more favourable, however due to the escalating costs of new large-scale nuclear projects such as Hinkley Point C and Flamanville in France, this may not necessarily be the case (Financial Times, 2016).

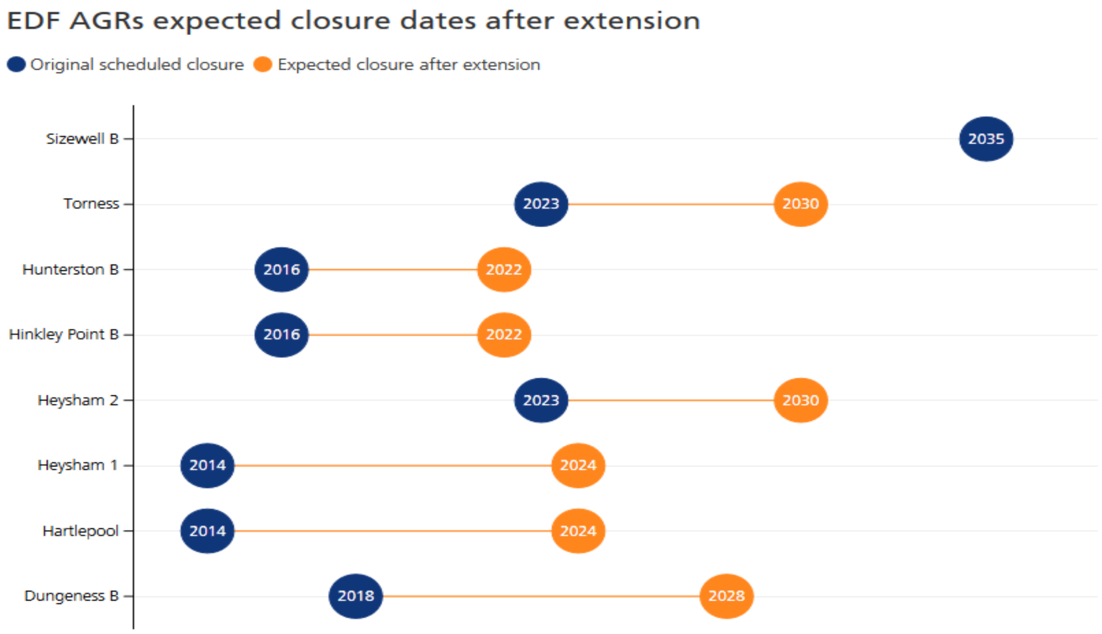
5.Extending the lifespan and Scotland's phase-out

France, the country with the highest percent of nuclear generated electricity has a total of 58 reactors most of which were built in the late 1970's and early 80's as a result of a government strategy to reduce its dependence on oil imports following the oil price shocks of the 1970's. This has resulted in one of the lowest CO_2 per unit of electricity generated in the world; only surpassed by the likes of Iceland and Norway with their abundance of geothermal and hydropower respectively. Électricité de France (EDF) which operates all the reactors hopes to extend the 40 years lifespan by a further 10 years, but the government announced in 2018 that nuclear as a share of the electricity mix would be reduced from 75% at present to 50% by 2035 (Reuters, 2018).

Much of the global nuclear capacity comes from an ageing reactor fleet, many of which are coming to the end of their lifespan. In the case of the UK to ensure that power demands in the years ahead are met, EDF – the owner of all seven sites currently operating - are extending the lifespan in order to avoid any supply crunch. The decision to extend the lives of plants at Hartlepool, Torness and two at Heysham, may have been partly motivated by concerns raised by reports such as Engineering the UK's Electricity Gap (Institute of Mechanical Engineers, 2016) about the ability of the National Grid to meet electricity demand as coal was phased out. Despite nuclear power generating 42.8% of the electricity in 2016 in Scotland, after the closure of Torness in 2030 the Scottish Government has no plans to continue the use of nuclear energy, although new technologies may be assessed (The Scottish Government, 2020).

Scotland has an excellent wind resource, and wind accounts for almost three-quarters of renewable electricity generation the question for policymakers in these circumstances is whether the continual expansion of variable renewable sources including wind can be continually expanded to remove the necessity of nuclear as a low-carbon electricity source? For more populous countries where demand is higher this may not be the case, and even in the case of Scotland, ensuring the security of supply is still dependent on technologies for flexible grid management which are still in their infancy.

Fig.5: EDF AGRs[1] expected closure dates after extension



Source (EDF, 2019)

6. The falling costs of renewables

Some sceptics have suggested that as the percentage of wind generation in the electricity mix increases the UK's electricity supply may be vulnerable to blackouts like the ones seen recently in California (The Washington Post, 2020). One way California is mitigating this risk is by building a series of battery energy storage systems (BESS); this may be useful for short periods on a small scale but may not be suitable at the moment for a state with a population of 40 million people. For the UK there is the potential to convert more of the hydroelectric power stations to pump storage which may offer a more affordable means of energy storage than utility-scale battery facilities, the . The construction of new subsea high-voltage links between Norway (North Sea Link) and Denmark (Viking Link) - adding to the links to Belgium, the Netherland, France and Ireland - may also go some way in alleviating these risks, but at the same time leaves the UK dependent on generation and availability in these countries. This is where nuclear advocates believe it can provide a secure low carbon, continuous and reliable baseload power - or even load-following power like in France - at an affordable price. The cost of power generation from the two main competing low carbon power sources is another area of contention though, and the cost appears to have moved well in favour for onshore and offshore wind. Announcements of contracts for new offshore wind at less than £40 per MWh, made the £92.50 per MWh strike price agreed for Hinkley Point C look, "very poor value for taxpayer's money" (National Audit Office, 2017) but the hope is that the two other new EDF plants proposed – Sizewell C and Bradwell B – would come about at

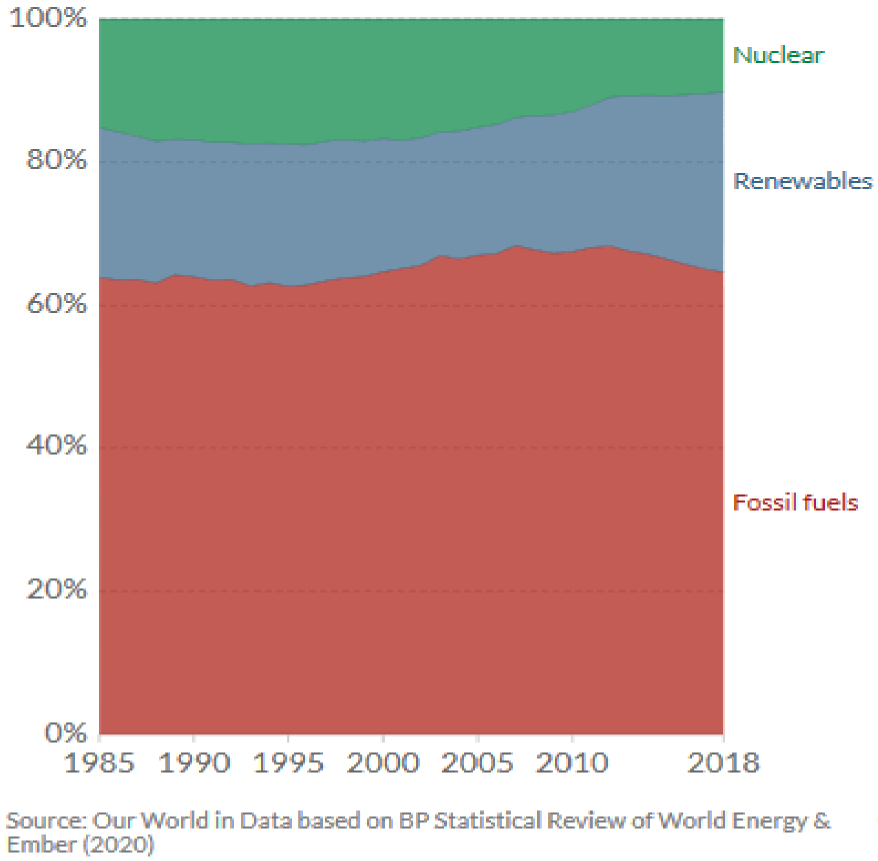
[1] AGR – Advanced Gas-cooled Reactor, a type designed and operated in the UK

cheaper cost of around £60 per MWh. Over the last two years, Toshiba and Hitachi have both dropped plans to build new projects in the UK, while there is growing criticism from some regarding the involvement of China General Nuclear Power Group (CGNP) in the Hinkley Point project. It appears now that opposition to a new generation of nuclear power plants being built in the UK (Financial Times, 2020) is based more on political concerns relating to costs and dependence on Chinese nuclear technology than it is on safety grounds and the management of waste.

7. SMRs

The rising costs of new large scale nuclear projects (Goldberg and Rosner, 2011) may be one of the main motivating factors behind the UK government's decision to promote smaller scale nuclear power generation in the form of small modular reactors (SMRs). The third section of the recently announced ten point plan for a Green Industrial Revolution outlined support for a generation of small and advanced reactors by providing £215 million worth of funding (UK Department for Business and Energy & Industrial Strategy, 2020)for a Rolls-Royce led consortium to build up to 16 power stations of this kind by 2050. If successful, it is claimed that these systems will be able to operate for 60 years and each provide 440 MW of electricity. The advantages are based on the idea of manufacturing components in a factory environment away from the expensive construction disruptions that hinder large scale projects. The use of robotics and digital technologies would then drive down production costs and ultimately provide electricity at a cost of around £60 per MWh. An article in *Spectrum* covering the history of small nuclear power plants and their failures (Ramana, 2015) is less enthusiastic, the author of which also does not think there is any demand for SMRs globally. Manufacturing methods and techniques as well as technological advances have come a long way since many of these failures, and if the target of building SMRs at a competitive rate is realised and the safe operation is proven they may play a considerable role in a future low-carbon energy mix.

Fig.6: Electricity production from fossil fuels, nuclear and renewables, World.



Source: (BP Statistical Review of World Energy, 2020b)

8.Conclusion

The last decade has seen significant developments in the reduction of costs and the scaling of wind and solar renewable energy sources as a more sustainable method of power generation. The decision for governments now is whether the construction of large-scale nuclear power with its long lead time between planning and operation is also necessary in the drive to reduce GHGs. The decision is very complex, but ultimately the key factors in meeting the growth in energy demand will be cost and emission reduction, because of this nuclear power generation will begin to play a larger role in the energy mix of an increasing number of middle-income countries in order to meet rising energy demands and reduce dependency on coal.

Currently nuclear electricity production in advanced economies is expected to fall by two-thirds by 2040 (International Energy Agency, 2019). Most of the new capacity for middle income and developing countries will be built by either Russia or China with civil nuclear cooperation an integral part of the latter's Belt & Road Initiative (Boqiang et al., 2020). As nations push the phase out of combustion engines for transport and the use of fossil fuels for heating in order to achieve carbon neutrality, the electrification of these sectors will result in significant increases in demand. Furthermore the upscaling of green hydrogen as a solution for larger, longer range transport and other hard-to-abate sectors will increase the need for low-carbon energy sources. Can this projected increase in demand be met by improvements in overall efficiencies, utility-scale battery storage systems, pumped hydropower and the further expansion of renewables in conjunction with artificial intelligence and other analytical developments; or will nuclear be needed as a dependable non-variable energy source?

The expansion of nuclear power will likely be required in both advanced and middle-income economies not only to provide stability as a baseline electricity source, but also to provide power to the alternative solutions within the hard to decarbonise sectors if the world is reduce GHG emissions and preventing global average temperatures rising above 2°C.

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