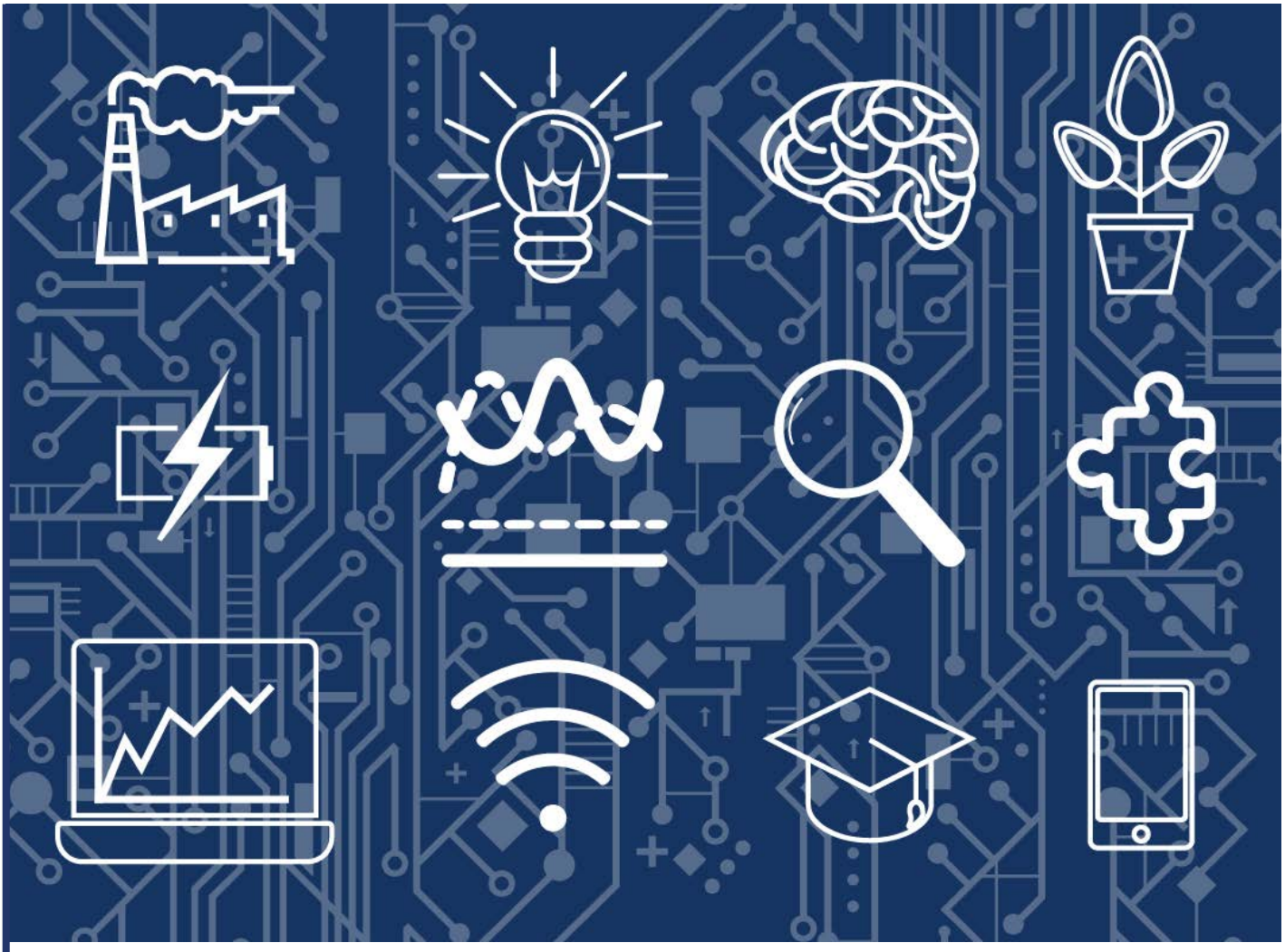
Intellectual Property Office

Advanced nuclear power

A worldwide overview of patenting related to the UK's ten point plan for a Green Industrial Revolution



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Advanced nuclear power
A worldwide overview of patenting related to the UK's ten point plan for a Green Industrial Revolution

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1. Introduction

1.1 Background

In June 2019, the UK became the first major economy to set a legally binding target to reach net zero greenhouse gas emissions by 2050, in recognition of the transformative change needed to tackle global climate change.[1]

The Energy White Paper (EWP)[2], published in December 2020, and the Industrial Decarbonisation Strategy[3], published in March 2021, set out complementary plans for the transformation of our energy system and industries, including actions to fully decarbonise electricity generation by 2050.

On the international stage, the UK has co-assumed[4] the presidency of COP26 (26th UN Climate Change Conference of the Parties) and is hosting the COP26 UN Climate Change Conference in Glasgow in 2021.[5,6]

In November 2020 the UK government released a ten point plan for a green industrial revolution[7], comprising:

- **Offshore wind:** produce enough offshore wind energy to power every home in the UK, producing up to 40 gigawatts by 2030.
- **Hydrogen:** reach a five gigawatt production capacity of 'low carbon' hydrogen by 2030 – for industry, transport, power and homes – and develop the first town heated by hydrogen by the end of this decade.
- **Nuclear:** provision for a large nuclear plant, as well as for advanced small nuclear reactors.
- **Electric vehicles:** phasing out sales of new petrol and diesel-powered vehicles by 2030, so as to accelerate the transition to electric vehicles and investing in grants to help buy cars and charge point infrastructure.
- **Public transport, cycling and walking:** making cycling and walking more attractive ways to travel and investing in zero-emission public transport for the future.
- **Zero-emission air and greener maritime travel:** supporting research projects for zero-emission planes and ships.
- **Homes and public buildings:** making homes, schools and hospitals greener, warmer and more energy efficient, including a target to install 600,000 heat pumps every year by 2028.

[1] https://www.gov.uk/government/publications/department-for-business-energy-and-industrial-strategy-outcome-delivery-plan/beis-outcome-delivery-plan-2021-to-2022 - b-introduction
[2] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
[3] https://www.gov.uk/government/publications/industrial-decarbonisation-strategy
[4] Together with Italy: https://www.ukcop26.org/pre-cop/
[5] The conference was originally scheduled to take place in 2020, but has been postponed to 2021 in view of the COVID-19 pandemic
[6] UN Climate Change Conference UK 2020 (Conference) https://www.ukcop26.org/the-conference/
[7] https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

- **Carbon capture:** developing world-leading technology to capture and store harmful emissions away from the atmosphere, with a target to remove 10 million tonnes of carbon dioxide by 2030.

- **Nature:** Protecting and restoring the natural environment, with plans to include planting 30,000 hectares of trees a year.

- **Innovation and finance:** Developing cutting-edge technologies and making the City of London the global centre of green finance.

Innovation may play a role in helping to achieve carbon net zero[8] and innovation may be reflected in patenting trends. Hence, this report is part of a series of studies relating to the technologies covered within the UK government's ten point plan for a green industrial revolution. This report analyses the worldwide patent landscape related to advanced nuclear power technologies.

This report is based on the analysis of published patent application data rather than granted patent data. Published patent application data gives more information about technological activity than granted patent data because a number of factors determine whether an application ever proceeds to grant; these include the inherent lag in patent processing at national IP offices worldwide and the patenting strategies of applicants who may file more applications than they ever intend to pursue.

Throughout this report, patents are counted either as single published patent applications or as patent families depending on the context. A 'patent application' refers to a single patent application made in one jurisdiction and published in that jurisdiction. Patent applications are counted once regardless of the number of subsequent publications. A 'patent family' refers to a group of patent applications made and published in different jurisdictions. Each member of a patent family is considered to relate to the same invention. A patent family is counted once regardless of the number of members or publications it contains.

For this study, the LexisNexis worldwide patent database was interrogated using PatentSight.[9] The data coverage of this database is that of DOCDB, the European Patent Office's (EPO) database.[10]

Throughout this report, reference is made to 'active' patent families. A patent family in PatentSight is defined as active when at least one patent family member is either in the pending stage or 'in force' state. PatentSight updates the legal status of documents held within its database weekly.

[8] https://www.gov.uk/government/publications/promoting-innovation-and-growth-the-ipo-at-work-2020-21/innovation-and-growth-report-2020-21
[9] https://go.patentsight.com/BI2.0/bi/secure/src/resources/documentation/syntax-cheat-sheet/SyntaxCheatSheet.pdf?45be120476a49463f31ebcd79b10b19e
[10] https://www.epo.org/searching-for-patents/data/coverage/weekly.html

1.2 Nuclear power

Nuclear power is not a particularly new source of energy having been used since the 1950s onwards. It is a source of low-carbon energy, however, since life cycle assessment shows that its carbon dioxide emission levels are similar to renewable energy sources, and significantly lower than fossil fuel energy sources.[11]

The nuclear power industry employs 60,000 people in the UK, and as a source of low-carbon electricity, nuclear power is likely to play a part in the future energy landscape of the UK. Within the government's ten point plan, there is a commitment to invest up to £215 million into Small Modular Reactors (SMRs), which would focus on small-scale nuclear reactors. Also, there is a commitment to invest up to £170 million for a research and development programme on Advanced Modular Reactors (AMRs). These Generation IV reactors may have the potential for a range of applications beyond electricity generation, including heat generation and the production of hydrogen.[12] As such, development of AMRs is an attractive proposition since they may help contribute to other goals with the ten point plan.

[11] https://web.archive.org/web/20130404145453/http://www.nrel.gov/analysis/sustain_lca_nuclear.html
[12] https://www.gov.uk/government/publications/advanced-nuclear-technologies/advanced-nuclear-technologies

2. Nuclear power in general

2.1 Worldwide patent landscape

Figure 1: Number of active nuclear power patent families, grouped by priority (first filing) year, 2001-2018

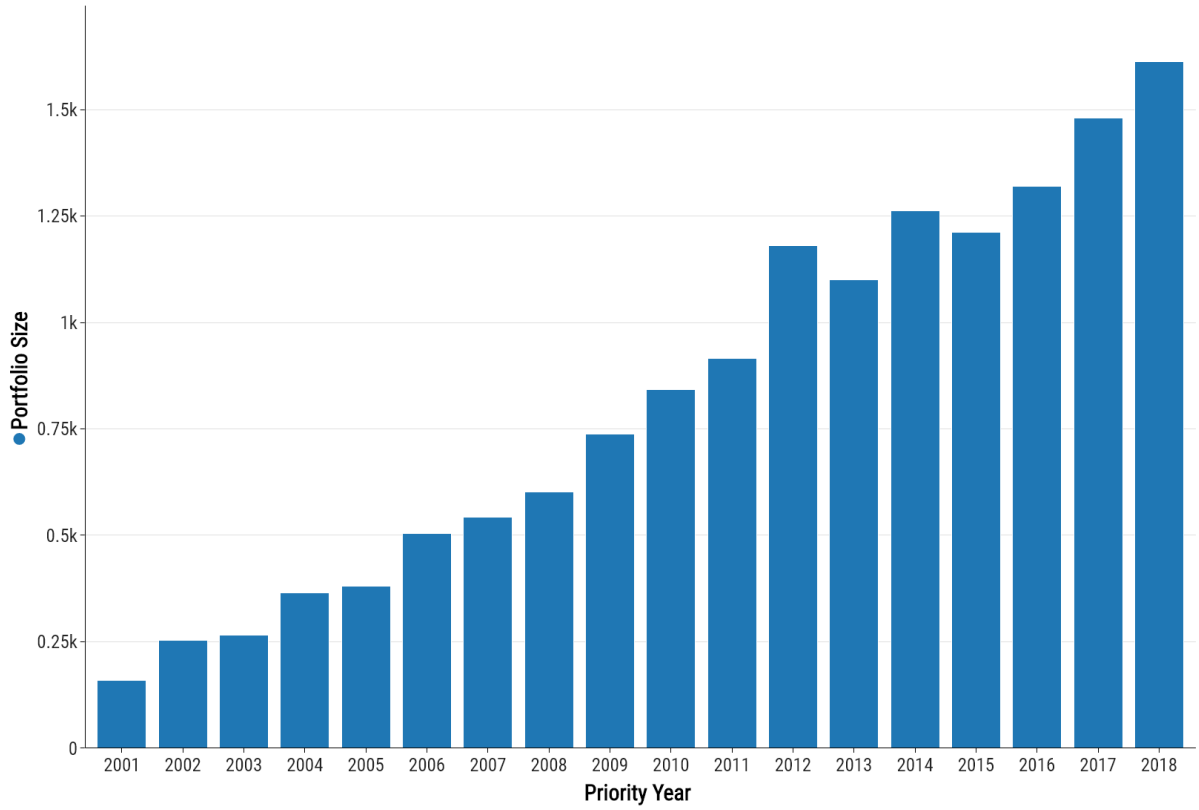


Figure 1 shows there has been a consistent increase in the number of active patent families relating to nuclear power (14,735) filed each year from 2001-2018. There were over ten times as many active patent families with a priority year of 2018 compared to 2001, suggesting that this technology area is continuing to develop over time.

Figure 2: World map showing where nuclear power patents are being protected, 2001-2018

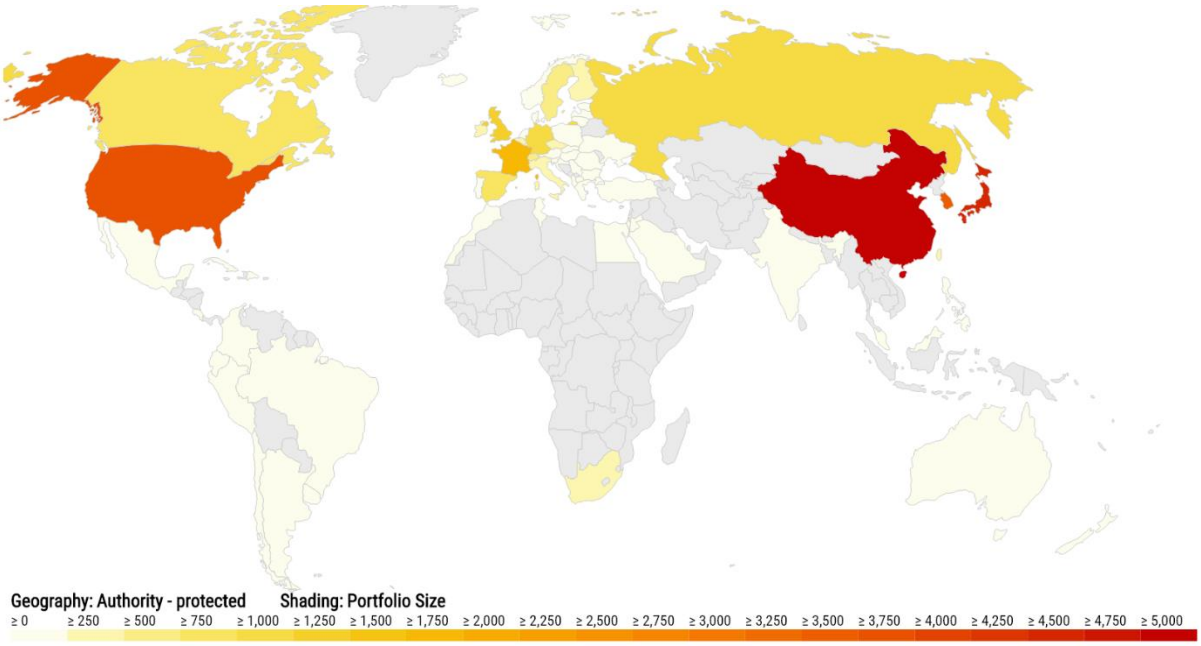


Figure 2 shows that most nuclear power patents are active in China, followed by Japan, the US and South Korea. This broadly follows general patenting trends in many sectors, where China has a substantially higher level of patenting activity in general. Russia shows more prominently in this map than for other technology areas, suggesting that Russia may be more active in nuclear power compared to in other technology areas.

Figure 3: World map showing the inventor countries of nuclear power patents, 2001-2018

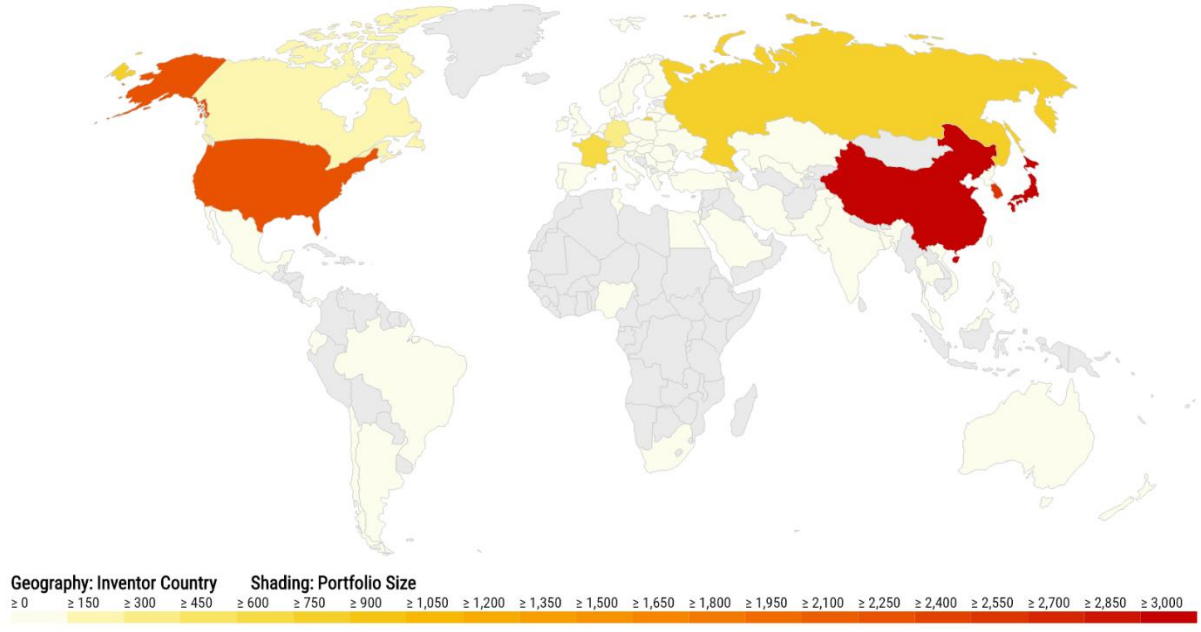


Figure 3 shows broadly the same trends as Figure 2, showing that nuclear power technologies are being protected in broadly the same countries as they are being invented.

Using the Relative Specialisation Index (RSI) can help to account for the fact that some countries file more patent applications than others in all fields of technology. The RSI compares the fraction of a country's technology-specific patents, out of all of its patents across all fields of technology, with the corresponding fraction of technology-specific patents worldwide.

Table 1: Relative Specialisation Index of top 10 countries for nuclear power patents, 2001-2018

Country	Relative Specialisation Index
France	0.646
United Kingdom	**0.258**
Canada	0.252
South Korea	0.233
Japan	0.085
USA	-0.111
China	-0.132
Australia	-0.362
India	-0.443
Germany	-0.517

Table 1 shows the Relative Specialisation Index (RSI)[13] of the top 10 patenting countries for nuclear power technologies. It shows that France is the most specialised country for nuclear power. The UK also has a figure above zero, showing that it is relatively more specialised in this area than you would expect given the absolute levels of patenting within the UK.

[13] See Appendix C for details of how the Relative Specialisation Index (RSI) is calculated

Figure 4: Top 20 owners of active nuclear power patent families, 2001-2018

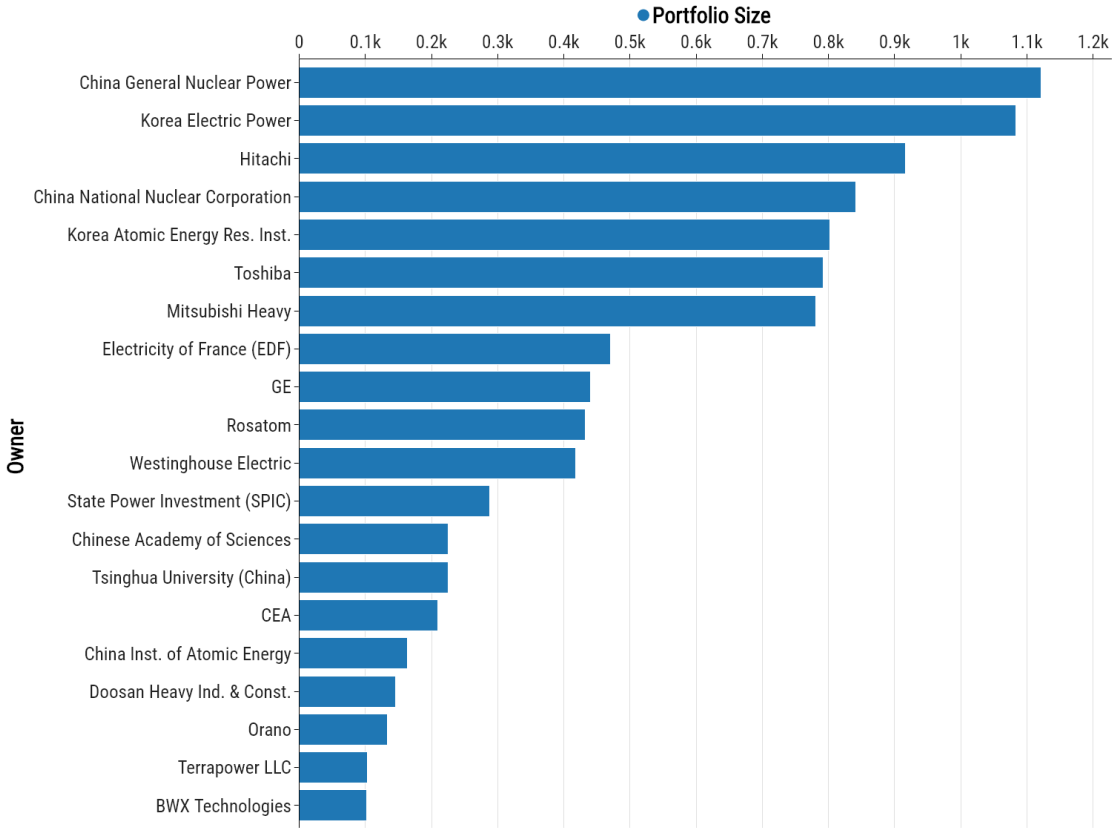
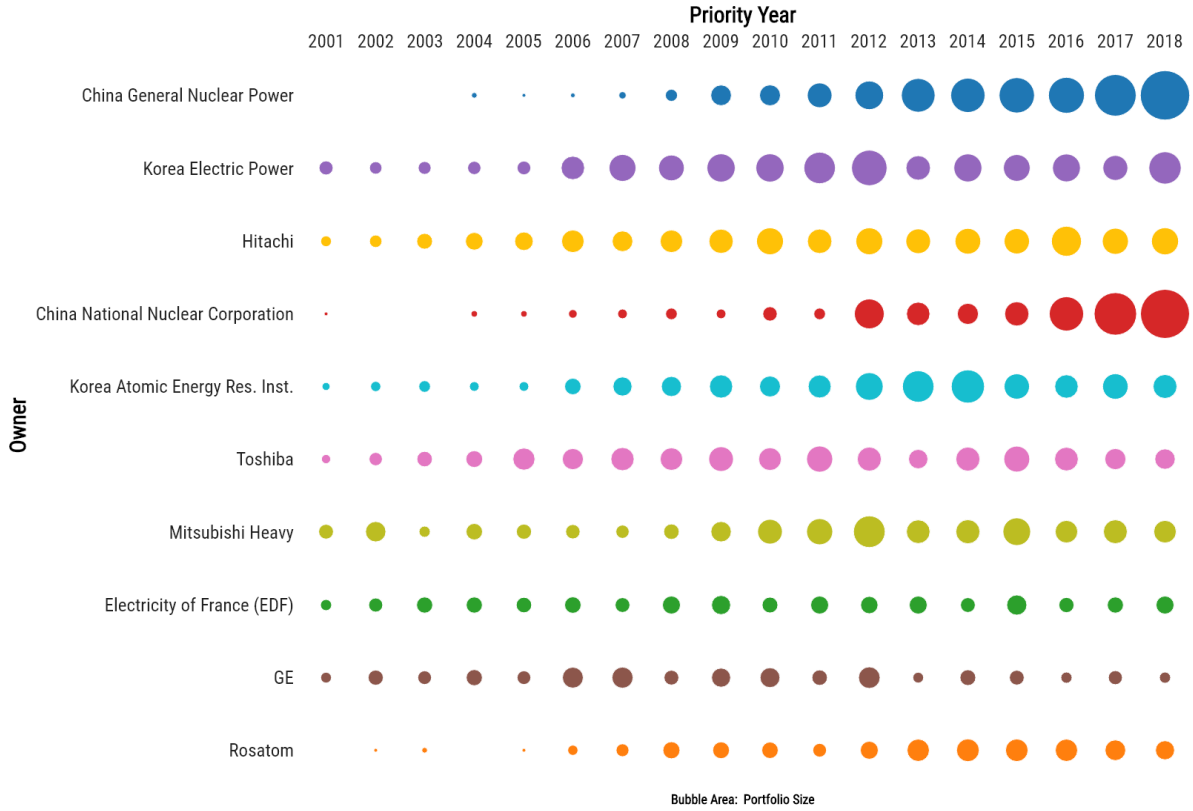


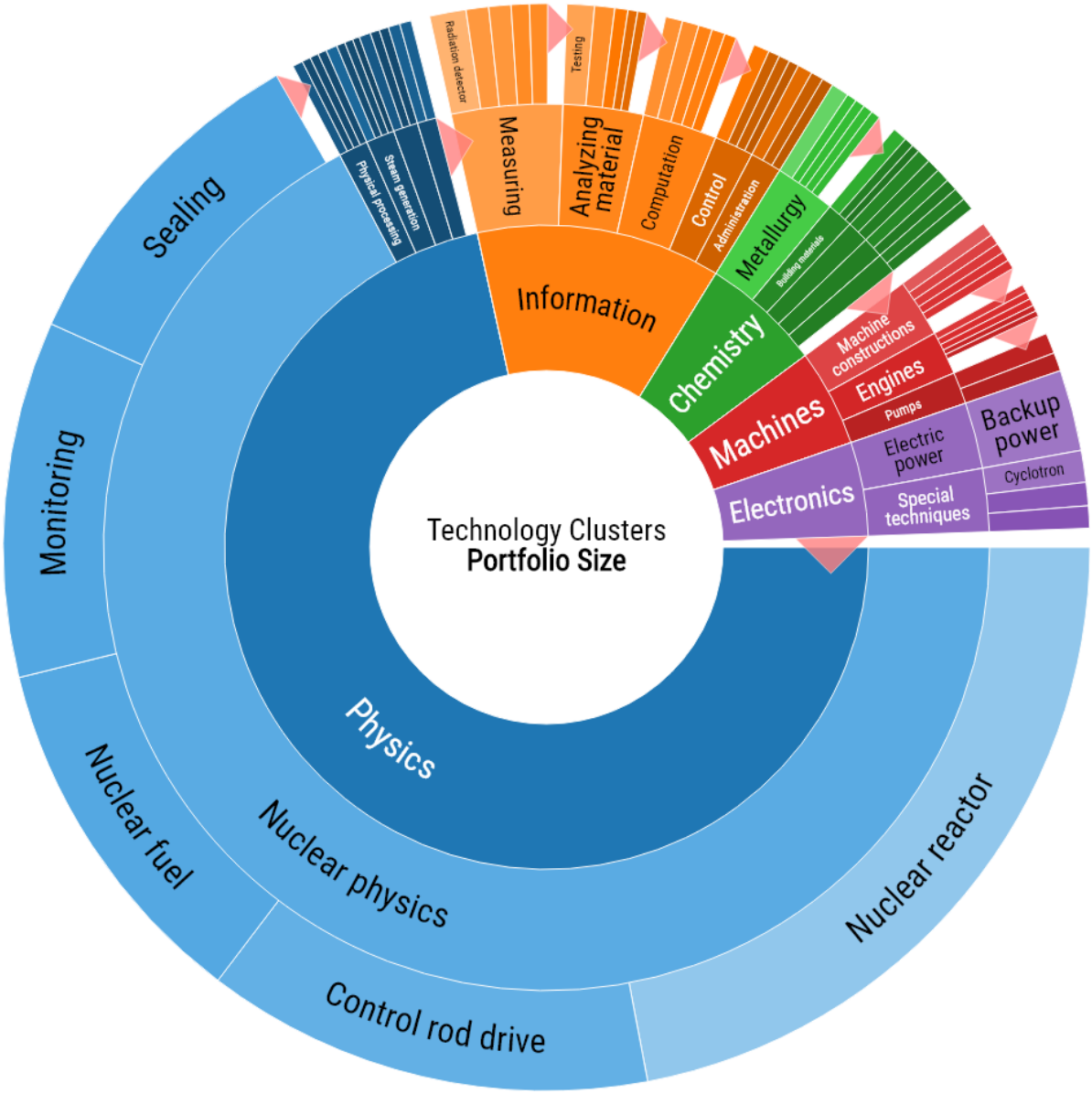
Figure 4 shows a number of different energy companies are active in this area. There are notable a significant proportion of Chinese companies, as well as other national energy companies which appear to be involved in nuclear power. 65% of patents relating to nuclear patents are owned by these top 20 owners.

Figure 5: Bubble chart matrix showing nuclear power patent portfolio size per year, grouped by the top 10 owners, 2001-2018



The bubble matrix in Figure 5 highlights the different activity levels of different patent owners in this field. China National Nuclear Corporation showed little activity until 2012, where it then began to increase its portfolio size from 2012-2018. EDF appear to have been maintaining a fairly consistent number of patent filings each year throughout this time period.

Figure 6: Sunburst chart of the technology clusters covered by nuclear power patent families, 2001-2018



Sunburst charts provide a quick and intuitive understanding of a technology area, including the categories of inventions that are protected and in what proportions. Figure 6 shows that 13% of nuclear power patents relate specifically to reactor technologies, whilst there are significantly fewer patents that relate to information and electronics.

2.2 UK patent landscape

Figure 7: Number of nuclear power patents active in the UK, grouped by priority (first filing) year, 2001-2018

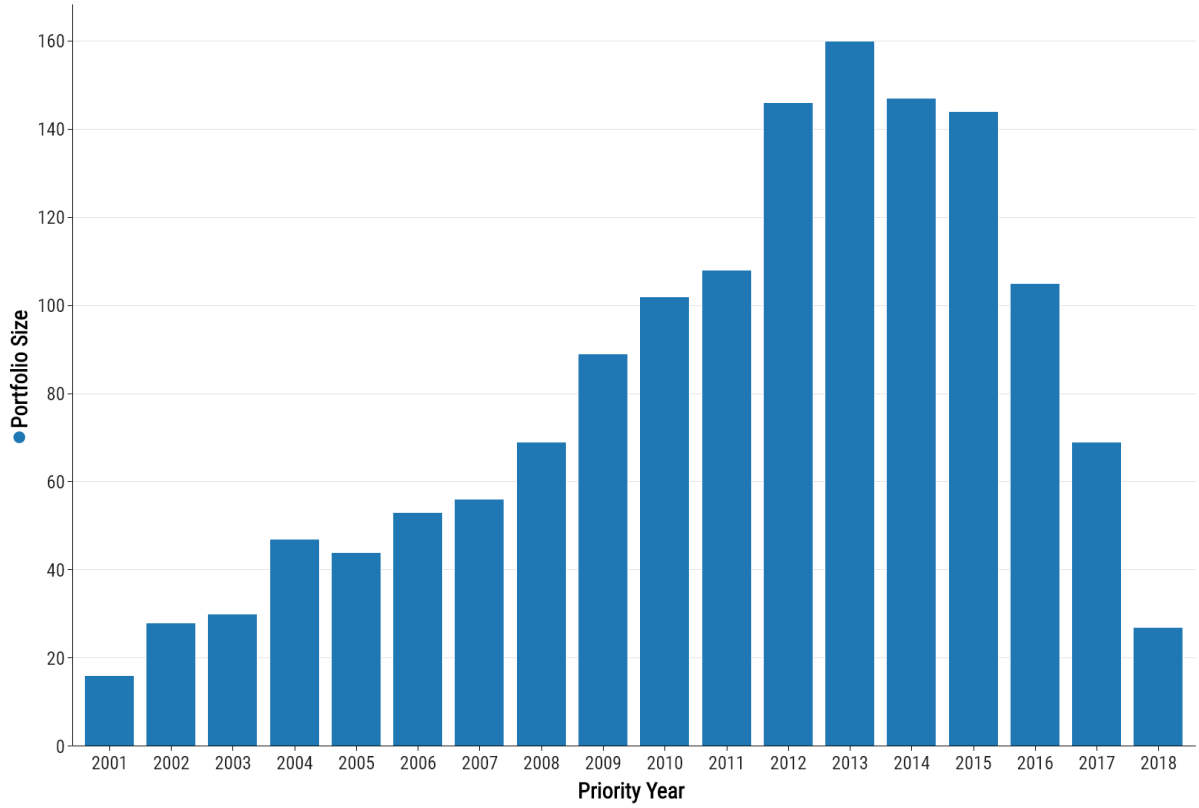
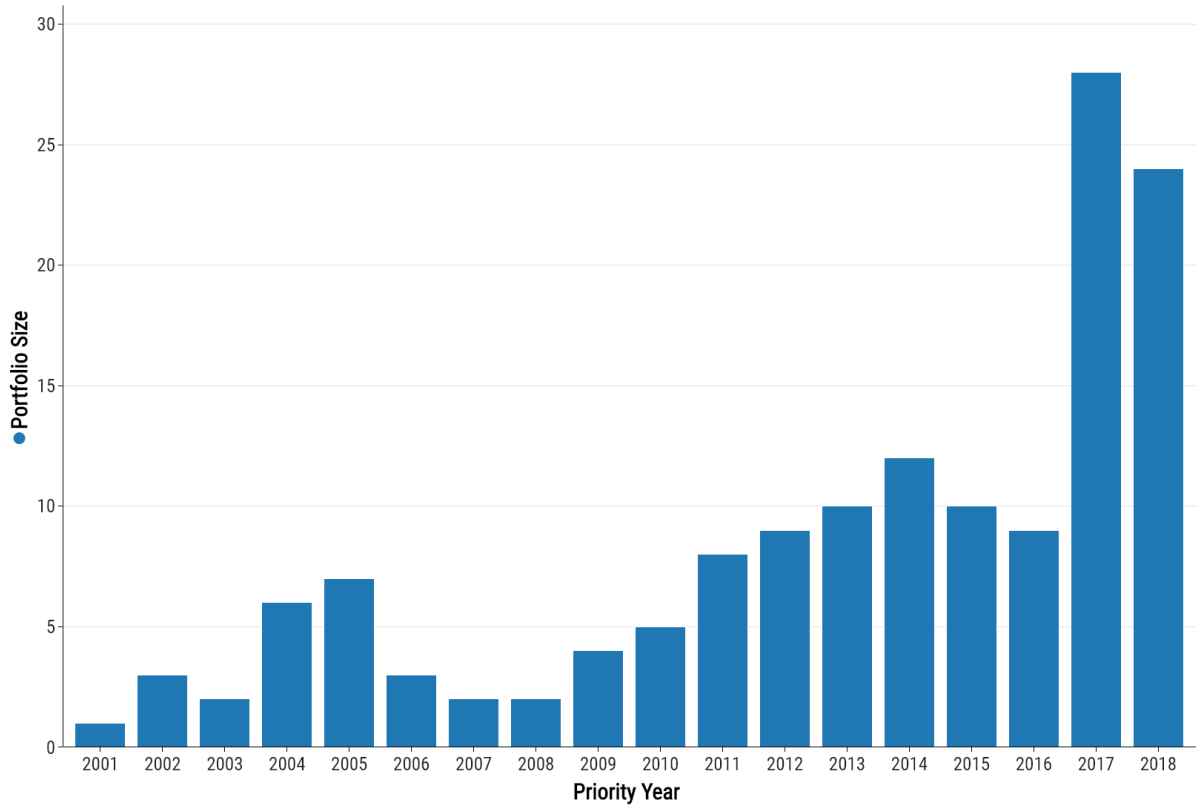


Figure 7 shows how the number of filings of nuclear power patents active in the UK (1,440 in total) increased significantly from 2001-2013. In the ten years from 2003 to 2013, the number of active patents filed each year increased five-fold. This may be indicative of the level of technological development during this time period. From 2014 to 2018, the number of active patents in this area being filed per year appears to have decreased, indicating a slower growth rate compared to 2003-2013.

Figure 8: Number of active nuclear power patent families invented in the UK, grouped by priority (first filing) year, 2001-2018



Looking at Figure 8 it is clear that there was relatively little patenting activity in this area from 2001 to about 2008, where the patents were invented in the UK (145). From 2009 until 2014, there appears to have been a small gradual increase in the number of patents being filed for each year. Following this, there was a significant increase in the growth rate in 2017-2018, with the number of patents filed tripling from 2016 to 2017. By looking in detail at the patents with a priority year of 2017-2018, it is clear that there are three main owners which were responsible for this increase, namely, Rolls-Royce, Tokamak Energy, and Westinghouse Electric.

Rolls-Royce has committed to developing SMR technology in the UK, which has been part-funded by UK Research and Innovation (UKRI).[14,15] This may help explain Rolls-Royce's patenting activity in this area, and shows that their patenting activity may be indicative of innovation occurring within this company.

Tokamak Energy is a UK based fusion power research company, established in 2009. Their focus is on achieving commercial fusion power generation.[16,17] As a result, this company's patenting activity may be an indicator of increased patenting activity in the UK relating specifically to nuclear fusion. Although not explicitly mentioned in the government's ten-point plan, nuclear fusion power is an area of power generation under extensive research, since it has the potential to generate relatively clean power for a vast number of years.

[14] https://www.rolls-royce.com/innovation/small-modular-reactors.aspx#/
[15] https://www.world-nuclear-news.org/Articles/UK-confirms-funding-for-Rolls-Royce-SMR
[16] https://www.tokamakenergy.co.uk/
[17] https://www.theengineer.co.uk/tokamak-energy-15-million-fusion/

Figure 9: Top 10 owners of nuclear power patents active in the UK, 2001-2018

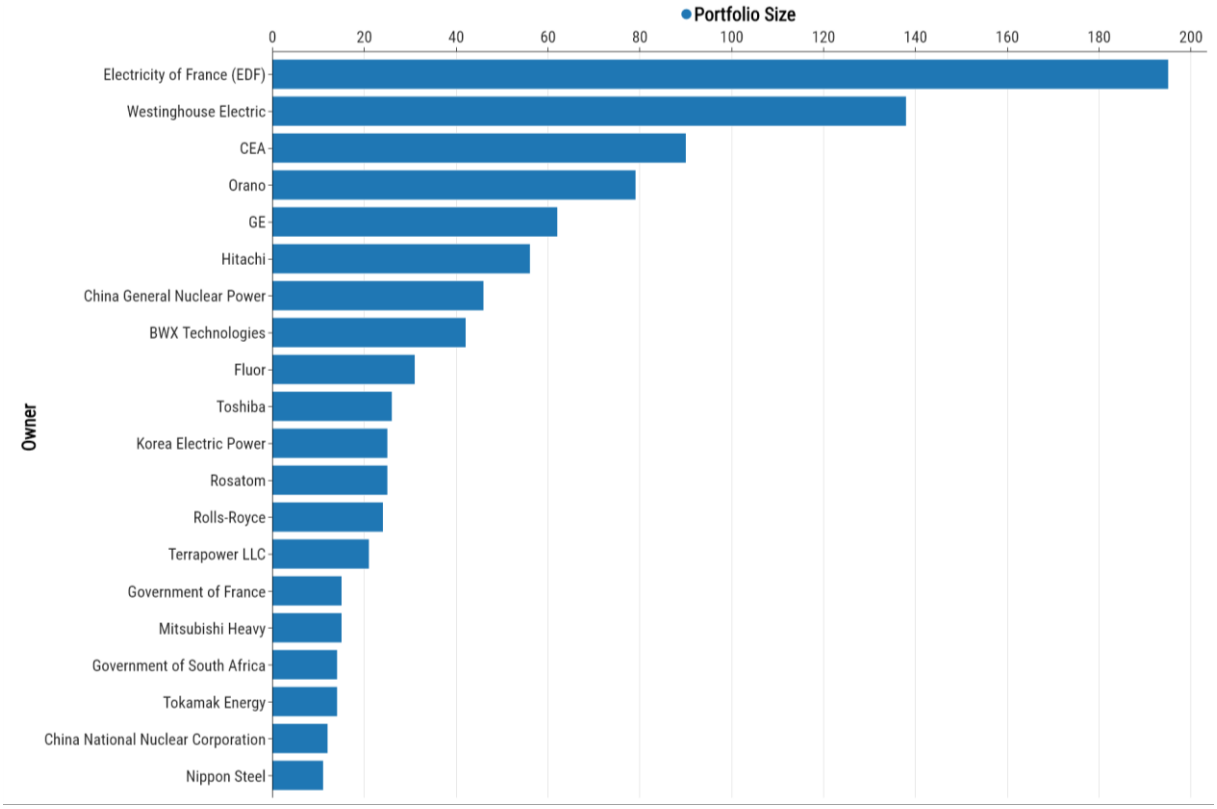


Figure 9 shows that there are a broad range of owners with nuclear power patents active in the UK. EDF have significantly more patents in this area compared to other owners, followed by Westinghouse Electric. There also appear to be some UK-based companies present here, such as Rolls-Royce and Tokamak Energy. Also present are some national governments (e.g. France and South Africa) suggesting that governmental ownership (or at least part-ownership) of nuclear power patents may be playing a role in this sector. These top 10 owners own around 65% of nuclear power patents active in the UK.

3. Small Modular Reactors (SMRs) and Advanced Modular Reactors (AMRs)

This section focuses specifically on patents which relate to SMRs or AMRs, since the development of these types of nuclear reactors are the focus of the government's ten-point plan.

3.1 Worldwide patent landscape

Figure 10: Number of active patent families relating to SMRs or AMRs, grouped by priority (first filing) year, 2001-2018

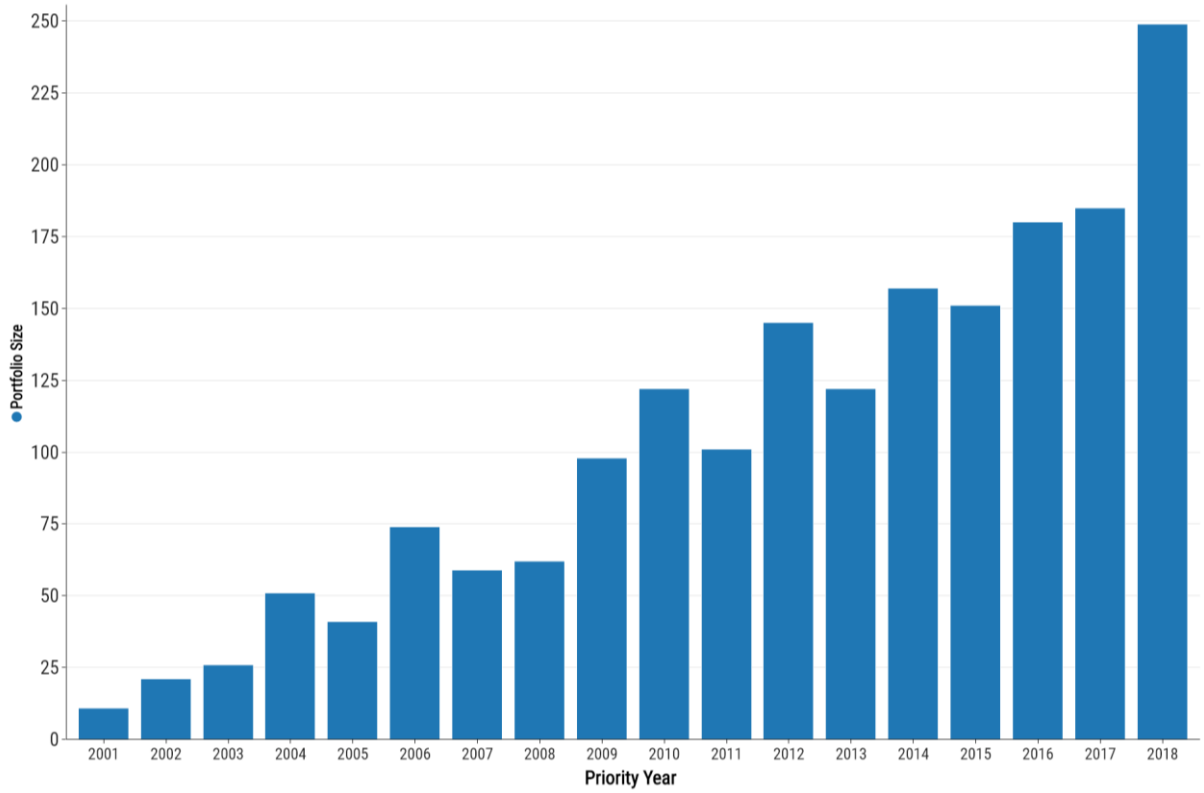


Figure 10 shows that the number of active patent families being filed each year (1,855 in total) relating to SMRs and AMRs has been increasing gradually over this time period. There also appears to have been a more pronounced increase in filing from 2017-2018, with a 35% increase in the number of active patents claiming priority in 2018 compared to 2017. This may be indicative of continuing and accelerating development of this technology area.

Figure 11: World map showing where patents relating to SMRs or AMRs are active, 2001-2018

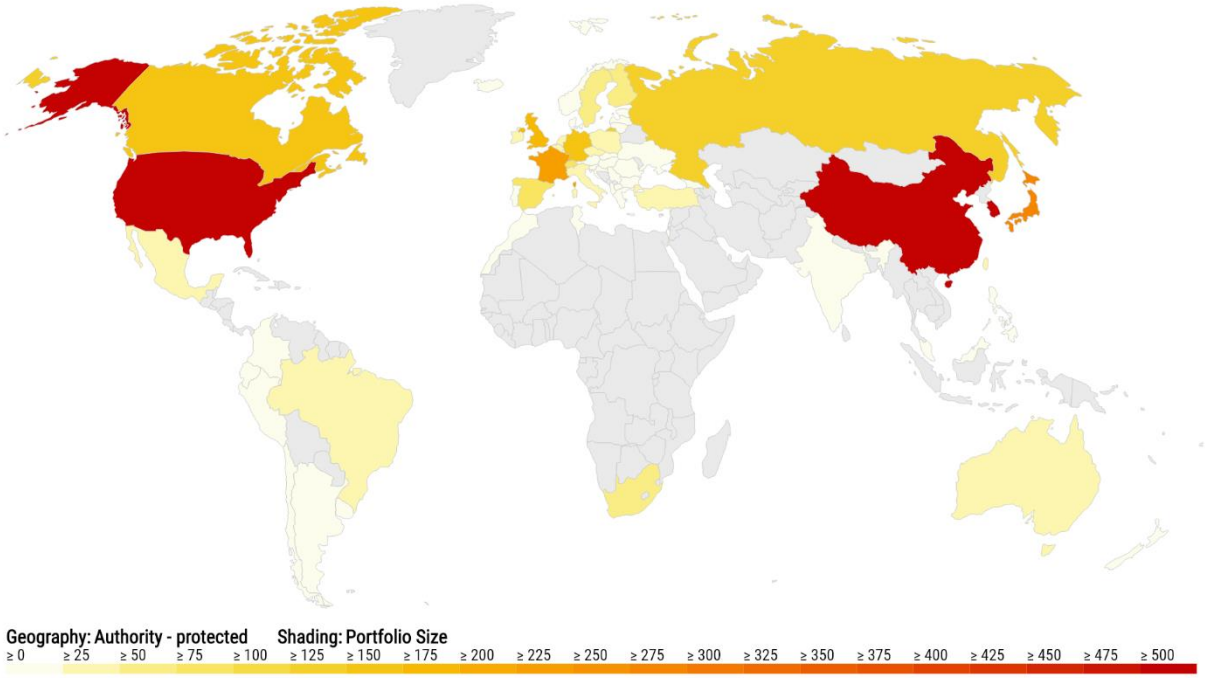


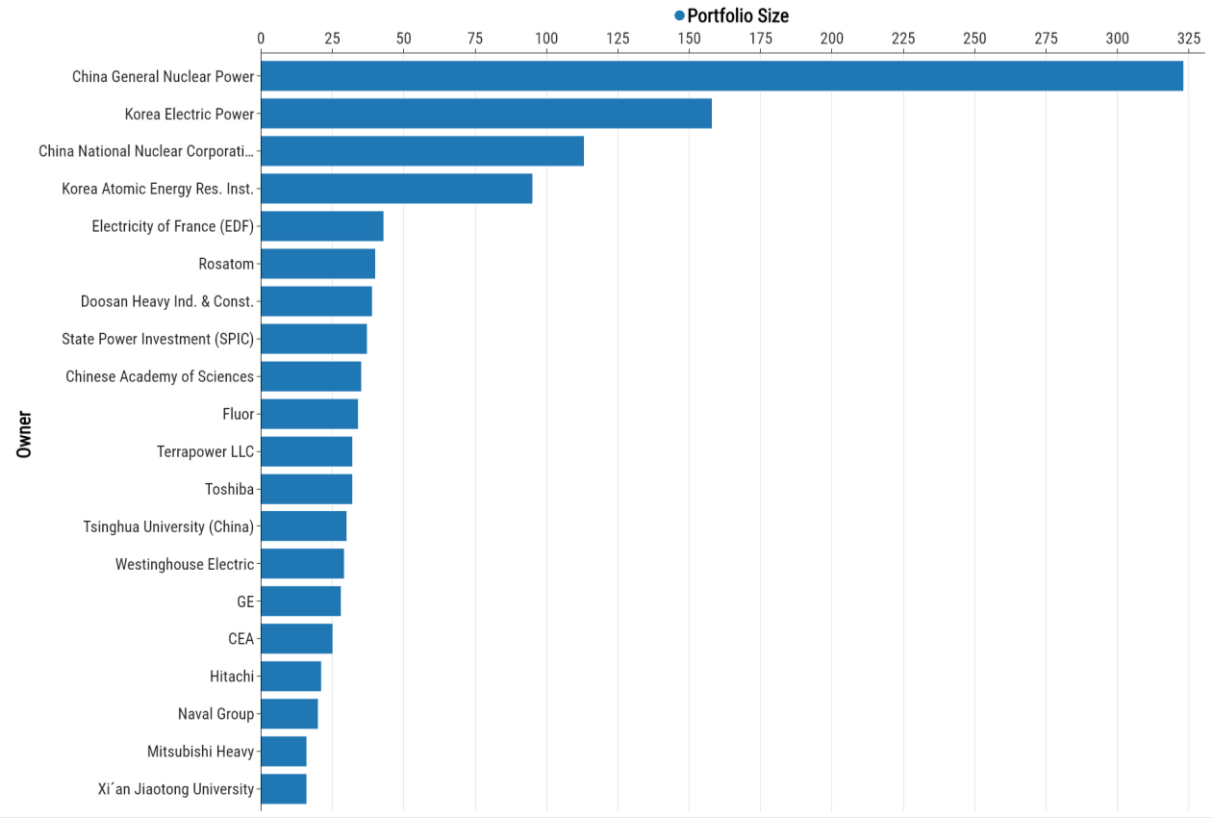
Figure 11 shows how patents relating to SMRs or AMRs are being protected in mostly the same countries as nuclear power patents in general (Figure 2). Of note, South Korea appears to be more pronounced in this map compared to Figure 2.

Table 2: Relative Specialisation Index of top 10 countries for SMR and AMR patents, 2001-2018

Country	Relative Specialisation Index
France	0.649
South Korea	0.338
United Kingdom	**0.317**
Canada	0.275
China	-0.010
India	-0.036
USA	-0.065
Australia	-0.095
Japan	-0.450
Germany	-0.503

Table 2 shows the Relative Specialisation Index (RSI) of the top 10 patenting countries for technologies relating to SMRs or AMRs. It shows that France is the most specialised country for this technology area. The UK also has a figure above zero, showing that it is relatively more specialised in this area than you would expect given the absolute levels of patenting within the UK. South Korea has a higher RSI for patents in this technology area compared to nuclear power in general, suggesting that it is more specialised in this particular area of nuclear power.

Figure 12: Top 20 owners of patents relating to SMRs or AMRs, 2001-2018



Looking at Figure 12, it is clear that China General Nuclear Power dominates this technology area, with about double the number of active patent families compared to the next largest owner. They also own 17% of the total number of patents relating to SMRs or AMRs. A number of Chinese-based companies stand out in this chart, showing that a substantial level of patenting activity relating to SMRs or AMRs appears to be occurring in China. South Korean companies also feature quite prominently on this chart, more so than for nuclear power in general. This may be reflecting the higher degree of specialisation in South Korea for SMRs or AMRs compared to nuclear power in general. 62% of patents relating to SMRs or AMRs are owned by these top 10 owners.

3.2 UK patent landscape

Figure 13: Number of patents relating to SMRs or AMRs active in the UK, grouped by priority (first filing) year, 2001-2018

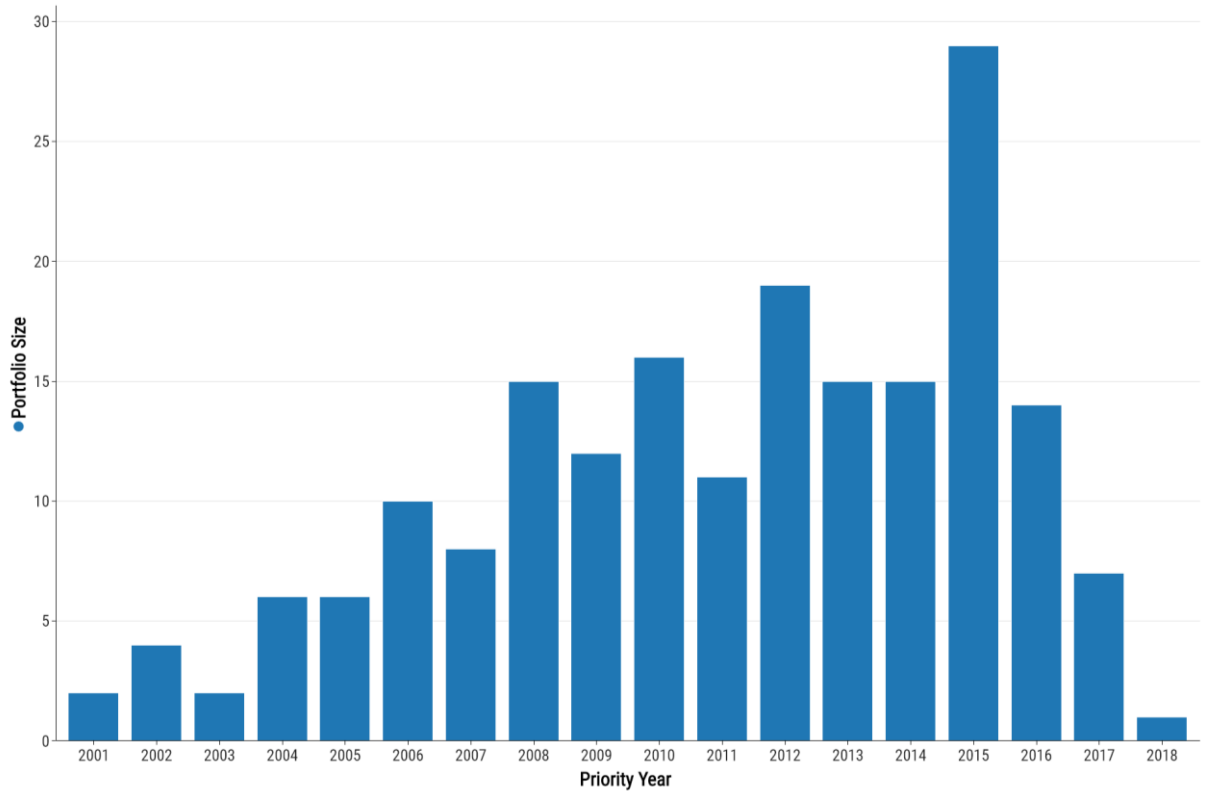


Figure 13, above, shows that there was a gradual increase in the number of active patent families being filed each year in this technology area from 2001-2012. Standing out clearly is an apparent peak in 2015, where there were 29 patent families active in the UK which have a priority date in 2015. These appear to have been by a range of different owners, and there is no clear reason for the increase in 2015 compared to other years.

Figure 14: Top 10 owners of patents relating to SMRs or AMRs active in the UK, 2001-2018

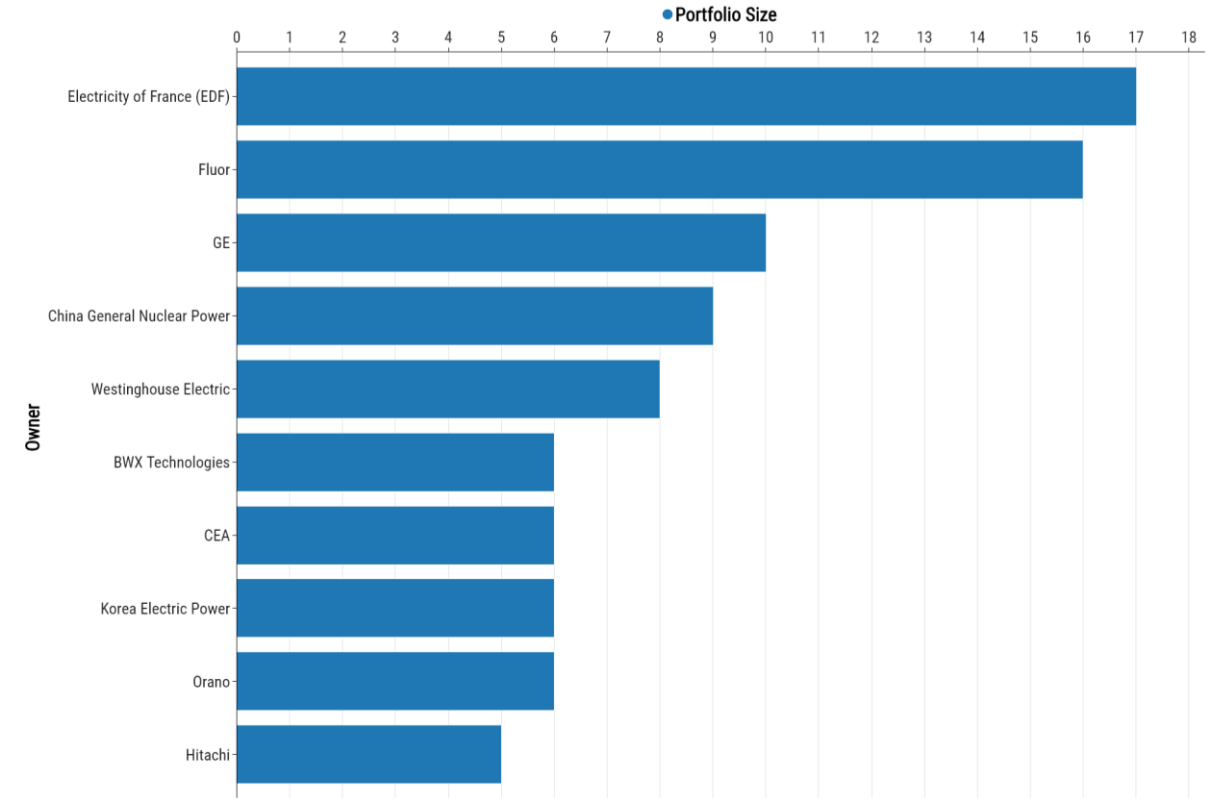


Figure 14 shows that EDF and Fluor are the most active owners in this area with active patents in the UK. This chart broadly reflects what was seen with nuclear power in general, but on a smaller order of magnitude. This suggests that the top owners of nuclear power patents have some patents relating specifically to SMRs or AMRs, but this makes up a part of their larger portfolio rather than being a main focus by these owners. 46% of patents relating to SMRs or AMRs relate are owned by these top 10 owners.

4. Conclusions

The UK's commitment to delivering new and advanced nuclear power is a key element of the ten point plan for a green industrial revolution. One reason for this is that a number of key elements of the plan will rely on a strong supply of electricity which will need to be generated in a low-carbon manner. Nuclear power has the potential to facilitate this.

Development of AMRs may complement investments in carbon capture, utilisation and storage (CCUS), hydrogen and offshore wind by unlocking efficient production of hydrogen and synthetic fuels. The UK is aiming to develop a large-scale nuclear power plant, which will be complemented with support of the development of SMRs. Hinkley Point C is currently under construction and is expected to produce 3.2GW of electricity capacity for around 60 years.[18]

[18] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/725960/HPC_Benefits_Realisation_Plan.pdf

The worldwide patent landscape for nuclear power shows that this is a growing technology area, with a significant amount of patenting activity occurring in China and the US. France appears to be relatively specialised in this area, compared to other European nations. This may be a result of the country's historic focus on nuclear power, and the fact that nuclear power is the largest source of electricity in France, where it accounts for approximately 70% of the country's electricity production share.[19] By comparison, the nuclear power accounts for approximately 14.5% of the electricity production share of the UK.[20]

Patenting activity relating to SMRs or AMRs worldwide is also increasing, albeit on a smaller scale compared to nuclear power in general. South Korea appears to be more specialised in this area compared to in nuclear power in general. This may be a reflection of the Korea Atomic Energy Research Institute's development of a System-integrated Modular Advanced Reactor,[21] showing that patenting activity can often tie-in with development of new nuclear technologies.

Looking specifically at the UK landscape, the number of active patent families relating to nuclear power increased up to around 2015, followed by a small decrease. Interestingly, this decrease was not seen in nuclear power related patents invented in the UK, where there was a significant increase in 2017-2018. Companies such as Rolls-Royce and Tokamak Energy appear to be at the forefront of this increase in activity. It is interesting to note how these two companies are focusing their R&D in nuclear power in different directions. Rolls-Royce is developing SMRs for use within the UK, which ties in with point 3 of the government's ten point plan. Tokamak Energy, however, is focused on developing nuclear fusion technology. Commercial nuclear fusion power reactors may be some distance away in the future, but it is interesting to note how a UK company is undertaking patenting activity in this field.

Looking specifically at SMRs and AMRs in the UK, EDF appear to be the most active company involved in this area in the UK. This may come as no surprise, given that EDF Energy, a British integrated energy company wholly owned by EDF, is one of the largest energy generators in the UK. EDF Energy took control of the UK nuclear generator British Energy in 2009, and currently owns eight nuclear power stations in the UK. EDF Energy is also the company behind the construction of a new reactor at Hinkley Point C,[22] and so is likely to play a role in helping the UK achieve net zero carbon electricity.

[19] https://pris.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=FR
[20] https://pris.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=GB
[21] https://world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx
[22] https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/about/reactor

Appendices

Appendix A: Search strategy

For this study, the LexisNexis worldwide patent database was interrogated using PatentSight[23].

A.1 Nuclear power

(IPC=(G21B, G21C, G21D, G21H) or CPC=(Y02E 30)) AND PriorityDate=(2001-01-01 TO 2018-12-31)

A.2 SMRs or AMRs

((IPC=(G21B, G21C, G21D, G21H) or CPC=(Y02E 30)) AND TAC=((modul* or SMR or SMRs or AMR or AMRs))) and PriorityDate=(2001-01-01 TO 2018-12-31)

Appendix B: Cooperative Patent Classification (CPC) definitions

G21B Fusion reactors

G21C Nuclear reactors

G21D Nuclear power plant

Y02E30/00 Energy generation of nuclear origin

[23] https://go.patentsight.com/BI2.0/bi/secure/src/resources/documentation/syntax-cheat-sheet/SyntaxCheatSheet.pdf?45be120476a49463f31ebcd79b10b19e

Appendix C: Relative Specialisation Index (RSI)

Relative Specialisation Index (RSI) was calculated to account for the fact that some countries file more patent applications than others in all fields of technology. In particular US, Chinese and Japanese applicants and inventors are prolific patentees.

The RSI compares the fraction of a country's technology-specific patents, out of all of its patents across all fields of technology, with the corresponding fraction of technology-specific patents worldwide.

A logarithm is applied to scale the fractions more suitably; an RSI of zero then represents a country that is no more or less specialised than the worldwide average.

The Relative Specialisation Index (RSI) for country c in technology t is defined as:

$$RSI_{c,\,t} = \ln\left(\frac{n_{c,t}/n_t}{N_c/N}\right)$$

where:

$n_{c,t}$ = number of patents for country c in technology t
n_t = sum of patents in all countries in technology t
N_c = number of patents for country c
N = sum of patents for all countries.

A value above positive indicates that a country has a higher specialisation in this field than would be expected, whilst a negative value indicates a lower specialisation than expected for that country.

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