European Commission

Patents as a measure of innovation performance in the clean energy sector: Assessment of patent indicators

Provision of technical assistance and study to support the development of a composite indicator to track clean-energy innovation performance of EU members

Independent
Expert
Report

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EUROPEAN COMMISSION

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clarity from complexity

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Clean Planet

EN

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Abbreviations

CCMT	Climate Change Mitigation Technology
CCS/U	Carbon Capture and Storage / Utilisation
CEII	Clean Energy Innovation Index
CET	Clean Energy Technology
CN	People's Republic of China
DG RTD	European Commission Directorate General for Research and Innovation
EPO	European Patent Office
EU	European Union
EU27	European Union in its correct (2020) composition, consisting of 27 Member States
EU28	European Union when it consisted of 28 Member States (before Brexit)
GDP	Gross Domestic Product
GHG	Greenhouse Gas
ICT	Information and Communication Technology
JP	Japan
JRC	Joint Research Centre
KA	Key Action
KR	Republic of South Korea
MI	Mission Innovation
OECD	Organisation for Economic Co-operation and Development
PATSTAT	EPO Worldwide Patent Statistical Database
PV	Photovoltaic
R&D	Research and Development
RD&I	Research, Development and Innovation
SET plan	Strategic Energy Technology plan
SET Plan KA	Strategic Energy Technology plan key action
TUSD	Trillion US Dollar
US	United States (of America)

1 Introduction

This is the second year report of the second deliverable of the study to support the development of a composite indicator to track clean energy innovation performance of EU member states and Mission Innovation countries, which contributes to the overarching aim of assessing progress in clean energy innovation by analysing output-related indicators.

The composite indicator (also known as the 'Clean Energy Innovation Index (CEII)') covers three dimensions: scientific publications, patents and trade (with a focus on export). This report covers the work on using patents as a measure of innovation performance and has three objectives:

1. Provide context on the limitations of patent data and its usefulness as a measure of innovation performance;

2. Provide insight on clean energy technology (CET) innovation performance from the perspective of patents;

3. Deliver the patent dataset for calculating the Clean Energy Innovation Index.

The report is structured according to these three objectives. In chapter 2, we discuss the main challenges of using patents as a measure of innovation performance and we present the most suitable patent indicators for measuring innovation performance in the clean energy sector, as assessed in the year one report of this study. Additionally, we summarise insights from a series of interviews with the clean energy industry, both on the common practices around intellectual property protection and patenting, and on their view on the representativeness of patent data for measuring innovation performance. In chapter 3 we perform a detailed assessment of the identified patent indicators in order to provide insight into the CET innovation performance of EU and Mission Innovation countries and to better understand the specificities of the different indicators and their merits for measuring innovation performance. In chapter 4, we draw conclusions regarding the patent activity of the EU and Mission innovation member countries as well as the focus of in-scope countries on specific clean energy technologies. Annex A includes the dataset that is used as input for the composite indicator calculations.

2 Patents as an indicator for measuring innovation performance

Patents are a commonly used indicator for measuring research, development & innovation (RD&I) performance, since the ability to patent an invention is a clear sign (amongst many others) of successful innovation activity. One of the key positive aspects of patent statistics is that they are readily available at a high level of granularity. However, there are also several drawbacks and challenges in using patent statistics for measuring RD&I performance.

In this chapter, we first discuss the key challenges of patent-based indicators as metrics of innovation performance, with particular reference to the CET sector. Next, we present the selection of patent indicators that are used in the analysis. In the first-year patent report we concluded that these indicators are the most suitable for measuring innovation performance (and inclusion in the CEII)[1]. These indicators are then analysed in more detail in the next chapter.

2.1 Key challenges of patent-based indicators

When dealing with patent statistics, there are several issues and peculiarities that need to be considered when interpreting the data. Some of these are merely practical challenges that require a transparent and consistent approach, but do not pose challenges beyond that. Others are more fundamental in nature and lead to debate around the usefulness of patent data for measuring innovation performance. In this section, we discuss the main issues.

Practical challenges

A first practical challenge in working with patent statistics concerns the **quality of the data** reported to the European Patent Office (EPO). The bi-annual uploads by national patent offices do not always include all relevant information on each patent, which may lead to underestimating the number of patents filed. The JRC has devised algorithms and working processes to improve the quality of the data sets[2], which are considered effective in resolving this issue.

A second challenge relates to avoiding **double counting** of patents. This may occur when patents are filed by multiple applicants, when patents are relevant for multiple technologies, or when patents are filed at multiple patent offices. Commonly used solutions to address these issues are available and include the use of fractional counts and patent families as done in the JRC method[3,4].

Fundamental issues

One of the more fundamental issues of using patent data for measuring innovation performance is the **time lag[5].** A complete dataset is only available after 3½ years due to the length of the process from filing a patent to the filed patent becoming available in PATSTAT. At present there is no approach to reduce the time lag for the full dataset, although there are early estimates (2-year lag) available for the EU-27. Due to this issue,

[1] European Commission, Directorate-General for Research and Innovation, Hoogland, O., Torres, P., Janzow, N., et al., Patents as a measure of innovation performance : selection and assessment of patent indicators : provision of technical assistance and study to support the development of a composite indicator to track clean-energy innovation performance of EU members, Publications Office, 2021, https://data.europa.eu/doi/10.2777/77424
[2] Pasimeni, F. (2019). SQL query to increase data accuracy and completeness in PATSTAT. World Patent Information, 57, 1-7.
[3] Fiorini A., Georgakaki A., Pasimeni F., & Tzimas E. (2017). Monitoring R&I in Low-Carbon Energy Technologies (JRC105642).
[4] Pasimeni, F., Fiorini, A. & Georgakaki, A. (2019) Assessing private R&D spending in Europe for climate change mitigation technologies via patent data. World Patent Information, 59, 1-11.
[5] Pasimeni, F. & Georgakaki, A. (2020) Patent-Based Indicators: Main Concepts and Data Availability (JRC121685).

measuring the impact of past policies to stimulate innovation through patent statistics can only be done with some delay.

Another key issue is that the **propensity to patent** may differ significantly across countries, sectors and time. In particular, Chinese companies tend to be more inclined to patent due to government policies that incentivise patenting and the option to file other types of patents with less stringent conditions. In addition, China has three categories of patents, namely invention, utility and design, which differ in terms of innovation quality[6] and that can create a discrepancy compared to the patents of other countries. Nevertheless, EPO excludes the utility and design patents from the dataset (which was used for the purposes of this analysis) when they are classified properly. On the other hand, there have been signals that EU companies have become less inclined to use patents as a knowledge protection strategy due to a reduced belief in its effectiveness.[7] In addition, the propensity to patent may differ according to the maturity of the industry. EU-based wind turbine manufacturers are, for example, relatively mature with most of the innovative features of their products already well-developed and patented, whereas their emerging competitors from China are younger and have more technology development and associated patenting going on. Due to such reasons, substantial differences in propensity to patent may exist, which make patent statistics less representative for innovation performance.

Another fundamental issue in using patent statistics concerns differences in the **value of patents**[8]**.** Not all patent offices apply the same rules for accepting patent applications, which causes differences in the quality of patents at the stage of filing. But more importantly, the commercial value of patents differs strongly, with only a small share of the filed patents having significant value. There are different possible approaches to assessing the value of patents and/or filtering high-value patents only. Patent citations may, for example, be used as a measure of their value but this increases the time needed to provide a measure of their impact as it takes a while to accumulate citations[9]. Another option is to exclude patents from the sample that are only filed domestically, in order to focus the analysis on patents with higher international relevance. However, this may skew the results in favour of companies from smaller countries, as these would naturally focus on larger, international markets due to the limited size of their home market. Overall, there is no simple solution to correct for differences in the value of patents, leading to a further need to interpret patent statistics cautiously.

Finally, patent statistics in absolute values may not always be fully representative of innovation performance due to **differences in "RD&I resources"** (quality and quantity of R&D personnel, equipment, etc.) and the underlying drivers, such as RD&I investments which are in turn related to the (absolute) scale of economic activity (GDP) in each country as well as the level of economic development (GDP per capita). Hence, patent numbers need to be scaled to a value that would correct for the "RD&I resources" available in a country and would try to capture the innovation performance or productivity in a way to make international comparisons meaningful. Potentially useful scaling factors include population, GDP or RD&I budgets. Such alternative factors can impress a specific meaning to the indicator. For instance, the use of population may lead to an interpretation in the sense of Invention propensity of inhabitants, while RD&I budget implies an interpretation in the direction of Productivity of the Research resources.

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[6] China Power Team (2016). Are patents indicative of Chinese innovation?
[7] In the year 1 report on patents for this study we elaborate more on this.
[8] OECD (2009). OECD Patent Statistics Manual 2009
[9] Popp, D. (2002). Induced innovation and energy prices. American economic review, 92(1), 160-180.

2.2 Selection of patent indicators for inclusion to the CEII

In the patents report of the first year of this study, an extended analysis on the merits of the potential patent indicators has been conducted which was based on literature review and patent data assessment. Based on this analysis, the selected patent indicators for inclusion in the clean energy innovation index are: number of inventions, number of high value inventions and number of international inventions. For each of those, a higher value indicates a higher innovation performance, all else being equal.

These indicators provide insights that complement each other and mitigate each other's weaknesses. The first and most simple indicator 'number of inventions' provides the best view on domestically filed patents, which may include important innovation outputs, in particular for countries with a large domestic market such as China[10]. However, the innovation performance measured by this indicator may be skewed by high volumes of relatively lower quality inventions and higher propensity to patent in specific countries. Both the number of high value inventions and the number of international inventions provide a way to exclude a share of the lower quality inventions and may therefore mitigate part of the issue of differences in the quality of patents. However, these indicators have drawbacks of their own as they may exclude important patents that are only filed domestically and may introduce a bias towards countries that are naturally more inclined to patent their inventions internationally due to their small home market. There are significant differences between high value and international inventions too, in particular the treatment of the EU members states as separate countries (in high value) or included in the EU as one country (in international) results in different conclusions. Overall, none of the three indicators are perfect measures of innovation performance, but all three provide relevant insights and are therefore analysed in more detail in the next chapter.

In our opinion, the indicators are best scaled by GDP to assess performance compared to the resources that each country could mobilise. We consider GDP a better scaling parameter than population because it accounts for differences in economic and innovation productivity per country.

2.3 Insights from industry interviews

When preparing the year 2 analyses for this study we initiated a series of interviews with the EU clean energy industry to create additional insights on their approach towards patenting and their view on whether or not patent statistics provide a useful measure of innovation performance. We completed interviews with people at the following companies (position of interviewee indicated between brackets) and highly appreciate the valuable insights that they shared with us:

- Enel Green Power SpA
- Northvolt
- Siemens Gamesa
- TNO
- Vestas

[10] As explained in section 2.2, this indicator also includes inventions with patent applications in foreign patent offices, accounted for "patent families" and fractional counting.

Within all of the interviewed organisations, the decision-making around patenting constitutes a **formalised process with multiple business areas involved**. Generally, inventions are identified and tracked from early stages to commercial application and eventually the end of their useful lifetime. The decisions around whether or not to protect the intellectual property and how to best protect it involve stakeholders from the engineering/technology development department, the commercial/business department and the legal/intellectual property department. Thanks to this formalised process, there is little room for decision-making based on sentiment around for instance the lack of effective IP enforcement in China, counter to the impression that we got in a previous study on innovation in clean energy.[11]

For the inventions with sufficient commercial value, **patenting is one of the dominant strategies for intellectual property protection**. In particular for product innovations (as opposed to process innovations), patents are often the preferred strategy as those can often be reverse engineered limiting the effectiveness of keeping the invention as a trade secret. In other cases, trade secrets are commonly used as a knowledge protection strategy. Furthermore, copyright, design, trademarks and defensive publications are all used by most of the interviewed organisations.

The concerns about **challenges to enforce patents in China are partially recognised but have not lead to a significant shift to other forms of IP protection than patenting**. Some interviewees indicated that although they recognise where the concerns come from, the possibilities to enforce intellectual property rights in China have actually improved considerably. Furthermore, EU companies often focus on other markets than China and are realistic in their assessment that the Chinese market is not a fully open market and comes with its own rules.

The trend in EU patent numbers[12] with a peak in 2012 and decreasing numbers until recent years is driven by a range of developments. One factor is the increasing maturity of clean energy technologies which has led to a decline in innovation (as measured by patents) in the design of the primary elements of the technology. The design of the blades of wind turbines is for instance relatively stable. Meanwhile, increased innovation activity occurs in the area of digitalisation and software which is partially patented and thereby offsets the decline in patents related to hardware to some extent. Another factor are the RD&I budgets which increased to very high levels around 2010 but were cut drastically after the 2011-12 financial crisis. Furthermore, the general opinion on the need for knowledge protection changed significantly within the EU, from an open innovation mindset in the early 2000s to a more business oriented view in which patents do play a crucial role nowadays.

Chinese patent numbers need to be interpreted cautiously. In line with the findings earlier in this chapter, the interviewees confirmed that the total number of inventions from China is not comparable to that of other countries, due to the possibility to file patents with less stringent conditions and the government incentives for patenting. The interviewees also confirmed that looking only at international inventions underestimates China's innovation performance as its home market is so large that there is much less of a need to enter foreign markets.

Overall, interviewees consider patent statistics as a reasonable measure of innovation performance, but the nuances need to be taken into account. Key nuances include the higher relevance of patents for product innovation, the possibility to

[11] In the year one report on patents for this study we referred to the inputs gathered during a series of conferences that we organised as part of a previous study 'Trinomics (2019) – Impacts of EU actions supporting the development of renewable energy technologies'. In those inputs, EU industry stakeholders expressed their concern that EU companies do not believe in patents as a useful intellectual property measure anymore, which would explain decreasing patent numbers. But this strong view was not confirmed during the interviews for this study.

[12] This trend is observed in all three indicators: Inventions, High Value Inventions and International Inventions.

file patents under less stringent requirements in China and the influence of the size of the home market on the tendency to file patents internationally. Overall, this is in line with the approach taken within this study, where we use both the simple number of inventions and the high value/international invention numbers to measure innovation performance, and the inclusion of patents statistics in a composite indicator which also includes statistics on other dimensions (i.e. on publications and export).

3 Detailed assessment of patent indicators and insights on innovation performance

This chapter provides a detailed assessment of the three patent indicators that have been selected for inclusion in the CEII: number of inventions, number of high value inventions and number of international inventions. The objective of this assessment is twofold. Firstly, we aim to establish a better understanding of the three indicators and their specificities per country and SET Plan KA. Secondly, we aim to provide a better understanding of innovation performance of EU countries and Mission Innovation members (MI-23)[13].

3.1 Main trends and developments

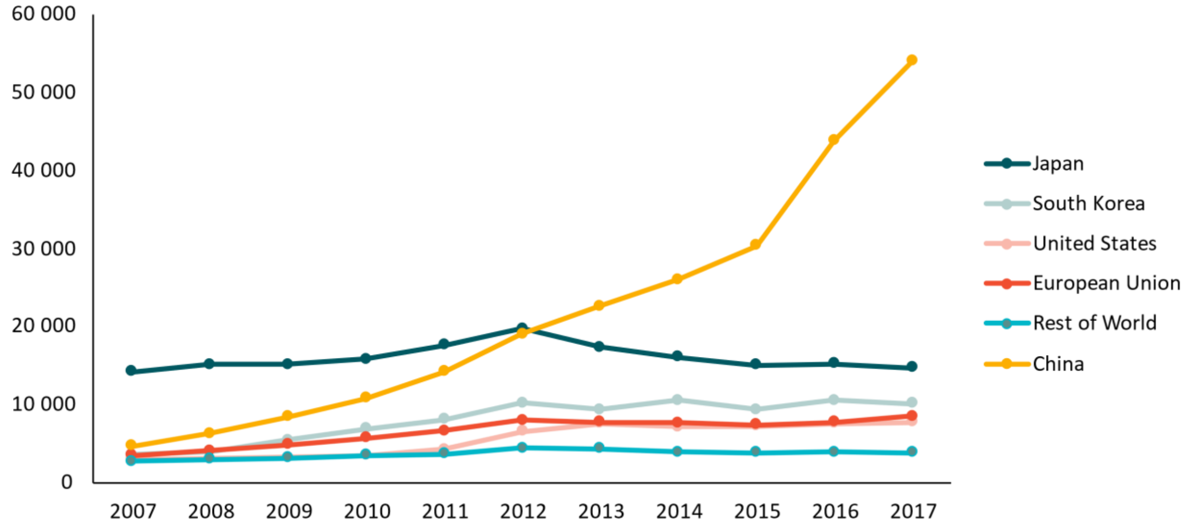
This section provides a high-level understanding of the main trends and developments for the three patent indicators of interest. First, the trend and distribution across the world players for all in-scope technologies is analysed. Secondly, the trends and distribution across KAs is presented. Finally, the performance scaled by GDP of individual countries is illustrated across all in-scope technologies on a worldwide and an EU level. In each analysis we identify trends and highlight key differences between the three indicators.

3.1.1 Patent trends across countries

Figure 1 portrays the number of inventions across all KAs by the main world players. These countries account for more than 90% of all SET plan KA-related inventions per year and are therefore labelled as 'world players' in this report. The trends and distribution across world players in Figure 1 clearly show that China is the dominant player when looking at the total number of inventions (without applying filters, e.g. identifying high-value inventions) and is extending its lead. In fact, China is the only world player for which the number of inventions exhibits an increasing trend.

[13] The Mission Innovation member countries included in the analysis (referred to as MI-23) are those with MI membership as of the end of 2018 (when the CEII project was designed), namely Austria, Australia, Brazil, Canada, Chile, China, Germany, Denmark, Finland, France, India, Italy, Japan, South Korea, Mexico, Netherlands, Norway, Saudi Arabia, Sweden, United Kingdom, United States, and United Arab Emirates. Morocco also became an MI member in 2019, and in September 2021, a new phase of MI (MI 2.0) was launched, in which Indonesia and Mexico are not participating. The EU27 is also a member of MI, but EU27 data are not included in the total values of indicators estimated for the MI category to avoid double counting of seven EU Member States that are also MI members

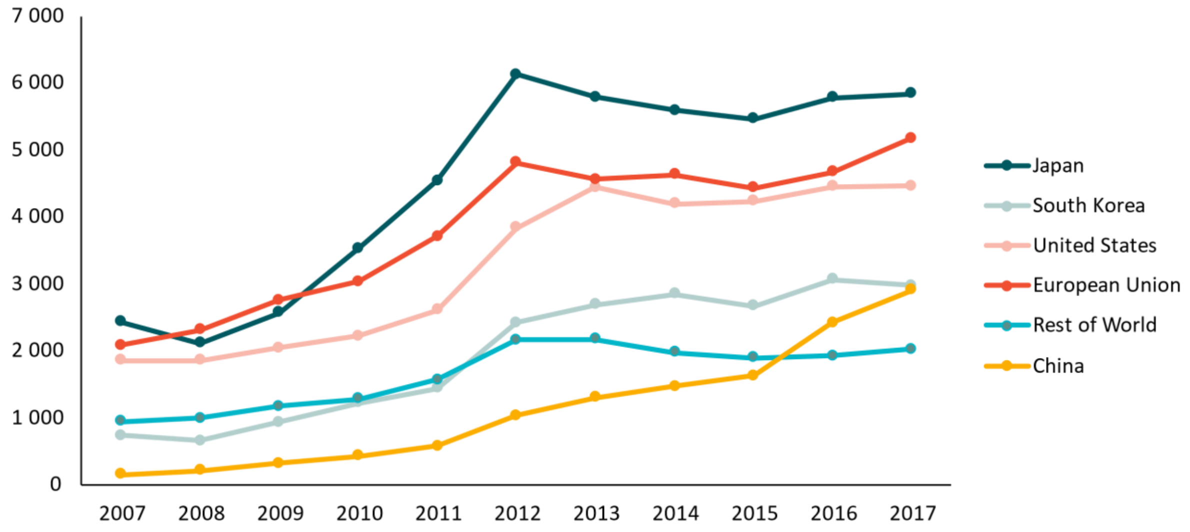
Figure 1: Number of inventions per region across all SET Plan KAs



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 2 shows the number of high value inventions, thereby excluding any invention which is only patented at a single patent office. As a result, the volume of inventions that are considered declined dramatically, in particular for China (50-fold decrease) but also for other countries (e.g. a 2 to 3-fold decrease can be observed for Japan). The resulting distribution across world players shows a leading position for Japan, the EU and US in particular, while South Korea also surpasses China. In terms of volume, a similar trend can be observed for most regions, with a peak at around 2012 and a relatively steady number of high value inventions afterwards. However, a steep rise is observed in high value inventions of China after 2015 indicating that Chinese companies are becoming more interested in patenting inventions internationally along with their already strong focus on domestic patent activity. An upward trend is also noticed in the high value inventions of the EU in the recent years.

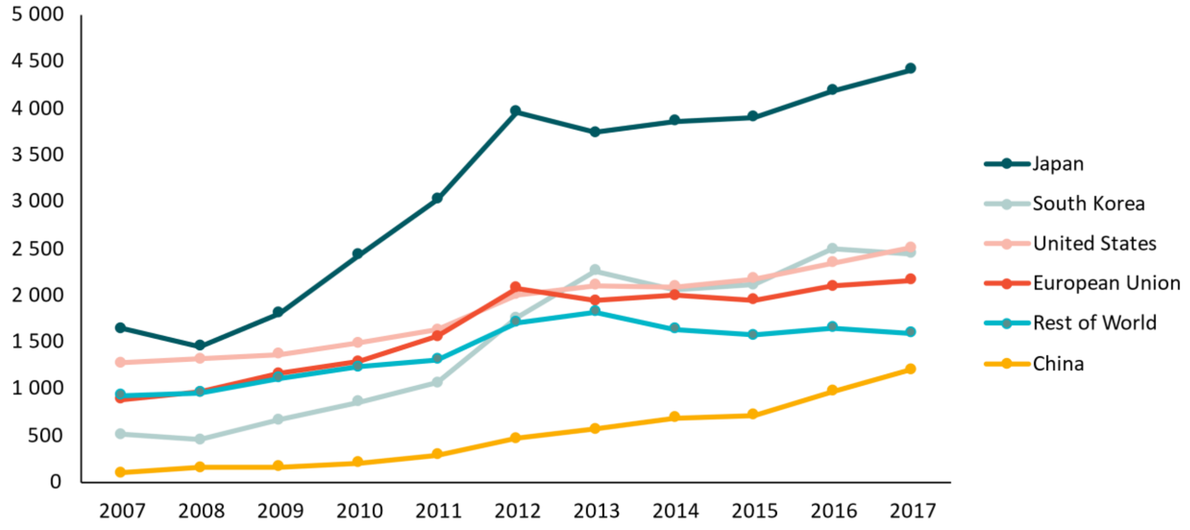
Figure 2: Number of high value inventions per region across all SET Plan KAs



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 3 shows the distribution and trends for the third indicator of interest: international inventions. This indicator only includes patent applications that are filed at a patent office in another country (treating the EU as one country) and thereby also excludes a significant portion of the inventions, but not the same portion as high value inventions. The distribution across world players shows that Japan has a particularly strong position in international inventions which is driven by a high number of international inventions in the battery sector, followed by new technologies and services for consumers and energy efficiency technologies. The EU and the US show a strong performance with an increasing number of international inventions during most of the period in scope. Similar to high value inventions, China has a relatively low number of international inventions compared to total inventions.

Figure 3: Number of international inventions per region across all SET Plan KAs

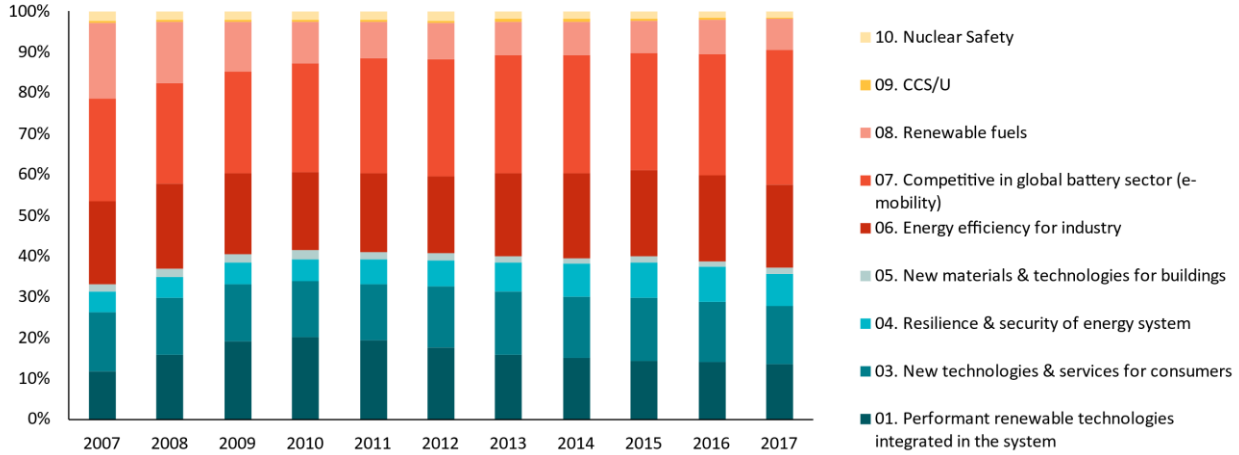


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.1.2 Trends in distribution of patents across SET Plan KAs

Figure 4 provides an overview of the distribution of the inventions per SET Plan KA for all countries in scope. It shows that the SET Plan KAs "Performant renewable technologies integrated in the system", "New technologies & services for consumers", "Energy efficiency for industry" and "Competitive in global battery sector (e-mobility)" account for the majority of the inventions, while "New materials & technologies for buildings", "CCS/U" and "Nuclear Safety" have particularly small shares. A notable trend in the distribution of shares is the declining share of "Performant renewable technologies integrated in the system", decreasing from 20% in 2010 to 14% in 2017. Another significant decrease is recorded in the shares of "Renewable fuels" from 19% in 2007 to 8% from 2013 onwards. However, this decline does not reflect the patent activity in absolute terms, as the number of inventions of this KA increased throughout that period. That contradicting result indicates that even though there is an interest in patenting in renewable fuels, the focus is lower compared to other SET Plan KAs (e.g., 'Competitive in global battery sector (e-mobility)' and 'Energy efficiency for industry').

Figure 4: Distribution of number of inventions across SET Plan KAs (all countries)



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

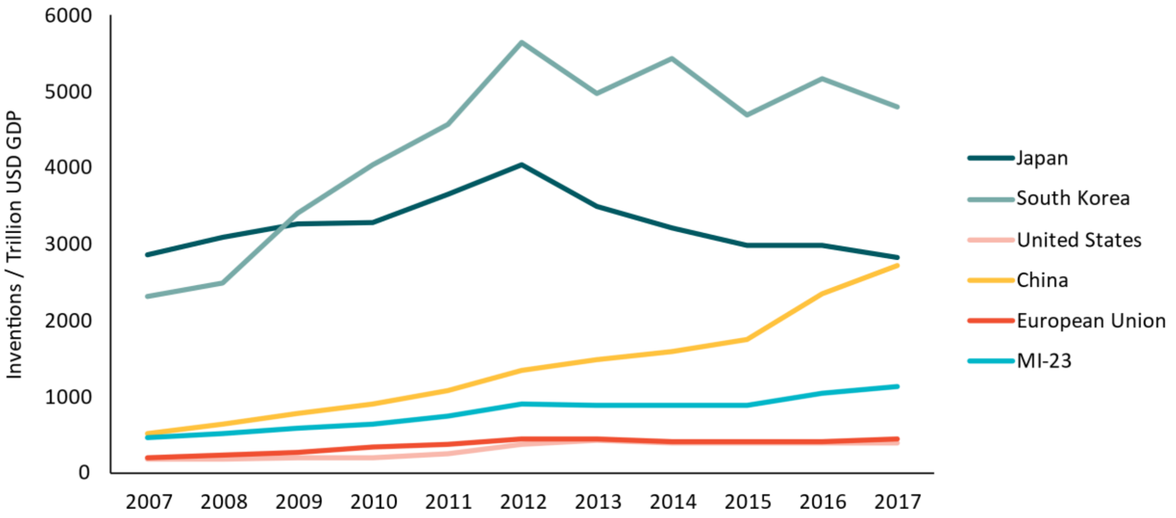
The distribution and trends across SET Plan KAs for the other two indicators (high value and international inventions) are similar and are therefore not discussed separately.

3.1.3 Patent trends scaled by GDP – World players

In this section, the performance of the world players is analysed by weighting the number of inventions by GDP (Trillion USD, PPP adjusted values)[14], thereby creating a comparable performance metric. Figure 5 provides the performance of world players measured by the total number of inventions per trillion US Dollars (TUSD) GDP. From this perspective, the dominant position of China in terms of number of inventions is less prominent, as both South Korea and Japan surpass China with a significant difference. The increasing trend in China's numbers is still noteworthy, showing strong performance improvement over the past decade. Both the US and EU, score relatively low on this indicator.

[14] World Bank (2019), Dataset on "GDP, PPP (constant 2017 international $)"; World Bank notes that "PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the United States. GDP is the sum of gross value added by all resident producers in the country plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2017 international dollars."

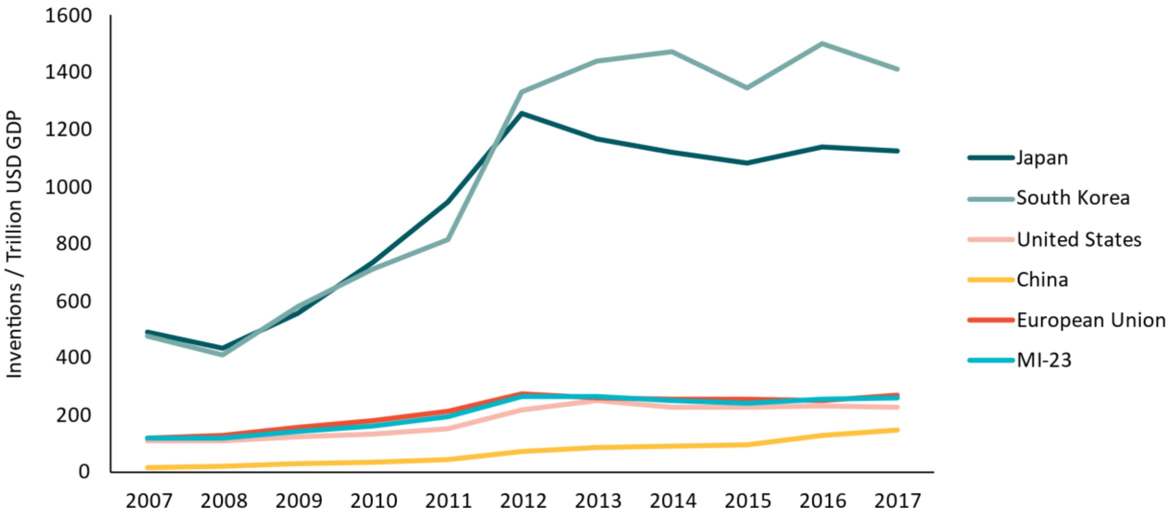
Figure 5: Number of inventions per unit of GDP across all SET Plan KAs



Data source (Inventions): Joint Research Centre (JRC) based on data from the European Patent Office (EPO)
Data source (GDP): World Bank

When considering only high value inventions scaled by GDP (Figure 6), South Korea and Japan have significantly higher values compared to the other world players, while China scores at the lowest end for the whole period analysed. However, in the most recent years it shows an improved performance. The EU, the US and Mission Innovation member countries show a similar performance with an increase up to 2012 and a stable performance afterwards.

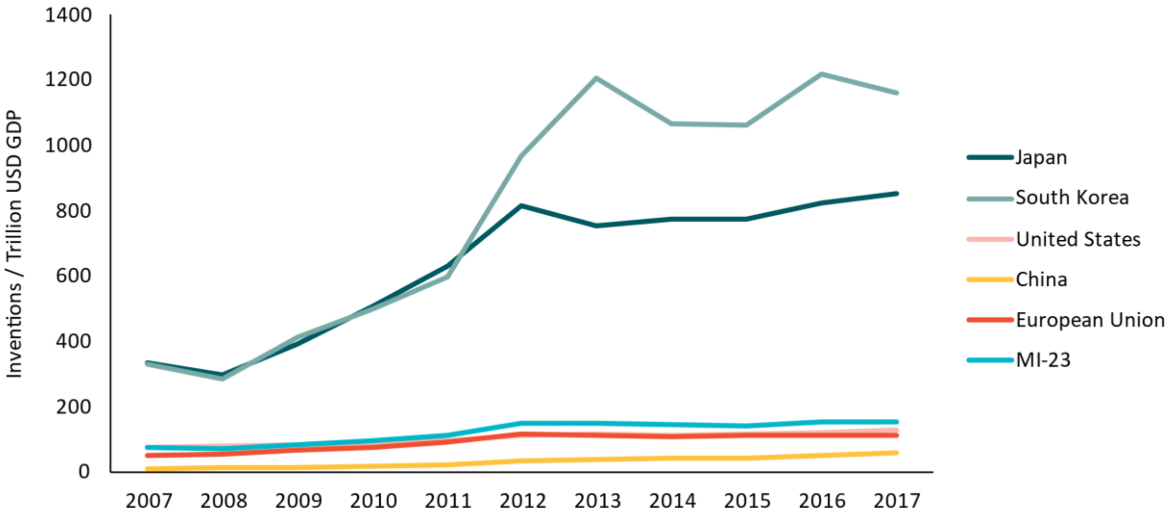
Figure 6: Number of high value inventions per unit of GDP across all SET Plan KAs



Data source (Inventions): Joint Research Centre (JRC) based on data from the European Patent Office (EPO)
Data source (GDP): World Bank

South Korea is also the top performer in international inventions scaled by GDP (Figure 7), also outperforming Japan by a wide margin over recent years. Both the EU and the US have improved considerably their performance in relative terms over the last decade. China has the lowest performance among all countries on this indicator, which can be explained by the fact that Chinese inventions are often only patented domestically[15], since it is more affordable and it has a large market to support the inventions.

Figure 7: Number of international inventions per unit of GDP across all SET Plan KAs



Data source (Inventions): Joint Research Centre (JRC) based on data from the European Patent Office (EPO)
Data source (GDP): World Bank

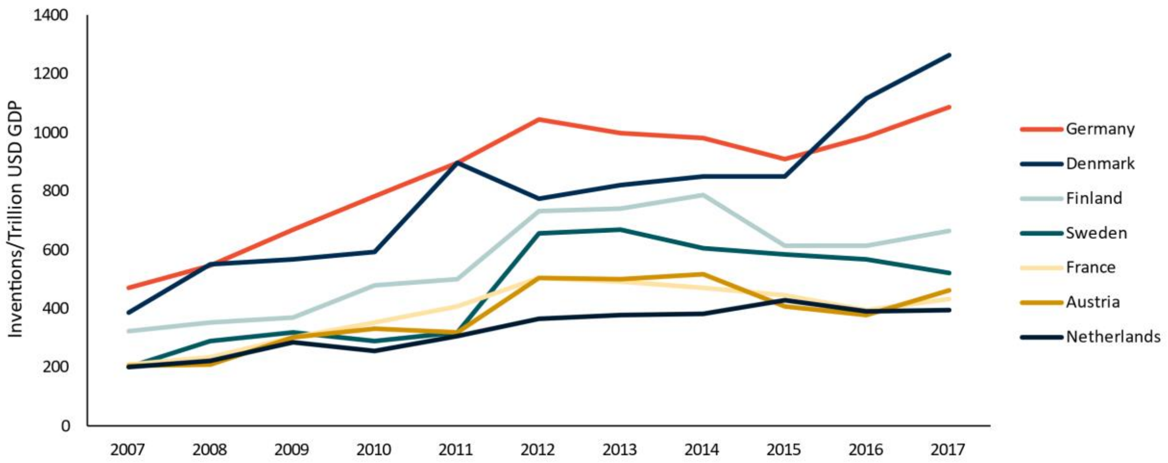
3.1.4 Patent trends scaled by GDP – EU27

Figure 8 summarises the performance of the EU Member States with the highest number of inventions per unit of GDP. The Nordic countries (Denmark, Finland and Sweden) and Germany have the highest number of inventions per GDP among the EU Member States, followed by Austria, the Netherlands and France. For high value and international inventions (graphs not shown), the same countries and pattern emerges, with only some minor changes in the ranking of the countries.

Compared to the world players, most of the top EU countries score higher than the US (+/- 300 inventions/TUSD) but significantly lower than South Korea (+/-4000 inventions/TUSD) and Japan (+/-2000 inventions/TUSD), with a similar pattern across all three indicators. Compared to China, it depends highly on the indicator selected, with China outperforming the top EU countries on number of inventions/GDP, while the top EU countries outperform China on high value and international inventions/GDP.

[15] China Power (2020). Are patents indicative of Chinese innovation?

Figure 8: Inventions per GDP across EU Member States which produce the most inventions



Data source (Inventions): Joint Research Centre (JRC) based on data from the European Patent Office (EPO)
Data source (GDP): World Bank
Note: excluding countries with less than 50 inventions per year

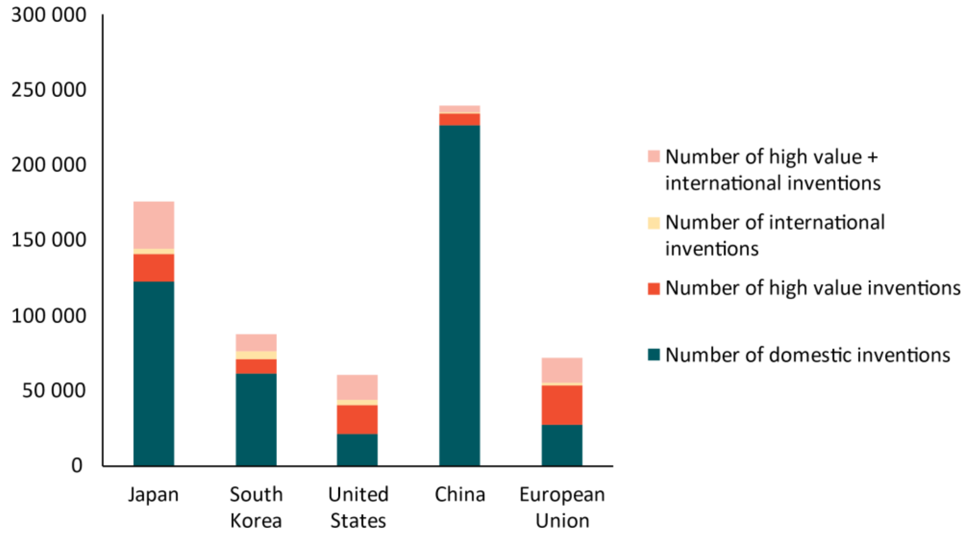
3.2 Patenting strategies per world player and SET plan key action

In this report we already provided several insights into differences in propensity to patent per country and how this leads to different conclusions on patent and innovation performance based on the indicator that is used. In this section we examine the differences between the three indicators of interest (number of inventions, high value inventions, international inventions) in more detail. For that, we categorise the patent applications (fractions) related to each invention into one of the following categories:

- Domestic invention: referring to patent applications that are filed domestically and are not part of a high value invention;
- High value invention: referring to patent applications that are part of a high value invention but are not international themselves;
- International invention: referring to patent applications that are filed internationally (i.e. country of applicant differs from country of patent office, counting the EU as one country) but are not part of a high value invention;
- High value and international invention: referring to patent applications that are filed internationally and are part of a high value invention.

When applying this categorisation it becomes immediately visible that there are very different strategies towards patenting at regional (i.e. the EU) and country level (see Figure 9 for a first impression). In the next sections we examine these differences in more detail, looking at the distribution of invention types per world player and per SET Plan KA.

Figure 9: Number of inventions per world player for all SET Plan KAs, broken down into types of inventions

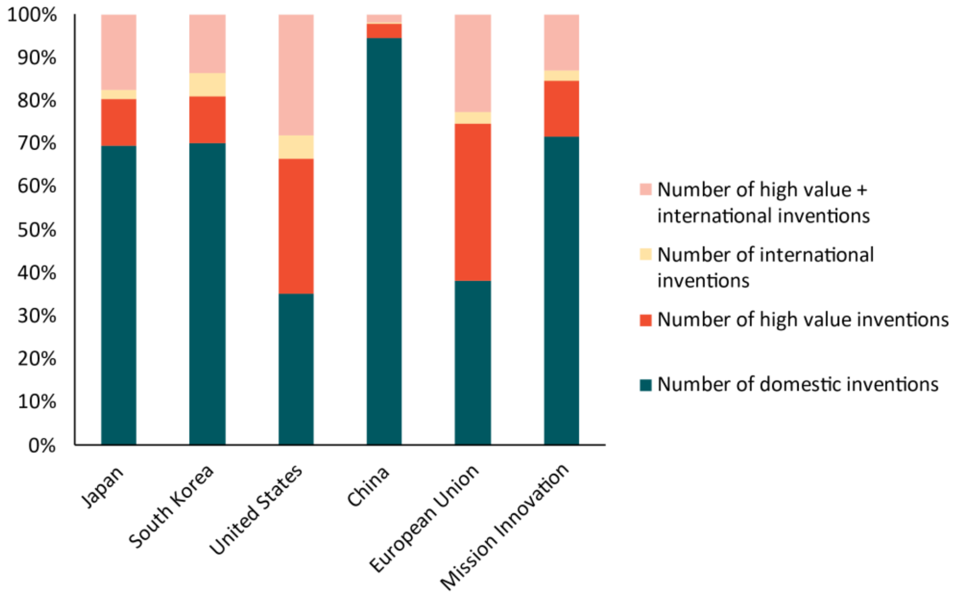


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.2.1 Distribution of invention types per world player

Looking at the distribution of invention types per world player (Figure 10), three distinct strategies can be distinguished. At one end, there is the strategy pursued by China which patents a lot of inventions domestically but generally does not file the patent internationally (96% of inventions are domestic). As indicated earlier, this can be explained by a variety of factors including the Chinese policies to stimulate patenting, the possibility to patent different types of inventions and the large home market. At the other end, there is a different approach pursued within the EU and US for which around half of inventions are high value and/or international. This observation may point to a relatively low eagerness to patent in general, limiting patenting to the few inventions with high commercial relevance, consistent with the low trust in patents as an effective intellectual property protection measure. The last strategy that can be distinguished is the one employed by Japan and South Korea which file the largest part of patents domestically but also a significant share of it internationally. The reasons for this may be a combination of a relatively high trust in patenting, an export oriented view and strong innovation performance in general.

Figure 10: Distribution of inventions per type for each world player

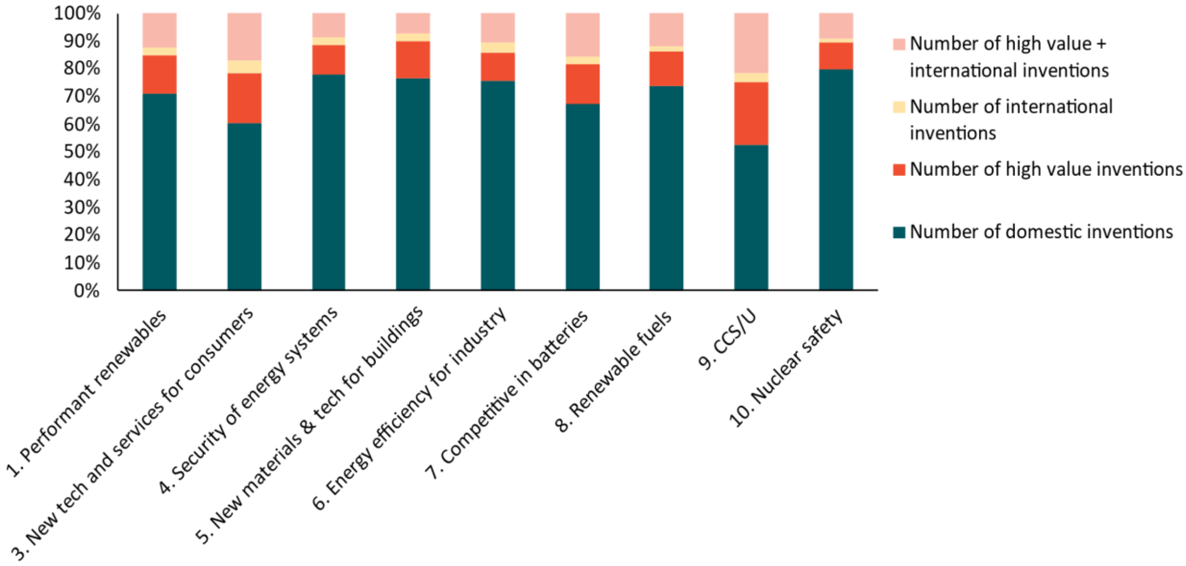


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.2.2 Distribution of invention types per SET Plan KA

The distribution of inventions per SET Plan KA (Figure 11) shows less distinct profiles than the comparison per country, indicating that differences in patenting strategy are more country-specific than technology-specific. Still, some noteworthy differences among SET Plan KAs can be observed. In particular the SET Plan KAs on technologies/services for consumers (#3), batteries (#7), and CCS/U (#9) have relatively high shares of high value/international inventions which may point to strong international competition and trade. Conversely, security of energy systems (#4), new materials and technologies for buildings (#5), energy efficiency for industry (#6) and nuclear safety (#10) show relatively high shares of domestic inventions indicating that there may be less international competition and trade in those areas, and that inventions may be tailored to the local industries and circumstances.

Figure 11: Distribution of inventions per type for each SET Plan KA



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3 Key developments by SET plan key action

Around 80% of inventions[16] for which patents were filed between 2007-2017 pertained to four of the nine KAs[17]:

- 'Performant renewable technologies integrated in the system', which includes Solar PV, Wind, and Concentrated Solar Power technologies, among others;
- 'New technologies & services for consumers', which includes ICT aiming at the reduction of own energy use and Energy efficient lighting technologies, among others;
- 'Energy efficiency for industry', which includes climate change mitigation technologies (CCMTs) for production processes for final industrial or consumer products, CCMTs for sector-wide applications and decarbonisation technologies targeted at specific industries;
- and the 'Global battery sector (e-mobility)', which includes battery technologies and electric vehicle charging technologies.

These SET Plan KAs are analysed in detail below, discussing the distribution of inventions across countries and the distribution of inventions across relevant technology types. We then provide a brief overview of key developments in the remaining five SET Plan KAs.

3.3.1 Performant renewable technologies

The trends and developments in the number of inventions for KA 1 'Performant renewable technologies' depend highly on the indicator selected. Considering the total number of inventions (Figure 12), China has become the dominant player with sharply increasing

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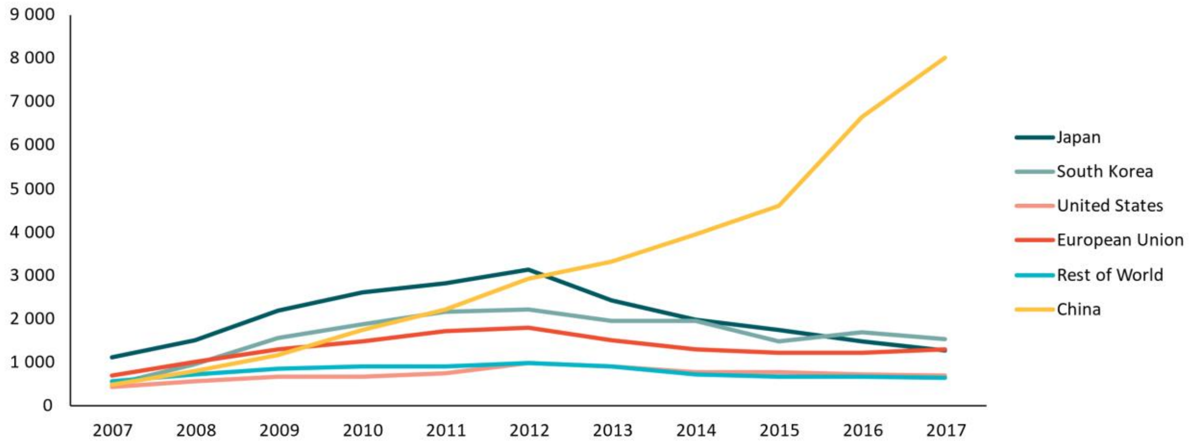
[16] This applies to all three indicators: inventions, high value inventions, international inventions

[17] How patents are matched to SET Plan KAs is described in Fiorini A., Georgakaki A., Pasimeni F., & Tzimas E. (2017). Monitoring R&I in Low-Carbon Energy Technologies (JRC105642).

number of inventions in the most recent years, while the number of inventions for other world players remained stable or declined.

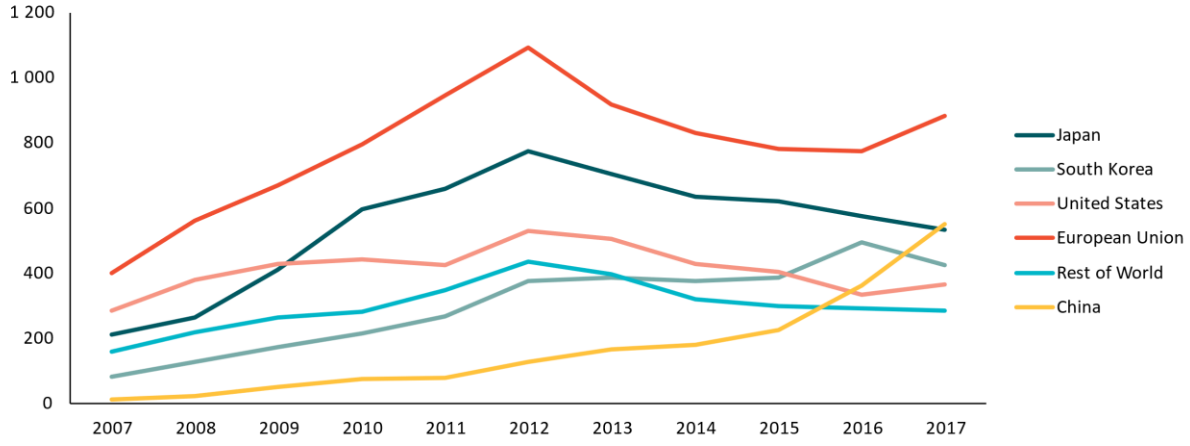
Figure 12: Number of inventions per world player for SET Plan KA 1. Performant renewables



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Considering only high value inventions (Figure 13), a totally different picture emerges with the EU leading the field and showing a significant increase in 2017 after a strong decline between 2012 and 2016. China is ranking lowest for most of the years in scope, while increasing rapidly its high value inventions after 2015. The other countries also show a peak in 2012, similar to the EU.

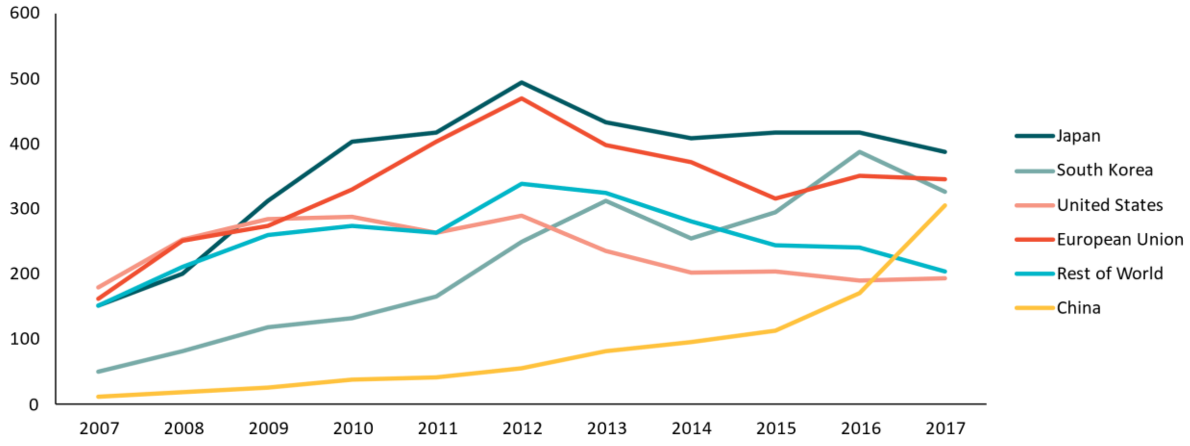
Figure 13: Number of high value inventions per world player for SET Plan KA 1. Performant renewables



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Considering only international inventions (Figure 14), a more mixed picture emerges with the EU and the US leading initially (2007-2008) after which the US lost its lead position around 2010/2011 and Japan caught up and surpassed the leading world players after 2009. China ranked lowest among the world players during the period 2007-2015, when it increased significantly its international inventions surpassing the US in 2017.

Figure 14: Number of international inventions per world player for SET Plan KA 1. Performant renewables



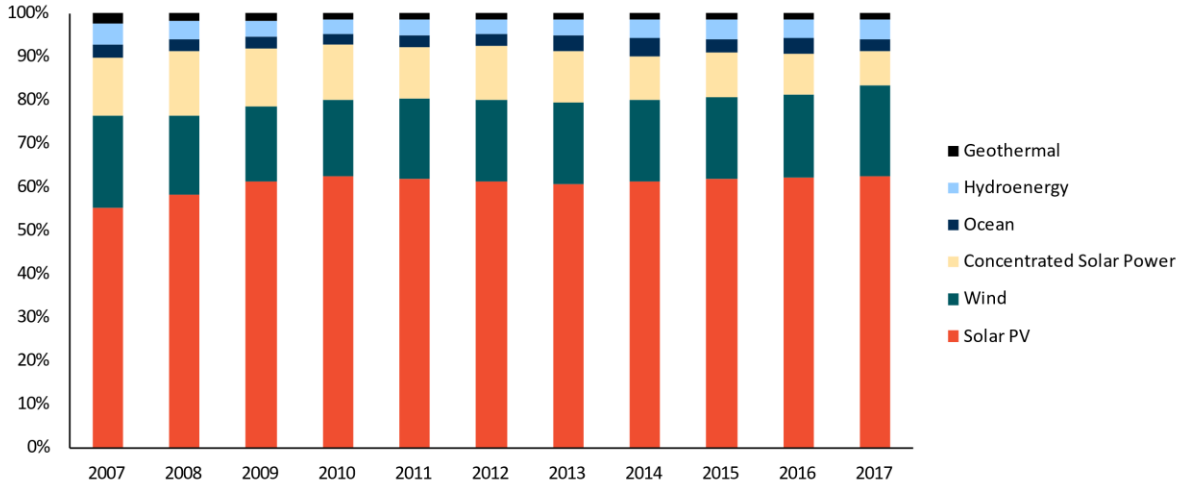
Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

The global distribution of inventions per technology under this SET Plan KA (Figure 15) shows that most inventions concern solar PV technology, which accounts for approximately 60% of the inventions, followed by wind (around 20%) and concentrated solar power (8-15%). The remaining 5-12% of inventions are distributed across ocean, hydroenergy and geothermal energy. In particular the high share of inventions for concentrated solar power is noteworthy, given the limited deployment of this technology to date.

The number of inventions related to renewables for all in-scope countries remained steady since 2010, fluctuating between 10,000 and 13,000 inventions per year, suggesting that innovation activities in this sector kept momentum even though renewables technologies have further progressed and matured.

The distribution of inventions and overall trend is similar for high value and international inventions, which are therefore not shown separately.

Figure 15: Distribution of inventions per technology for SET Plan KA 1. Performant renewables

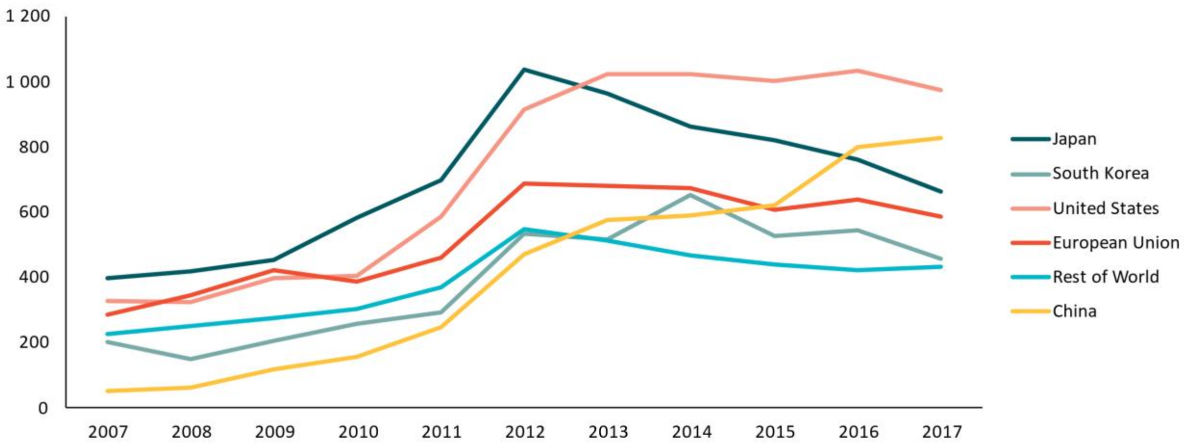


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3.2 New technologies & services for consumers

For KA 3. 'New technologies and services for consumers', the total number of inventions (graph not shown) shows a similar pattern as for most SET Plan KAs: a dominant position for China with strongly increasing numbers during the entirety of the time frame considered. Considering only high value inventions (Figure 16), a more mixed picture emerges with strong performance of Japan and the US in particular, while China scores relatively well for this KA, compared to its relatively lower performance on high value inventions for most KAs.

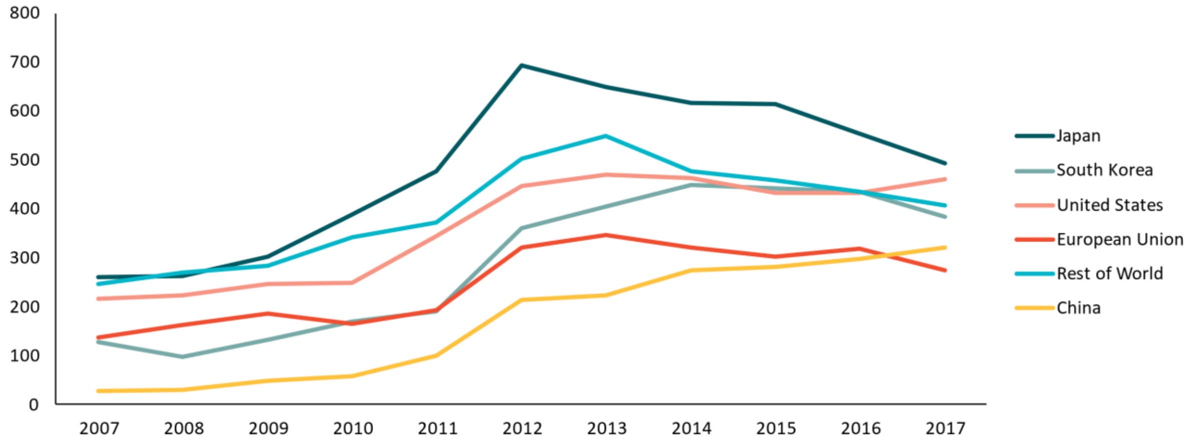
Figure 16: Number of high value inventions per world player for SET Plan KA 3. New technologies & services for consumers



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Data on international inventions for this SET Plan KA (Figure 17) show a particularly strong performance of Japan, with South Korea also ranking much higher than on the other indicators. Furthermore, a relatively high share of international inventions is related to applications filed by other countries than the five world players. In fact, the 'rest of world' countries capture around 20% of the international inventions for this SET Plan KA, showing that the inventive activity for 'New technologies and services for consumers' is distributed across the world.

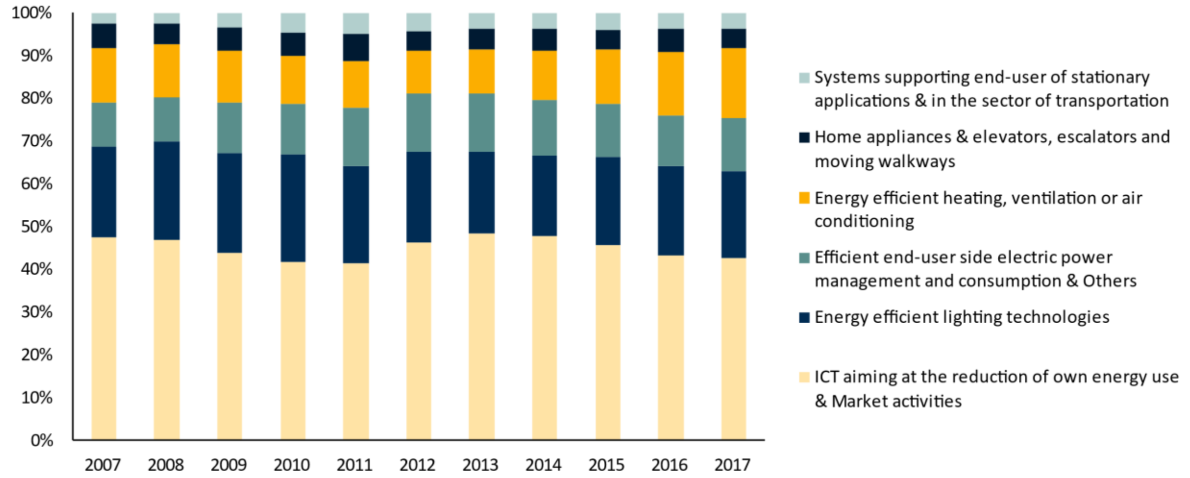
Figure 17: Number of international inventions per world player for SET Plan KA 3. New technologies & services for consumers



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 18 below shows that most of the inventions on 'New technologies and service for consumers' relate to ICT for reduction of own energy use, energy efficient lighting, end-user electric power management, and energy efficient heating/ventilation/air conditioning. Also, for high value and international inventions (graphs not shown), these four categories cover most of the inventions, although ICT aiming at the reduction of own energy use has a considerably larger share, accounting for more than 50% of the high value and international inventions under this SET Plan KA.

Figure 18: Distribution of inventions per technology for SET Plan KA 3. New Technologies and Services for Consumers

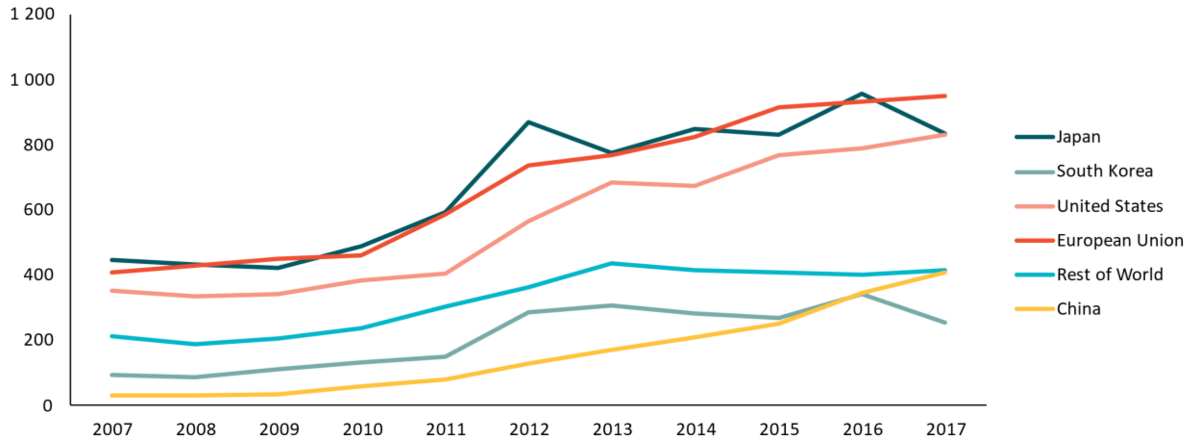


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3.3 Energy efficiency for industry

For KA 6. 'Energy efficiency for industry', China also dominates the total number of inventions, accounting for 50-65% of global inventions per year from 2013 onwards (graph not shown). Considering only high value inventions (Figure 19) the EU, Japan and US are leading. China is rapidly catching up in recent years, already overtaking South Korea.

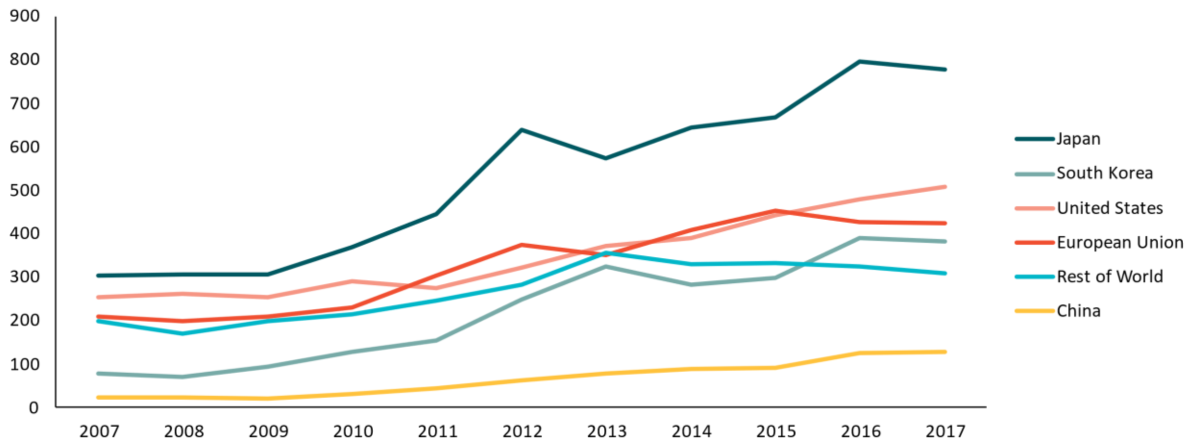
Figure 19: Number of high value inventions per world player for SET Plan KA 6. Energy efficiency for industry



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

When considering only international inventions (Figure 20), Japan has the strongest position, with the US and the EU following at a distance.

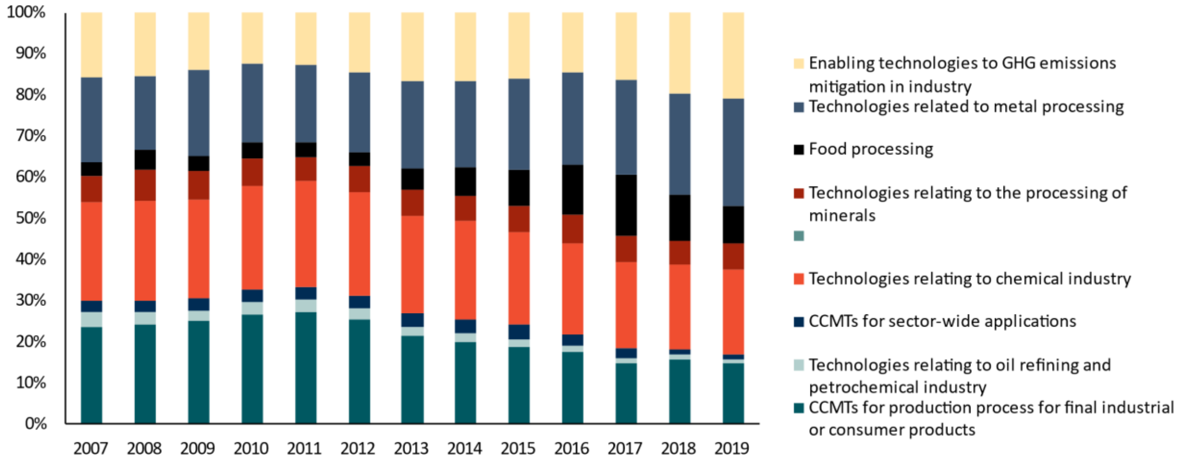
Figure 20: Number of international inventions per world player for SET Plan KA 6. Energy efficiency for industry



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

There are many technologies included in the SET Plan KA 'Energy efficiency for industry', ranging from several sector-wide climate change mitigation technologies (CCMTs) to technologies for specific industries such as chemicals, metal processing, and food processing. For all three patent indicators, a similar breakdown is visible as shown below (Figure 21) for the total number of inventions: the top four technologies are responsible for over 80% of the inventions. These top four technologies include CCMTs for production processes, technologies related to chemicals, technologies related to metal processing and enabling technologies to GHG emissions mitigation in industry.

Figure 21: Distribution of inventions per technology for SET Plan KA 6. Energy efficiency for industry

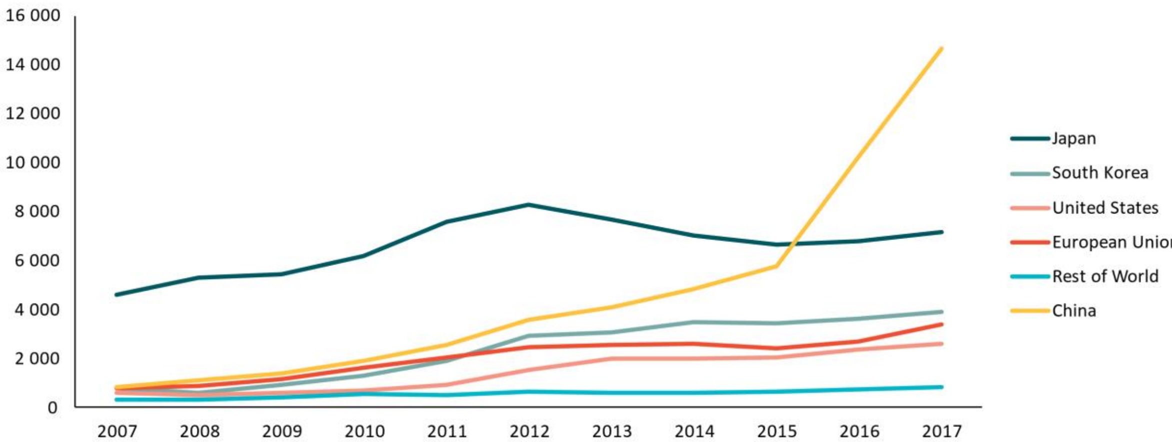


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3.4 Competitive in the global battery sector

For KA 7. 'Competitive in the global battery sector (e-mobility)', the total number of inventions (Figure 22) shows a different picture than for most of the other SET Plan KAs, with a less dominant position for China and a very strong position for Japan. Still, China also took the lead on this SET Plan KA in the most recent years.

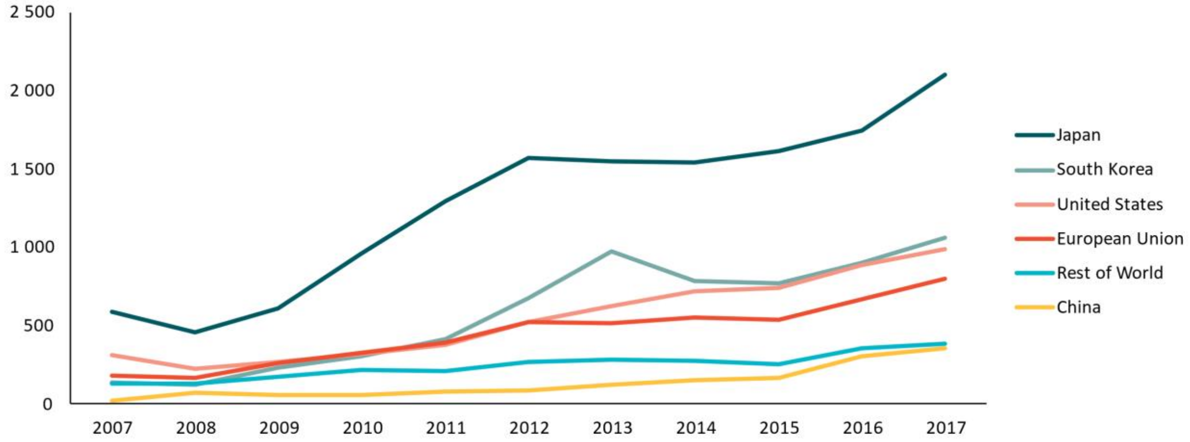
Figure 22: Number of inventions per world player for SET Plan KA 7. Competitive in the global battery sector (e-mobility)



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

The strong position of Japan is further emphasised when looking at high value inventions (graph not shown) and international inventions (Figure 23). For both indicators, Japan has the most inventions by a wide margin, accounting for 30-50% of high value and international inventions for each year. Next to Japan, also South Korea has a strong position in this area.

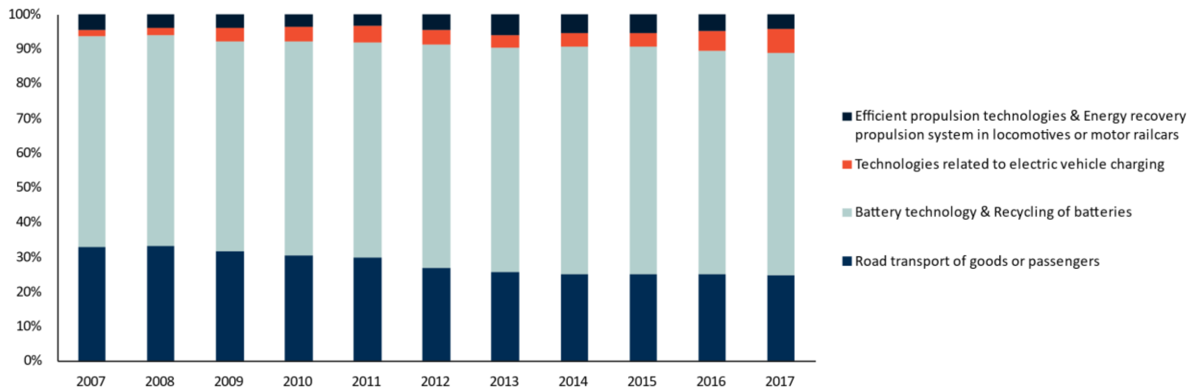
Figure 23: Number of international inventions per world player for SET Plan KA 7. Competitive in the global battery sector (e-mobility)



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Within this KA, most of the inventions pertain to Battery technology & Recycling of batteries, which ranges from 61-64% of all inventions in this SET Plan KA (Figure 24), with similar shares for high value and international inventions. Most of the remainder of the inventions are related to the road transport technologies.

Figure 24: Distribution of inventions per technology for SET Plan KA 7. Competitive in the global battery sector (e-mobility)



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3.5 Other SET Plan KAs

The remaining KAs are responsible for 16-20% of global inventions. Among those, most inventions are for SET Plan KA 4. 'Resilience and security of the energy system' and SET Plan KA 8. 'Renewable fuels' which are responsible for 5-7% and 8-9% of the global inventions respectively (see Table 1). Key technologies within 'Resilience and security of the energy system' are enabler technologies for GHG emission mitigation, such as stationary energy storage and smart grids. 'Renewable fuels' includes technologies such as fuel cells, and applications to transportation and in buildings. The remaining SET Plan KAs are 5. 'New materials and technologies for buildings', 9. 'CCS/U' and 10. 'Nuclear safety', which capture approximately 3% of the global inventions in total, which corresponds to a total of 80-150 inventions annually. In KA 4 and 5, China dominates the total inventions, EU the high value inventions, while Japan holds most of the international inventions. Japan is also the top performer in KA 8. 'Renewable fuels' as it ranks first in all three indicators, while the US is the most active world player in KA 9. 'CCS/U'.

Table 1: Overview of key features of KAs 4, 5, 8, 9 and 10

SET Plan KA	Share of inventions[18] (2007-2017)	Key technologies	Most active world players
4. Resilience & security of energy system	5-7%	GHG emission mitigation enabler technologies	China (total inventions) EU (high value inventions) Japan (international inventions)
5. New materials and technologies for buildings	1-2%	Integration of renewables in buildings	China (total inventions) EU (high value inventions) Japan (international inventions)
8. Renewable fuels	8-9%	Fuel cells Application to transportation & in buildings	Japan (total inventions) Japan (high value inventions) Japan (international inventions)
9. CCS/U	1%	N/A	US (total inventions) US (high value inventions) US (international inventions)
10. Nuclear Safety	1-2%	N/A	Japan (total inventions) US (high value inventions) US (international inventions)

Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

[18] Range denotes variation between the different indicators (total inventions, high value inventions, international inventions).

3.4 Profiles of world players

This section presents a profile of the world players' patenting activity on clean energy technologies, namely the United States (US), the European Union (EU), China (CN), Japan (JP) and South Korea (KR). Additionally, the patenting activity of the group of countries that are members of Mission Innovation (MI) are analysed. We also discuss the trends and developments per world player individually.

Table 2 (total inventions), Table 3 (high value inventions) and Table 4 (international inventions) present an overview of the distribution of the cumulative number of inventions per SET Plan KA for each world player, between 2007 and 2017.

While the overall pattern appears similar there are some country-specific observations regarding several SET KAs. Firstly, China has approximately double the share of high value and international inventions for the SET Plan KA 3 'New technologies and services for consumers', while the opposite is true for SET Plan KAs 4 'Resilience and security of the energy system' and 6 'Energy efficiency for industry', indicating that companies more often choose to file patents only domestically for those technologies, which could be due to inventions being more specific to the local circumstances and industries. On the other hand, South Korea patents more domestically on technologies related to SET Plan KA 1 'Performant renewable technologies integrated in the system', while it files more high value and international patents for the SET KA 7 'Competitive in global battery sector (e-mobility)', which indicates the country's interest to be competitive on this sector at a global scale.

Other observations that can be drawn by comparing countries and regions are that all world players and especially Japan, have a strong focus on the battery sector, while there is an overall interest on the new technologies for services and consumers and on energy efficiency in industry. In the following sections we discuss the trends for each world player in more detail.

Table 2: Distribution of total inventions per SET Plan KA for each world player (2007-2017)

Actions	US	CN	JP	KR	EU	MI	*Global*
01. Performant renewable technologies integrated in the system	13%	15%	13%	20%	20%	15%	16%
03. New technologies & services for consumers	26%	14%	11%	17%	12%	15%	15%
04. Resilience & security of energy system	6%	10%	5%	5%	6%	7%	7%
05. New materials & technologies for buildings	1%	2%	1%	1%	3%	2%	2%
06. Energy efficiency for industry	16%	30%	13%	15%	16%	19%	20%
07. Competitive in global battery sector (e-mobility)	26%	21%	41%	30%	32%	30%	29%
08. Renewable fuels	8%	7%	13%	9%	10%	9%	9%
09. CCS/U	1%	0%	0%	1%	1%	1%	1%
10. Nuclear Safety	2%	1%	2%	3%	1%	3%	2%

Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Table 3: Distribution of high value inventions per SET Plan KA for each world player (2007-2017)

Actions	US	CN	JP	KR	EU	MI	*Global*
01. Performant renewable technologies integrated in the system	12%	15%	12%	15%	21%	13%	15%
03. New technologies & services for consumers	22%	36%	15%	20%	14%	17%	19%
04. Resilience & security of energy system	6%	5%	4%	3%	6%	4%	5%
05. New materials & technologies for buildings	1%	1%	1%	1%	2%	1%	1%
06. Energy efficiency for industry	17%	14%	15%	11%	18%	13%	16%
07. Competitive in global battery sector (e-mobility)	29%	25%	42%	41%	29%	30%	33%
08. Renewable fuels	9%	3%	9%	8%	9%	7%	8%
09. CCS/U	1%	0%	1%	1%	1%	1%	1%
10. Nuclear Safety	2%	1%	1%	1%	1%	2%	1%

Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Table 4: Distribution of international inventions per SET Plan KA for each world player (2007-2017)

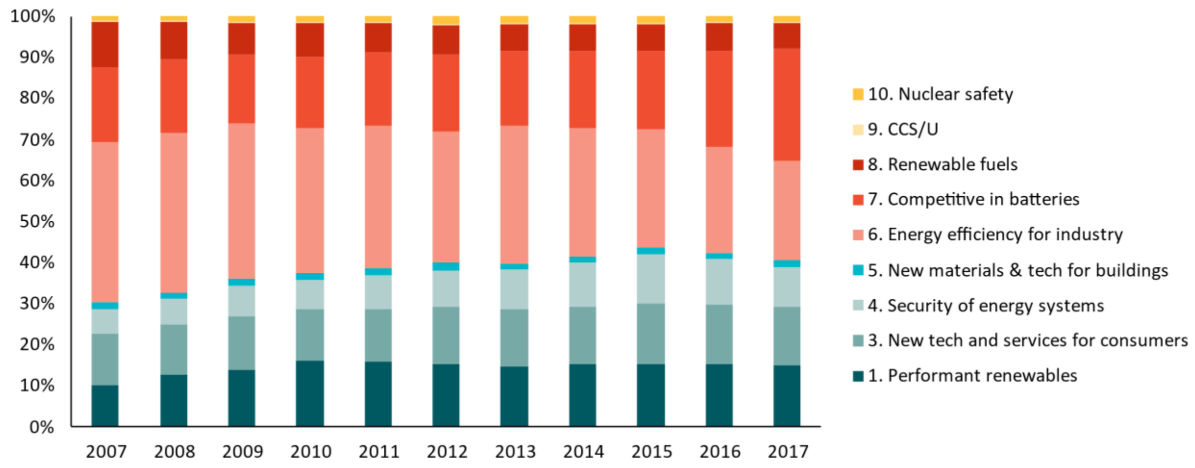
Actions	US	CN	JP	KR	EU	MI	Global
01. Performant renewable technologies integrated in the system	13%	17%	12%	14%	20%	12%	15%
03. New technologies & services for consumers	20%	34%	15%	19%	15%	16%	19%
04. Resilience & security of energy system	6%	4%	4%	4%	5%	4%	5%
05. New materials & technologies for buildings	1%	1%	1%	1%	1%	1%	1%
06. Energy efficiency for industry	19%	13%	17%	15%	20%	15%	18%
07. Competitive in global battery sector (e-mobility)	30%	27%	41%	38%	27%	30%	32%
08. Renewable fuels	9%	3%	9%	7%	9%	7%	8%
09. CCS/U	1%	0%	1%	0%	1%	1%	1%
10. Nuclear Safety	2%	1%	1%	1%	1%	2%	1%

Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.1 China

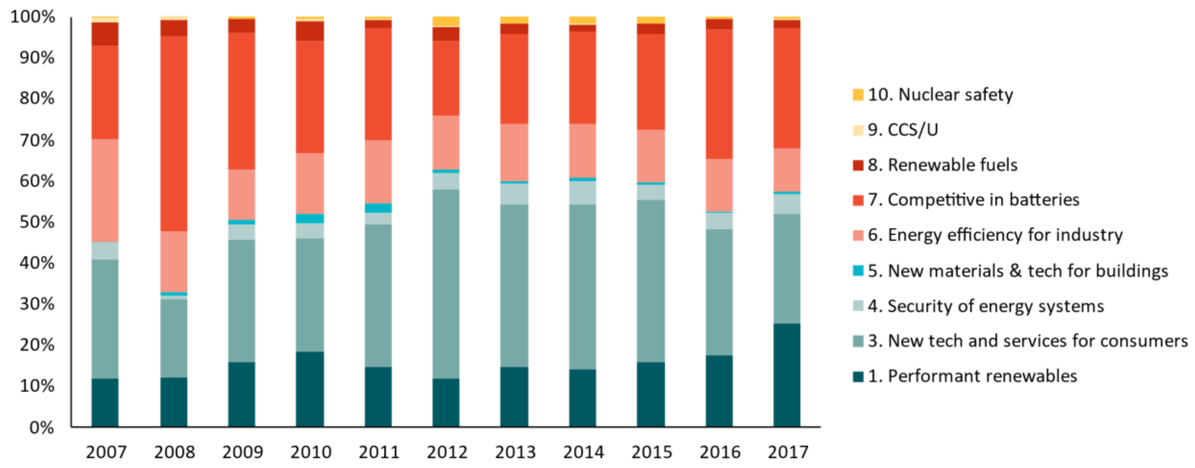
China experienced a significant increase in patenting activity for SET Plan KAs, growing its total number of inventions from approximately 5,000 per year in 2007 to more than 50,000 per year in 2017. Similar increases can be observed for high value inventions (150 to 2,900) and international inventions (90 to 1200). China's distribution of total inventions across SET Plan KAs (Figure 25) is markedly different from international inventions (Figure 26) and high value inventions (graph not shown – similar to international inventions). For total inventions, SET Plan KA 6. 'Energy efficiency for industry' accounts for a much larger share than for international and high value inventions, while the opposite is true for SET Plan KA 3. 'New technologies and services for consumers'. SET Plan KA 8 'Renewable fuels' holds in both cases a significant share of the patents.

Figure 25: Distribution of total inventions across SET Plan KAs – China



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 26: Distribution of international inventions across SET Plan KAs – China

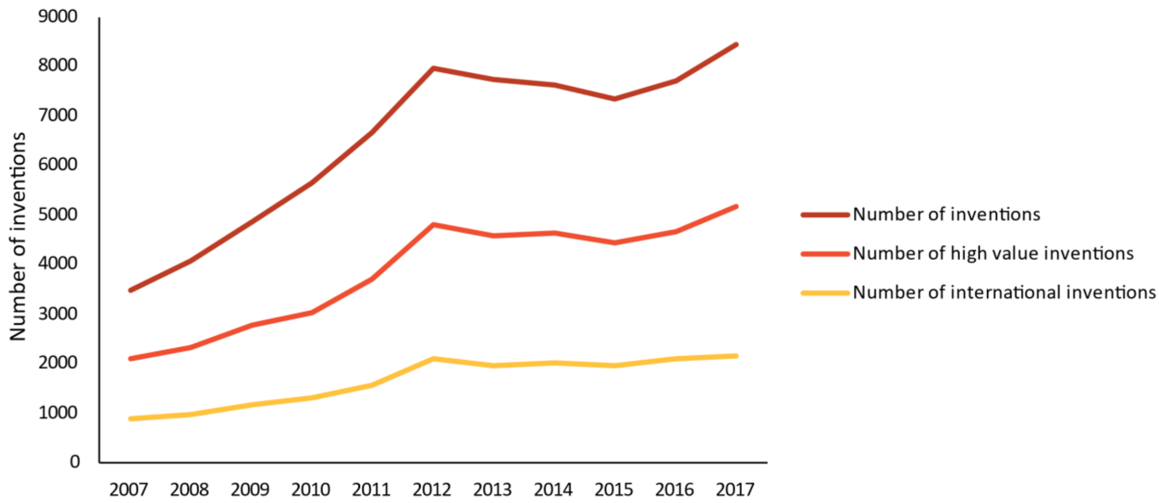


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.2 European Union

The EU experienced an overall strong increasing patenting activity across all KAs from 2007 to 2017 with total inventions growing from 3,500 inventions to more than 8,000 (see Figure 27). From 2012 to 2015 a slight decrease can be observed from 7900 to 7300 inventions respectively, yet the number of inventions picked up again in 2016. A similar pattern can be observed for high value inventions and to a lesser extent for international inventions.

Figure 27: Total inventions by the European Union across all SET Plan KAs



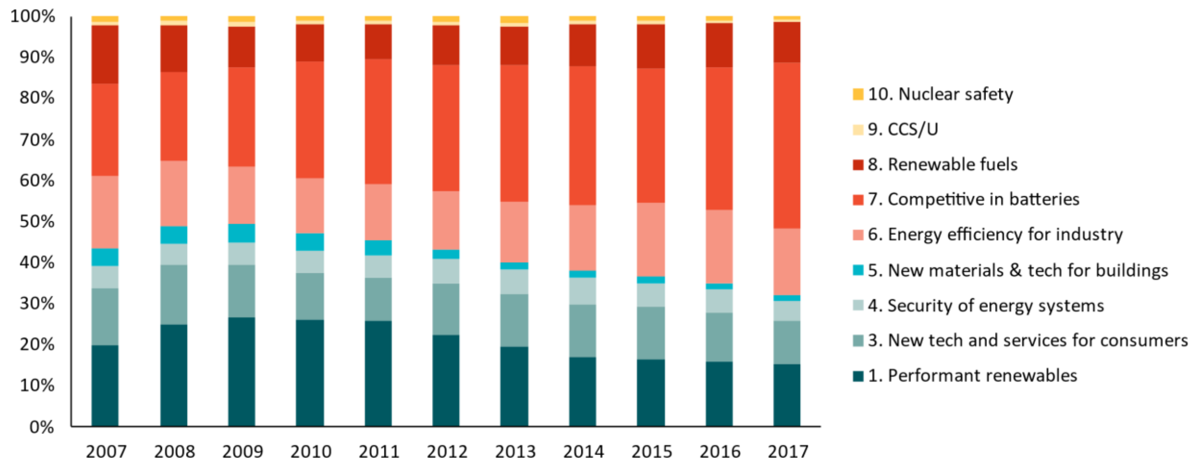
Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

The EU has a strong focus on KA 7 'Competitive in global battery sector (e-mobility)', with up to 40% of its total inventions and international inventions related to this action in 2016 and 2017 (see Figure 28 and Figure 29)[19]. The largest share of the total inventions regards the technologies related to 'Road transport of goods and passengers', with almost three times the number of inventions in 2017 than in 2007. Within the same action, the EU focuses on 'Battery technology & Recycling of batteries' and 'Efficient propulsion technologies'.

Further, the EU shows significant patenting activity on KA 1. 'Performant renewables', with an average of about 20% of total inventions between 2007-17. However, the share has been declining in the most recent years. Wind and Solar PV are the technologies with the largest number of inventions within this action, however patenting activity in the latter has decreased steadily since 2012.

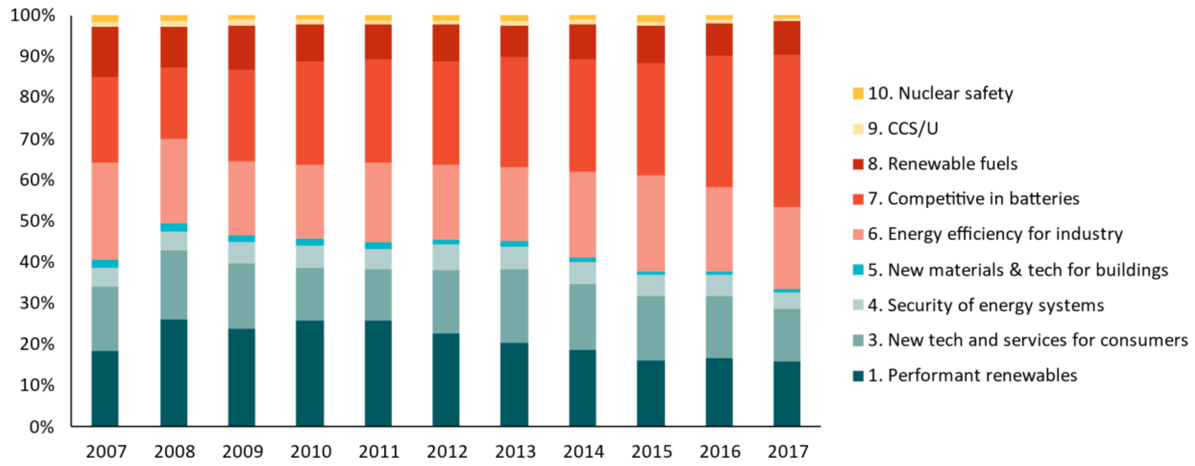
[19] The same applies for high value inventions.

Figure 28: Distribution of total inventions across SET Plan KAs – European Union



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 29: Distribution of international inventions across SET Plan KAs – European Union



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

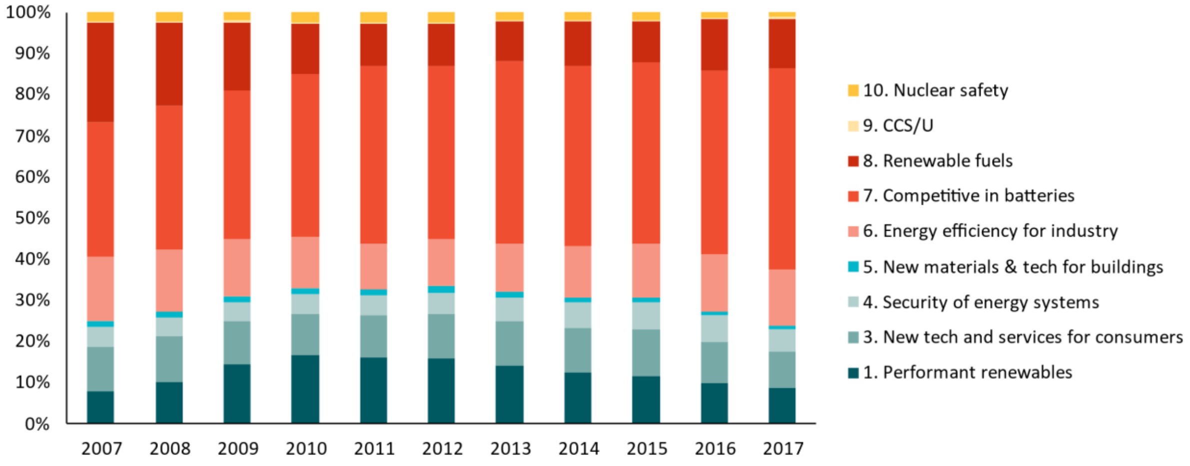
3.4.3 Japan

Japan had relatively stable patenting activity in terms of total number of inventions, with values fluctuating around 15,000 inventions per year for most of the in-scope years (2007-17); an exception is recorded for the period 2011-2013 when Japan increased its patenting activity averaging 18,000 inventions per year. Both high value inventions (1,800 to 5,800) and international inventions (1,600 to 4,400) increased significantly between 2007 and 2017.

As mentioned earlier, Japan's patenting activity has a very strong focus on KA 7. 'Competitive in global battery sector' (see Figure 30 and Figure 31). With 30-50% of its inventions concentrated in this action, Japan is the world player with the highest allocation of inventions to this action, with most inventions concerning 'Battery technology & Recycling of batteries' followed by 'Road transport of goods and passengers'.

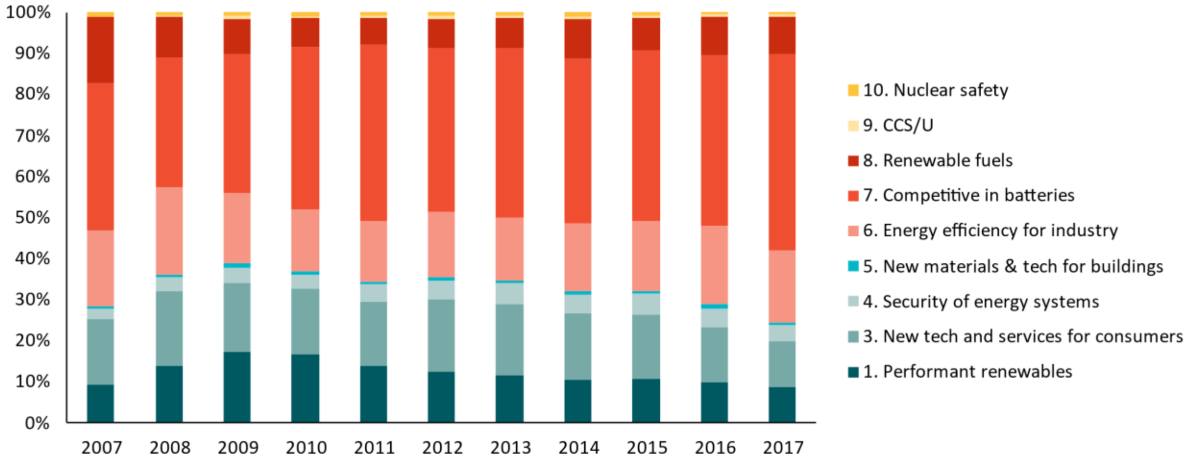
In contrast, when compared to other world players Japan has the least focus on KA 1. 'Performant renewables', with only 12% of its inventions dedicated to this action. Despite this, Japan had significant patenting activity in Solar PV, which accounted for almost 80% of its inventions under this action.

Figure 30: Distribution of total inventions across SET Plan KAs – Japan



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 31: Distribution of international inventions across SET Plan KAs – Japan



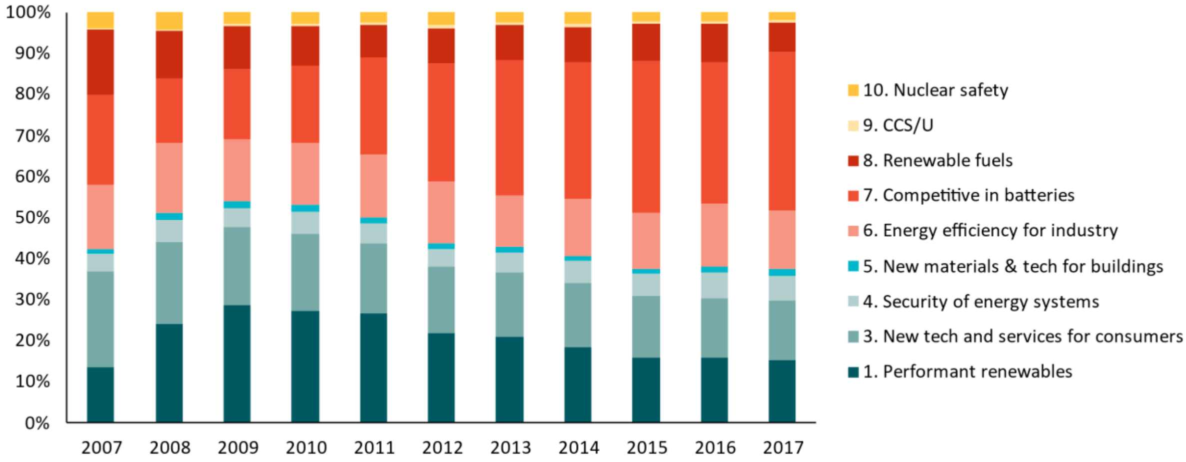
Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.4 South Korea

South Korea increased its patenting activity in CETs considerably over the 2007 – 2016 time period, with a particularly sharp increase from 2007 to 2012 when the total number of inventions almost tripled from 3,500 to more than 10,000. Afterwards, the total number of inventions remained stable at around 10,000 inventions per year. A similar pattern can be observed for high value inventions (700 in 2007 to 3000 in 2017). For international inventions the increase is even more dramatic, growing from 500 in 2007 to more than 2,400 in 2017.

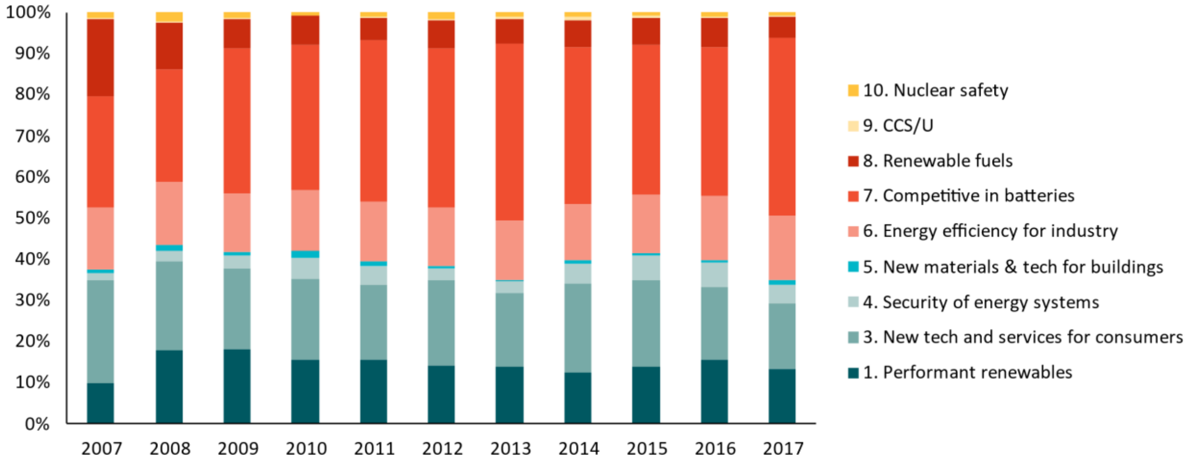
South Korea's focus on specific technologies fluctuated over time; in the most recent years South Korea's inventions are focused on KA 7 'Competitive in batteries' which accounts for more than 40% of the total inventions per year. A moderate focus regards also KA 3 'New tech and services for consumers' and KA 1 'Performant renewable technologies integrated in the system' with ICT technologies and Solar PV being the most patented technologies in the respective actions (Figure 32 and Figure 33).

Figure 32: Distribution of total inventions across SET Plan KAs – South Korea



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 33: Distribution of international inventions across SET Plan KAs – South Korea



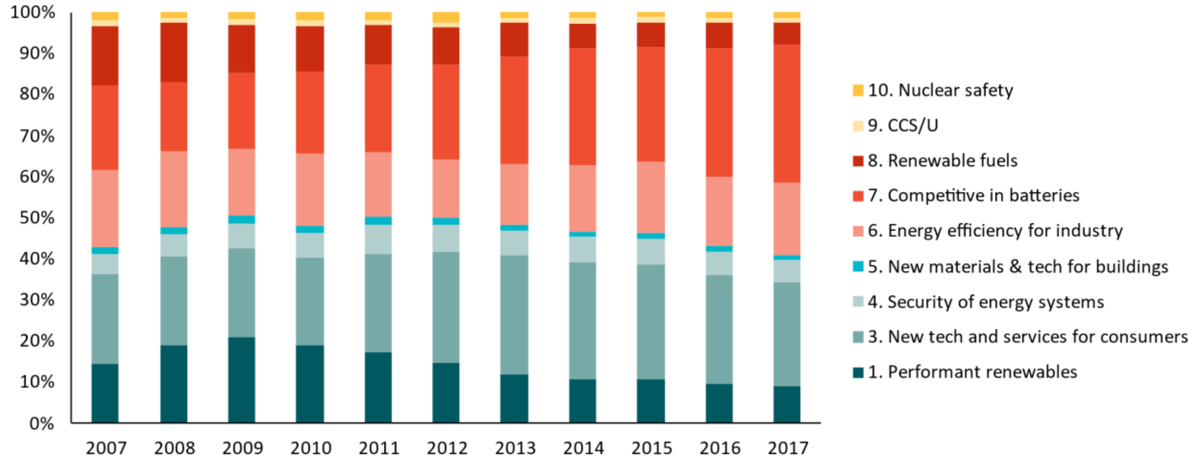
Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.5 United States

The United States increased its patenting activity in CETs considerably since 2007, growing from almost 3,000 inventions in 2007 to approximately 7,500 inventions per year from 2013 onwards. During this time period, the US decreased its focus on KA 1. 'Performant renewables', with a reduced number of inventions for almost all renewable technologies. Additionally, the US seems to have shifted the focus from KA 'Renewable Fuels' as the share of the inventions decreased from 14% in 2007 to 6% in 2017. Meanwhile, the US strongly increased its focus on KA 7 'Competitive in batteries' rising from 21% in 2007 to 34% in 2017 of its total inventions. 'Battery technology & Recycling of batteries' hold the biggest share of total inventions within this KA.

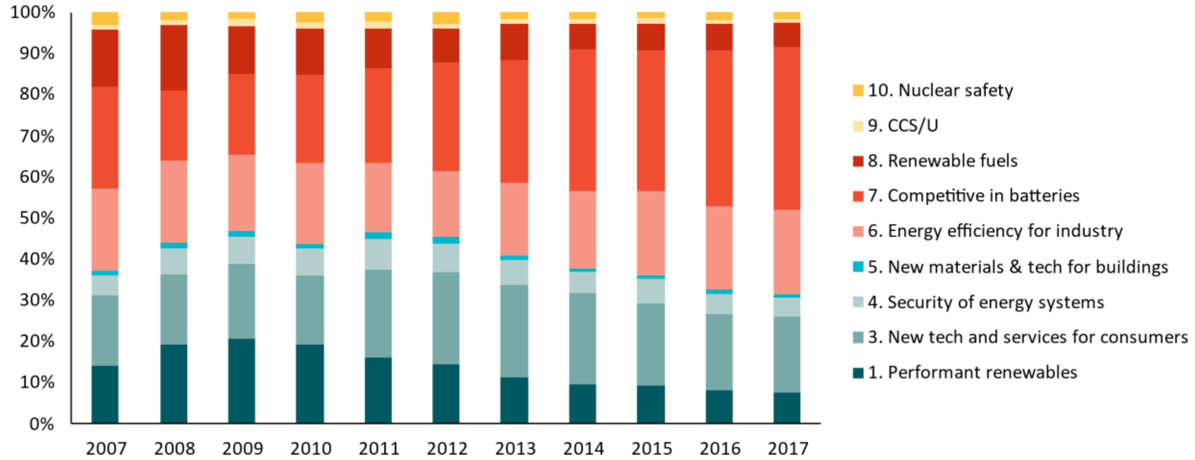
The trends are similar in all three indicators: total inventions (Figure 34), high value inventions (graph not shown), and international inventions (Figure 35).

Figure 34: Distribution of total inventions across SET Plan KAs – United States



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 35: Distribution of international inventions across SET Plan KAs – United States

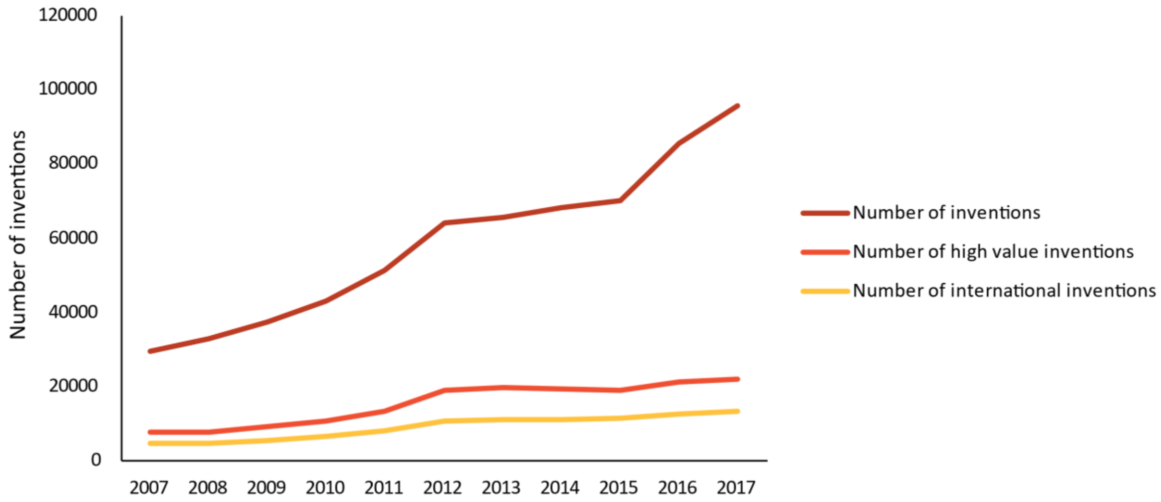


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.6 Mission Innovation member countries

The number of inventions for the group of Mission Innovation member countries (MI-23) combined tripled between 2007 and 2017, from slightly less than 30,000 in 2007 to more than 95,000 inventions in 2017 (Figure 36). This is primarily due to the large growth in total inventions for China (+49,000). The growth stagnated from 2012 but picked up again from 2016 onwards. There was also significant growth in the number of high value inventions (7,500 in 2007 to more than 20,000 in 2017) and international inventions (4,500 in 2007 to 13,000 in 2017), but the growth stagnated from 2012 onwards and the numbers increased only slightly again in the last two years.

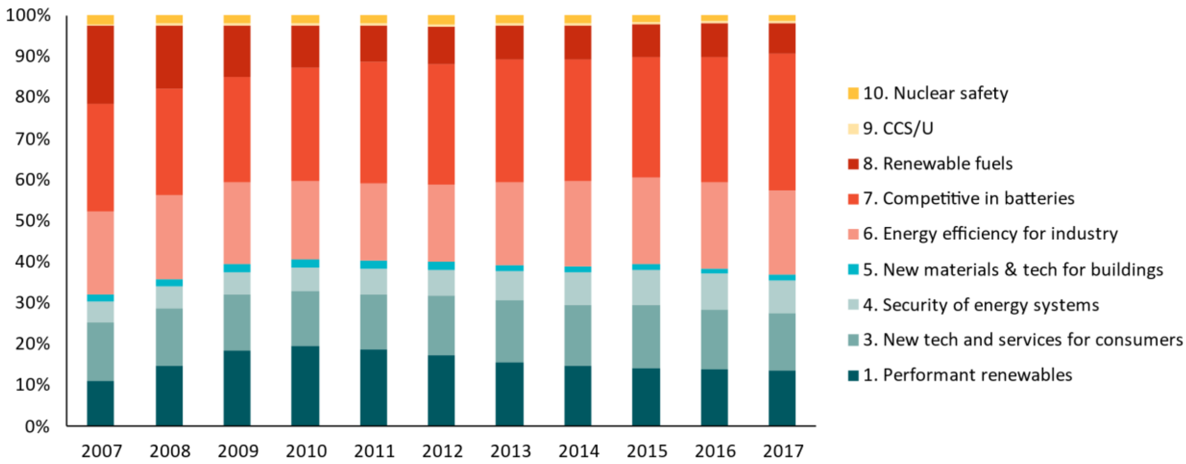
Figure 36: Total inventions of MI-23 across all SET Plan KAs



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

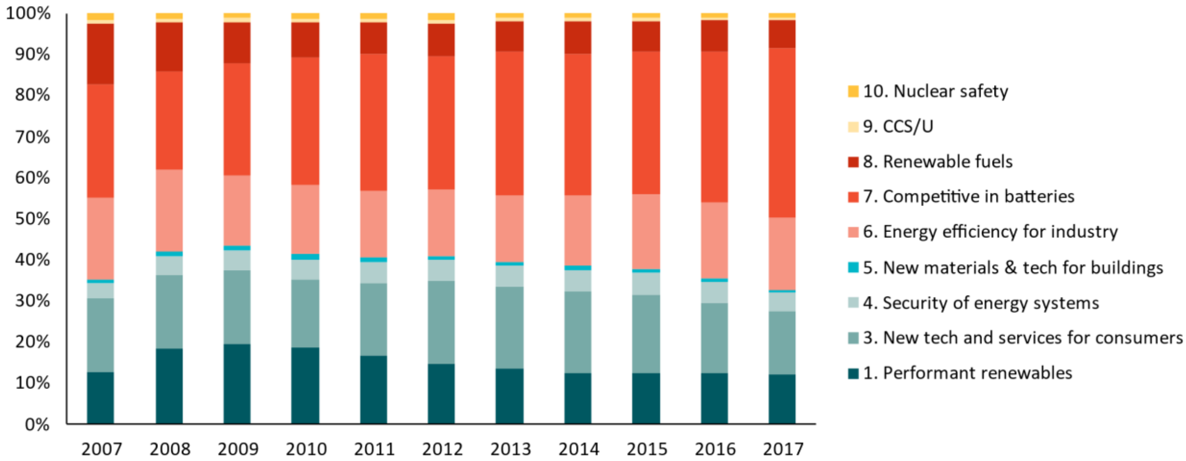
The distribution of inventions across KAs (Figure 37) shows an increasing focus on Plan KA 7 'Competitive in global battery sector (e-mobility)', and a stable high interest in KAs 6 'Energy efficiency for industry' and 3. 'New technologies & services for consumers'. KA 1. 'Performant renewables' peaked around 2010/2011 but declined afterwards and remained stable in the most recent years. The trends appear the same when considering the international inventions (Figure 38).

Figure 37: Distribution of total inventions across SET Plan KAs – MI-23



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Figure 38: Distribution of international inventions across SET Plan KAs – MI-23



Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

4 Conclusions and recommendations

In the first part of this report, and more extensively in the year 1 report, we explained why we selected three patent indicators for inclusion in the Clean Energy Innovation Index (CEII): total inventions, high value inventions and international inventions. A more detailed assessment was performed for these three indicators, which aimed to better understand the merits of including each in the CEII and to provide insight into innovation performance from the perspective of patents.

The assessment of the three indicators revealed that there are five world players in terms of patent volume for clean energy technologies (aggregated by SET Plan KAs): China, EU, Japan, South Korea and the US. Together, these countries/regions account for more than 90% of all inventions related to clean energy technologies. China leads the total number of inventions with strongly increasing numbers over the past decade. A particularly high share of inventions from China are only filed domestically. The EU, Japan and the US are leading in terms of high value inventions, with a peak around 2012 and slightly decreasing or stable numbers afterwards. Japan leads in terms of international inventions, with particularly strong growth during most of the in scope years.

When scaling the numbers of inventions to GDP, Japan and South Korea lead on all three indicators, indicating exceptionally strong innovation performance for those countries. Within the EU, the scaled number of inventions show the strongest innovation performance for the Nordic countries and Germany, followed by Austria, France and the Netherlands.

Out of the nine technology areas (SET Plan KAs), four account for the majority of inventions (+/- 80%). These are:

- 1. Performant renewable technologies integrated in the system
- 3. New technologies and services for consumers
- 6. Energy efficiency for industry
- 7. Competitive in the global battery sector

The EU is leading in the KA 'Performant renewable technologies integrated in the system' when considering the high value inventions and Solar PV is the most patented technology within this action. Japan is showing a strong performance in both KAs 3 'New technologies and services for consumers' and 6 'Energy efficiency for industry' considering the international inventions, while in KA 7 'Competitive in the global battery sector' Japan and recently China are leading the path when looking at the total inventions.

Patenting activity across different technology sectors also differs in terms of international orientation, with patents for consumer technologies (KA3), batteries (KA7) and CCS/U (KA9) often filed at multiple patent offices/countries, while patents for security of energy systems (KA4), new materials and technologies for buildings (KA5) and industrial energy efficiency (KA6) are most often filed only domestically.

Overall, we conclude that all three indicators (total inventions, high value inventions, international inventions) provide different, complementary insights and therefore have added value.

Annex A: Patent dataset for Clean Energy Innovation Index

Tables A-1 to A-3 provide the performance of the in-scope countries for the three indicators used in the analysis (i.e., number of inventions, number of high value inventions and number of international inventions) for the period 2007-2017 at All SET Plan Action level. The detailed dataset can be provided upon request.

Table A-1:Number of inventions for all in-scope countries, EU27 average and MI-23 members average for the period 2007-2017

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Austria	90.0	93.1	129.4	145.2	143.3	228.6	225.7	235.0	187.6	176.7	223.2
Belgium	65.8	68.0	88.9	91.5	106.1	130.5	117.6	128.3	113.2	143.4	147.2
Bulgaria	n/a	7.3	0.7	2.1	4.2	8.6	5.5	4.5	7.7	4.9	2.3
Cyprus	2.6	4.8	2.6	1.9	1.0	2.5	2.5	6.0	3.3	n/a	3.7
Czech Republic	27.5	19.7	21.2	14.4	30.9	35.5	36.4	30.4	23.8	30.6	24.9
Germany	1815.6	2129.7	2471.0	3011.9	3579.7	4179.7	4009.3	4043.2	3800.0	4208.8	4754.3
Denmark	113.3	161.1	157.8	167.2	257.4	222.5	237.6	251.0	256.9	346.9	401.0
Estonia	3.5	3.2	1.6	4.7	3.2	2.5	2.3	6.5	3.2	7.5	7.3
Greece	4.0	1.1	4.0	4.5	11.4	7.2	8.0	1.7	3.9	10.5	6.5
Spain	133.4	132.7	201.4	185.8	212.8	239.8	241.1	214.2	177.4	174.0	182.2
Finland	83.2	91.3	88.1	118.3	126.0	182.2	182.6	193.3	152.2	155.9	174.1
France	580.5	659.2	813.1	969.0	1150.6	1423.4	1400.8	1347.5	1294.9	1158.3	1296.0
Croatia	0.6	1.0	0.2	4.3	2.7	1.2	2.0	0.2	1.0	1.4	n/a
Hungary	10.9	6.6	5.7	10.9	12.0	11.9	14.3	10.7	10.2	10.4	12.3
Ireland	19.9	30.1	28.4	29.3	23.6	41.0	35.6	33.4	47.8	42.7	51.2

Italy	171.8	203.3	318.6	319.6	292.3	344.2	275.4	220.5	269.4	284.5	260.7
Lithuania	n/a	1.7	1.1	0.5	1.0	2.0	8.0	5.0	3.3	2.2	1.3
Luxembourg	5.1	11.9	24.7	19.1	47.4	26.5	20.4	29.1	25.7	18.6	18.6
Latvia	8.7	7.6	7.2	6.4	8.1	6.0	22.9	6.8	12.7	9.4	5.5
Malta	3.4	1.9	1.6	1.8	2.5	0.9	2.9	2.1	2.8	12.8	2.7
Netherlands	176.2	196.5	243.4	224.3	271.9	319.3	331.4	338.7	385.9	362.2	376.5
Poland	42.3	49.6	55.8	97.3	131.0	186.7	173.5	153.7	181.3	168.1	145.7
Portugal	17.0	12.3	13.6	16.4	11.4	13.8	9.7	17.1	23.2	28.9	11.7
Romania	10.4	23.6	31.0	51.1	55.9	33.3	31.5	32.2	41.8	34.8	45.9
Sweden	90.4	130.7	136.4	132.7	151.0	307.5	316.9	294.1	296.8	293.8	276.1
Slovenia	1.5	1.4	3.5	5.8	3.6	6.7	11.7	13.3	4.2	7.6	7.8
Slovakia	2.3	1.0	1.0	3.9	8.0	4.0	14.1	8.0	11.4	4.4	7.3
United Arab Emirates	0.7	0.9	1.1	1.2	3.8	2.4	7.3	4.6	3.2	3.5	16.2
Australia	87.2	99.1	95.5	112.2	109.6	140.1	143.6	113.6	129.8	160.1	132.9
Brazil	115.4	113.4	96.9	97.6	132.8	119.5	101.1	104.2	106.2	119.6	139.4
Canada	188.8	145.1	182.1	186.0	266.3	313.2	324.3	276.5	271.2	302.1	290.0
Chile	4.0	3.7	8.3	5.5	9.5	15.7	13.3	15.0	18.3	13.5	16.3
China	4654.7	6286.5	8354.5	10797.9	14156.5	18986.9	22581.1	26019.6	30329.4	43734.7	53933.0
Indonesia	n/a	n/a	1.0	0.9	0.6	n/a	n/a	n/a	2.0	n/a	n/a
India	18.2	17.7	28.5	27.5	47.7	63.5	112.3	79.1	96.6	96.3	85.8

Japan	14136.0	15094.8	15081.3	15760.5	17559.0	19712.4	17353.7	16042.2	15022.8	15161.1	14658.6
Korea, Rep.	3566.4	3960.9	5450.1	6898.5	8088.9	10213.1	9291.3	10481.0	9291.9	10539.7	10097.7
Mexico	10.0	17.1	18.1	22.4	37.5	48.4	46.9	58.3	60.4	61.9	41.6
Norway	40.7	50.4	60.7	43.4	57.4	61.7	54.4	38.8	49.0	64.5	64.5
Saudi Arabia	6.9	7.4	6.9	13.2	22.6	41.8	74.3	71.9	75.2	64.8	100.9
United Kingdom	289.7	319.1	366.7	400.6	433.1	572.8	631.1	606.0	627.2	550.3	617.2
United States	2979.8	2996.0	3194.8	3500.4	4247.1	6551.7	7572.6	7104.8	7241.4	7517.1	7710.5
European Union	22.5	24.5	28.9	31.5	38.4	46.9	42.3	42.1	42.4	42.8	49.4
Mission Innovation (MI-23)	176.0	195.1	215.6	240.0	278.0	353.9	358.7	367.2	388.7	464.0	514.3

Note: In-scope countries are ordered EU to Non-EU, and then alphabetically.

Table A-2:Number of high value inventions for all in-scope countries, EU27 average and MI-23 members average for the period 2007-2017

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Austria	58.9	58.9	77.6	90.9	106.4	165.9	168.4	170.0	127.6	132.2	162.9
Belgium	35.6	34.5	57.8	64.8	63.7	91.5	89.5	99.5	90.7	103.7	115.8
Bulgaria	n/a	0.0	0.6	0.6	0.0	2.0	4.0	2.5	4.7	2.9	2.3
Cyprus	2.6	2.8	2.3	1.6	0.7	0.5	1.0	3.0	1.3	n/a	2.2
Czech Republic	5.0	10.4	3.2	5.6	9.2	11.3	10.9	12.4	8.1	10.6	9.9
Germany	1021.7	1146.7	1314.0	1538.7	1812.6	2282.2	2072.3	2153.0	2024.7	2269.7	2662.6
Denmark	88.1	118.9	116.5	125.4	181.2	167.1	178.0	207.4	197.1	269.9	318.4
Estonia	1.5	0.4	1.6	2.7	0.0	1.5	1.3	4.0	2.2	3.5	6.3
Greece	3.1	1.1	0.8	1.5	3.9	4.2	2.4	0.7	0.8	4.2	2.0
Spain	63.0	51.4	93.4	94.3	114.0	146.2	129.3	124.5	109.0	102.4	112.5
Finland	59.7	64.3	73.1	90.6	103.2	144.9	146.4	143.8	107.7	115.9	115.3
France	371.2	409.6	499.9	539.3	721.7	975.7	977.8	957.9	908.3	818.9	875.9
Croatia	0.6	0.0	0.0	2.3	0.7	1.2	0.0	0.2	0.0	1.4	n/a
Hungary	2.9	2.5	2.3	4.1	4.0	6.0	10.3	4.2	3.7	6.2	5.3
Ireland	16.6	18.5	19.7	19.2	19.2	29.1	28.3	24.9	41.3	29.2	32.6
Italy	129.5	123.3	163.8	165.4	176.5	230.7	186.1	149.5	181.9	212.2	190.7
Lithuania	n/a	0.7	1.1	0.5	0.0	2.0	3.0	4.0	1.3	1.7	1.0
Luxembourg	3.8	11.4	17.9	10.6	36.4	17.6	11.9	19.1	23.7	16.6	13.0

Latvia	1.7	1.6	1.0	0.4	0.1	1.3	3.4	0.0	1.7	0.4	2.0
Malta	1.4	0.9	0.6	1.8	0.0	0.9	1.9	1.1	2.8	11.8	1.7
Netherlands	132.5	138.6	172.9	151.6	203.4	238.1	233.5	250.5	290.1	266.7	258.8
Poland	2.8	15.9	11.5	11.6	13.7	34.3	25.0	37.4	32.0	13.5	29.1
Portugal	5.0	5.3	4.6	7.4	4.4	3.3	5.2	10.1	17.2	19.2	8.2
Romania	0.9	0.0	1.5	0.4	0.5	0.0	4.1	1.2	0.0	1.0	1.5
Sweden	67.6	88.0	113.5	96.3	123.7	245.4	256.2	240.6	244.3	245.6	233.9
Slovenia	1.0	0.4	2.5	3.6	1.4	4.7	8.7	7.7	2.4	5.6	5.8
Slovakia	2.3	1.0	0.0	0.5	3.0	0.0	2.1	0.0	2.4	4.4	4.4
United Arab Emirates	0.2	0.9	0.1	1.2	1.4	0.4	6.3	3.1	1.5	1.2	6.1
Australia	50.0	63.4	52.0	65.7	63.6	86.6	77.1	80.8	87.1	85.1	82.3
Brazil	18.0	19.2	13.6	17.3	21.5	24.6	24.4	22.4	22.6	25.4	13.3
Canada	108.9	95.0	127.6	136.8	163.6	203.9	210.9	188.1	185.2	210.3	219.4
Chile	4.0	1.7	2.0	4.5	3.0	6.2	9.2	11.0	12.3	7.5	10.8
China	151.1	208.1	319.5	427.6	572.3	1030.5	1293.5	1467.2	1626.3	2413.8	2905.1
Indonesia	n/a	n/a	1.0	0.9	0.6	n/a	n/a	n/a	1.0	n/a	n/a
India	12.1	9.3	18.9	18.0	33.3	33.7	64.7	38.2	52.4	58.7	33.6
Japan	2426.9	2113.7	2565.0	3529.7	4542.4	6122.4	5786.3	5592.9	5462.4	5781.0	5832.9
Korea, Rep.	734.7	650.3	929.4	1212.9	1440.1	2414.0	2689.4	2841.1	2667.6	3065.3	2971.3
Mexico	5.2	6.1	3.1	5.5	7.3	11.9	6.7	15.4	15.2	12.1	9.9

Norway	31.7	33.1	49.4	30.0	46.3	47.5	40.1	29.5	38.0	44.5	44.2
Saudi Arabia	5.4	3.4	4.9	6.8	18.1	29.4	47.4	37.8	44.9	31.4	67.4
United Kingdom	172.2	198.2	243.9	255.9	318.3	436.2	473.5	466.5	468.9	405.1	499.7
United States	1849.2	1850.6	2044.7	2216.3	2608.0	3835.9	4442.4	4189.4	4229.6	4453.3	4460.7
European Union	13.4	14.0	16.4	16.9	21.4	28.3	24.9	25.6	25.6	25.9	30.3
Mission Innovation (MI-23)	45.2	44.1	51.5	59.9	72.1	103.5	106.5	104.1	105.5	113.7	118.1

Note: In-scope countries are ordered EU to Non-EU, and then alphabetically.

Table A-3:Number of international inventions for all in-scope countries, EU27 average and MI-23 members average for the period 2007-2017

Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Austria	14.6	19.8	29.1	25.9	34.4	55.6	53.5	64.6	51.4	56.9	68.2
Belgium	23.5	23.1	30.8	36.0	43.9	42.7	47.6	52.9	51.3	59.3	49.7
Bulgaria	n/a	0.0	0.0	0.1	0.0	1.1	1.1	0.8	2.0	1.7	0.4
Cyprus	2.3	3.1	1.7	1.1	0.6	0.5	1.4	5.1	2.1	n/a	1.5
Czech Republic	0.8	3.0	1.4	1.5	4.4	2.6	3.7	6.4	3.5	3.9	4.2
Germany	341.1	396.3	480.5	608.3	681.9	893.8	803.5	832.5	823.6	954.7	1065.5
Denmark	57.4	67.6	63.0	64.2	93.3	87.0	84.7	99.9	86.5	131.0	146.1
Estonia	1.7	0.1	0.9	1.4	0.0	0.6	0.2	2.6	2.5	3.0	4.1
Greece	1.6	0.2	0.2	1.1	0.9	1.0	3.8	0.0	0.4	1.5	3.0
Spain	17.3	19.6	30.0	33.3	46.3	57.5	45.5	36.4	40.0	42.5	33.3
Finland	44.9	33.9	39.5	42.4	45.3	76.8	83.4	83.6	61.9	66.5	53.1
France	182.6	175.4	219.7	233.1	300.4	399.3	388.4	378.0	331.5	313.5	320.4
Croatia	0.0	0.0	0.0	1.1	0.1	0.0	1.0	0.1	0.0	0.7	n/a
Hungary	0.6	0.7	0.3	1.5	1.8	3.7	4.6	3.0	2.1	2.3	3.4
Ireland	9.0	12.0	12.2	13.7	11.6	16.4	17.4	17.2	25.2	25.7	26.7
Italy	50.2	41.2	69.5	67.5	79.7	115.1	92.5	107.7	105.0	95.5	93.6
Lithuania	n/a	0.0	0.1	0.3	0.0	0.3	0.5	1.6	0.7	0.5	0.5
Luxembourg	2.8	5.2	11.8	6.9	22.4	9.5	7.0	14.4	13.9	9.2	9.1

Latvia	1.0	1.1	0.4	0.4	0.1	0.6	6.5	3.8	6.9	4.4	1.8
Malta	0.0	0.4	1.5	0.4	1.5	0.3	1.0	0.1	1.2	3.1	0.9
Netherlands	89.4	94.1	109.4	93.8	121.5	162.0	145.4	148.0	180.2	166.3	148.7
Poland	0.6	3.0	3.0	2.4	2.3	5.5	4.7	8.7	11.5	6.5	9.5
Portugal	2.6	1.8	2.9	3.2	3.3	2.9	5.2	3.9	8.4	11.0	5.6
Romania	1.4	0.1	0.7	0.1	0.0	0.0	0.1	0.8	1.0	1.5	2.6
Sweden	36.6	62.5	51.4	45.2	63.4	139.5	134.0	123.5	130.9	129.1	103.4
Slovenia	0.0	0.0	0.1	0.0	0.3	1.1	1.4	1.6	1.9	1.5	2.2
Slovakia	0.3	0.0	0.0	0.0	0.3	0.0	0.3	0.0	1.2	2.3	0.9
United Arab Emirates	0.1	0.5	0.0	1.2	3.5	2.2	4.5	3.6	2.9	3.4	13.8
Australia	24.3	27.1	24.0	27.4	31.3	38.4	40.7	31.9	43.5	62.4	45.0
Brazil	6.1	9.6	6.6	3.9	7.0	6.8	7.8	8.3	6.4	11.4	7.1
Canada	88.2	71.8	93.5	99.9	136.6	166.6	190.9	151.3	145.3	177.8	153.9
Chile	0.6	0.3	0.7	0.9	0.9	0.7	3.4	1.6	3.4	1.3	2.8
China	94.2	154.7	163.7	207.0	285.4	467.5	563.1	683.0	712.2	968.8	1205.1
Indonesia	n/a	n/a	0.1	0.3	0.1	n/a	n/a	n/a	0.6	n/a	n/a
India	8.4	8.8	12.1	14.2	27.3	26.9	47.7	43.7	50.9	57.4	41.9
Japan	1644.0	1446.7	1806.1	2426.7	3021.6	3960.6	3736.0	3861.7	3901.5	4187.5	4412.7
Korea, Rep.	511.2	454.5	661.7	854.2	1058.9	1752.7	2256.7	2061.2	2107.7	2489.3	2445.1
Mexico	1.9	1.4	0.9	1.4	2.6	3.6	4.9	6.9	8.2	6.1	4.8

Norway	12.9	16.1	19.8	12.2	20.7	20.6	18.2	18.0	17.5	23.3	17.9
Saudi Arabia	4.9	7.1	5.8	12.3	21.2	37.3	61.7	63.0	65.8	53.9	87.0
United Kingdom	83.1	74.2	111.6	115.6	146.2	179.4	195.5	201.0	210.7	182.4	217.5
United States	1271.4	1312.3	1366.0	1486.3	1627.0	2000.2	2100.8	2089.3	2172.7	2339.0	2504.1
European Union	5.7	5.8	6.9	7.2	9.0	12.2	10.6	11.0	11.3	11.6	12.6
Mission Innovation (MI-23)	27.5	26.6	30.8	36.0	42.4	58.5	60.5	59.8	62.3	67.8	70.7

Note: In-scope countries are ordered EU to Non-EU, and then alphabetically.

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The Clean Energy Innovation Index (CEII) is a composite indicator designed to track progress in clean energy innovation performance, as measured through the lens of scientific publications, patents and export. This report focuses on the patents dimension of the CEII. In this report, Trinomics evaluates how patent indicators can be analysed to gauge clean energy innovation within the European Union (EU) and Mission Innovation member countries. It assesses the suitability of using specific indicators to compare innovation levels across countries and also examines recent patenting trends in detail, with a focus on trends in the EU, US, China, Japan and South Korea.

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