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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

Independent Expert Report

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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	Join Research Centre
KA	Key Action
KR	Republic of 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 report is 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 members, 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. This report covers the work on using patents as a measure of innovation performance and has three objectives:

1. Identify patent indicators with relevance for measuring clean energy technology (CET) innovation performance;

2. Provide insight on CET innovation performance from the perspective of patents;

3. Propose a selection of patent indicators most suitable for measuring innovation performance and hence for inclusion in the Clean Energy Innovation Index;

4. 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 with those in mind, identify the most relevant patent indicators for measuring innovation performance in the clean energy sector. 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 and make a final proposal on which patent indicators to include in the CEII.[1] Annex A includes the dataset that will be used as input for the composite indicator calculations.

[1] Note that there is a separate deliverable for the development of CEII in which several statistical tests will be performed which may alter the final selection of indicators for the CEII. Hence, the output of this report is a proposal of indicators to select, rather than a final selection.

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 success.

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 identify the potentially useful indicators and approaches to assess innovation performance while mitigating the impact of the main challenges. Finally, we perform an initial selection of patent indicators that are potentially suitable for measuring innovation performance (and inclusion in the CEII). 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, measuring the impact of past policies to stimulate innovation through patent statistics can only be done with some delay.

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[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).

Another key issue is that the **propensity to patent** may differ significantly across countries, sectors and time. EU-based renewable energy companies have, for example, become less inclined to use a patent to protect their intellectual property, as lawsuits to enforce patents in China have not always reached a favourable conclusion for the patent holder, while costing significant time and money. Hence, several EU companies report that they use secrecy and speed to reap the benefits of their inventions, rather than patents (see Box 1 for further information).[6]

Box 1 Insights from the EU renewables industry on the declining EU share of global patents

In the Study on the impacts of EU actions supporting the development of renewable energy technologies conducted for DG RTD in 2018[7], Trinomics performed an analysis of the innovation outputs of the EU renewables sector and assessed the extent to which the EU RD&I funding programmes (Horizon 2020 and predecessors) contributed to the results. Patent applications were one of the output indicators that were assessed and a common thread across all renewable energy technologies was that patent applications by EU companies peaked between 2008 and 2012 and decreased significantly afterwards. We discussed this observation with all eight renewable energy sectors (biofuels, bioenergy, geothermal, hydro, ocean, solar PV, solar thermal, wind) during a series of conferences (one for each technology) and around 20 expert interviews. Many technology-specific factors were cited such as the decline of the EU solar PV manufacturing industry, the maturity of the EU wind energy industry, the lack of a sufficiently large market for solar thermal and the shift to more SME driven innovation in the ocean energy sector.

However, one reason was commonly cited across technologies: EU companies have less trust in patents as an effective measure to protect intellectual property. Several industry representatives had first-hand experience with innovative products that they protected with an international patent and launched in the international market, only to find out that competitors copied all innovations within a year and court cases do not rule in favour of the patent holder. As a result, these companies changed their knowledge protection strategies and chose secrecy and speed as their main strategy. Meanwhile, for most renewable energy sectors a strong increase in patents from China could be observed which contributed to a consistently declining EU share of globally filed patents.

Another commonly applicable finding was that there is little correlation between public RD&I funding (EU and Member State funding combed) and patent applications. No matter which hypothesis was applied for the average time lag between the funding and the patent application (we tested anything from 0 to 5 years), no strong correlation could be observed. Hence, the decreasing EU applications cannot be attributed to a lack of public funding.

Meanwhile, Chinese companies have become more inclined to patent, as patents provide them with credibility that is considered important in accessing foreign markets. 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

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[6] Inputs from industry participants at series of conferences organised by Trinomics with the scope of the study Trinomics (2019) – Impacts of EU actions supporting the development of renewable energy technologies, available at: https://op.europa.eu/nl/publication-detail/-/publication/a4e37c63-75f5-11e9-9f05-01aa75ed71a1/language-en/format-PDF/source-119528788

[7] Trinomics (2019) – Impacts of EU actions supporting the development of renewable energy technologies, available at: https://op.europa.eu/nl/publication-detail/-/publication/a4e37c63-75f5-11e9-9f05-01aa75ed71a1/language-en/format-PDF/source-119528788

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. Box 2 provides some insights that may lead to higher propensity to patent for China and Korea in particular (sources: [8] [9] [10]).

Box 2 Insights into the propensity to patent in China and Korea

An often-cited reason for the high number of patents from China and Korea is that these countries have policies in place to stimulate patenting and that these policies particularly aim to increase the volume of patents, rather than the quality. Hence, high numbers of patents from these countries may not necessarily signal high innovation performance. We conducted a literature review on this issue to identify if there is any proof and understanding of these policies leading to high volumes of lower quality patents.

A key insight for the situation in China is that China's patents are divided in three categories, namely invention, utility, and design patents which differ in terms of innovative capacity. Invention patents have the highest innovation qualities since they refer to new technological options or improvements of a product or a process. Utility patents refer to the new technical options targeting the shape, the pattern or their combination of a product, therefore they are typically lower in technical innovative content. Design patents relate to the design of the shape or the pattern of a product hence they lack in technical innovative content. Most of the patents that are filed by Chinese inventors are utility patents, which have lower quality relative to the other categories. On the contrary many countries (e.g. the U.S) do not have utility patents as a sub-category, hence there could be a significant difference in the quality of the patents between China and the other countries. Additionally, the government's policies focus on the quantity rather than the quality of patents by providing subsidies, bonuses and lower taxes to the companies with more patents. Hence, there are reasons to believe that the average quality of Chinese patents is lower than in other countries and regions.

For Korea, no clear evidence of lower patent quality could be found in the literature. The main reasons for Korea's strong patenting performance that are cited in the literature include the presence of large companies, the focus on products rather than services and the focus on exports. All of these do not necessarily signal a lower quality of the patents filed.

Another fundamental issue in using patent statistics concerns differences in the **value of patents[11].** 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. 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

8 China Power Team (2016). Are patents indicative of Chinese innovation?
9 Warner, E. (2015). Patenting and Innovation in China: Incentives, Policy, and Outcomes.
10 World Intellectual Property Organization (WIPO). (2012). The Economics of Intellectual Property in the Republic of Korea.
11 OECD (2009). OECD Patent Statistics Manual 2009

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.

2.2 Identification of relevant patent indicators and approaches

As indicated in the previous section, there are several issues when using patent data to evaluate innovation performance. Some of these are practical in nature and have been sufficiently resolved by the common working practices applied by the JRC and others. For the issue around the time lag, no realistic solution has yet been conceived.[12] For the issues around differences in RD&I resources, quality of invention and propensity to patent there are potential ways of addressing / mitigating those through using more sophisticated indicators than only measuring the number of inventions and/or to combine different indicators into a composite patent indicator. In this section we identify the most relevant patent indicators available and discuss their merits.

For a proper understanding of the different patent indicators, it is important to first explain some of the working practices that the JRC applies and how this affects the resulting values:

1. Patent applications for the same invention are grouped into patent families. Patent families are also called 'inventions'. Within the context of this study both terms can be used interchangeably. A patent family/invention can consist of a single application or many applications;

2. Each patent family/invention is counted once, irrespective of the number of patent applications it consists of. This way, double counting of the same invention is prevented;

3. The 'fractional counting' technique is applied to divide the patent family/invention in equal fractions per applicant and technology. For example, if a patent family/invention includes four applicants, each will be assigned with 0.25 of the invention;

4. In all cases, the unit of measurement is the number of inventions, which does not have to be an integer due to fractional counting.

[12] Approaches to provide early estimates are not considered robust enough by the JRC as there is no clear pattern in the data that is missing and needs to be estimated. For example, in one year a lot of applications from country A can be missing, while in the next year country A's data could be one of the most complete datasets. Hence, assumptions on which data is presumably missing are not very robust.

Further details on the working practices are available in the publications in the footnote.[13]

The first indicator to consider is the simple **number of inventions** which is the most basic patent indicator as it just measures the plain number of inventions for which a country (i.e. entities legally based in a given country) has filed patents. The "number of inventions" is a useful indicator because it provides the most clean view on the volume of inventions produced by a country and is easy to understand. The main drawback is that it does not correct for differences in quality of inventions and propensity to patent.

The second indicator is **'high value' inventions** which only counts inventions consisting of multiple patent applications that are filed at more than one patent office. Filing patents at more than one patent office entails more effort and costs for the applicant, hence those inventions are expected to have a higher market value on average. As a result, this indicator may exclude a large share of patents with low commercial value which may mitigate differences in the average quality of patents filed per country.

The third indicator is **international inventions** which only counts patent applications where the country of the applicant differs from the country of the patent office. Similar to 'high value inventions', filing patents in more than one country entails more effort and costs for the applicants and may be considered as an indication that the patent is more valuable (than those filed only in the applicant's home country). A particular feature of this indicator is that the EU is treated as one country. This makes sense given that there is also a European Patent Office (EPO) and that EU countries and markets are relatively small which would lead to a higher inclination for EU applicants to file their patent at multiple EU patent offices or directly at the EPO (see Box 3 for further details on the differences between 'high value' and 'international' inventions).

[13] Fiorini A., Georgakaki A., Pasimeni F., & Tzimas E. (2017). Monitoring R&I in Low-Carbon Energy Technologies (JRC105642). For a description of the methodology applied see also Box 4.1 of the 2020 EU Industrial R&D Investment Scoreboard (JRC123317).

Box 3 Cases to illustrate differences between high value and international invention numbers

Understanding how a country's performance on the high value and international inventions indicators differs requires understanding the details of how these numbers are calculated. In this box we present four illustrative examples to show the most relevant differences between the indicators.

Case 1: Primary impact on EU patent numbers

This case considers an invention made by a Belgian firm which applies for a patent at the Belgian and Dutch patent offices. As the patent is filed at multiple patent offices, the whole patent family/invention is counted as a high value invention. But since the applicant and the patent offices are all within the EU neither of the fractions (applications) are counted as international inventions.

Country applicant	Country patent office	Fraction	High value invention	International invention
Belgium	Belgium	0.5	Y	N
Belgium	Netherlands	0.5	Y	N
Value counted			1	0

Case 2: Part of the family can be considered international

This case considers an invention made by a Chinese company which files for a patent at the patent offices of China and the United States. As the patent is filed at multiple patent offices, the whole patent family/invention is counted as a high value invention. But only one of the fractions (applications) is international, while the other is domestic, which results in counting half the patent family/invention as an international invention.

Country applicant	Country patent office	Fraction	High value invention	International invention
China	China	0.5	Y	N
China	United States	0.5	Y	Y
Value counted			1	0.5

Case 3: The more patent offices the patent family is filed at, the higher the international share

This case considers an invention made by a Korean company which files for a patent at four different patent offices. As three of the four patent applications are international, 75% of the patent family/invention is counted as an international invention.

Country applicant	Country patent office	Fraction	High value invention	International invention
Korea	Korea	0.25	Y	N
Korea	China	0.25	Y	Y
Korea	Japan	0.25	Y	Y
Korea	United States	0.25	Y	Y
Value counted			1	0.75

Case 4: Under specific circumstances, international inventions can be higher than high value inventions

This case considers an invention made jointly by a Korean and Chinese company which file for a patent only at the Chinese patent office. As it is only filed at one patent office, it is not counted as a high value invention. But the application by the Korean company is international, which can lead to international invention values being higher than high value invention values.

Country applicant	Country patent office	Fraction	High value invention	International invention
China	China	0.5	N	N
Korea	China	0.5	N	Y
Value counted			0	0.5

The fourth indicator only considers **granted patents** which implies a certain minimum quality level of the invention in terms of novelty and uniqueness and thereby eliminates several low(er) quality inventions. An important drawback of this indicator is that the granting procedure takes time which adds to the overall lag in measuring innovation performance. Additionally, the requirements for granting patents may differ per country, which may cause challenges for comparability across countries.

The fifth indicator considers **patent specialisation**, which is a measure of the relative specialisation of a country in a certain technology compared to the global average specialisation in terms of share of total inventions:

$$Patent\ specialisation\ index = \frac{P_{d,i}/\sum_d P_{d,i}}{\sum_{di} P_{d,i}/\sum_{d,i} P_{d,i}}$$

where i is the country and d the technological field. The numerator expresses the share of inventions of a country in a particular technological field over the total inventions of the country in all technological fields. The denominator expresses the share of world inventions in the specific field over the world inventions of all technological fields. Specialisation metrics can indicate where countries have distinct advantages in developing subsets of technologies; patent specialisation is often used as a predictor of areas where countries will eventually specialise in technological exports.[14] However, specialisation is generally not considered an absolute measure of innovation performance as it measures innovation performance in a specific field relative to the other fields the country is active in and relative to the average specialisation across the world.

The sixth approach considers **patent collaboration,** a measure of patents co-filed by international parties, where:

$$Patent\ collaboration\ index_{year\ x} = \frac{Patent\ applications\ filed\ jointly_{year\ x}}{Total\ patent\ applications\ filed_{year\ x}}.$$

Patent collaboration indices can be further refined; for example, an index on a selected collaborator would consider patent applications filed jointly with that selected partner. Patent collaboration metrics can be used to gauge cross-fertilisation of ideas, to indicate strong R&D relationships between countries, and to assess where certain countries might be boosting their innovation performance through relationships with their international counterparts. The OECD includes international patent collaboration as a key measure of innovation in environment-related technologies.[15] Patent collaboration indices typically consider EU Member States separately, and may therefore require caveats as Member States collaborate more frequently and easily within the EU than outside of it. Similar to specialisation, collaboration is also generally not considered an absolute measure of innovation performance but rather an attribute of the innovation system that may drive innovation performance.

For the sake of completeness, we have also identified several other indicators that are used in the literature but have been discarded for use in this project due to clear shortcomings for measuring innovation performance. These indicators and the reason for their dismissal are listed in Table 1.

Another key issue when measuring innovation performance through inventions is that larger/richer countries have more resources available and could therefore be expected to file a higher number of patents, without this necessarily being a sign of strong innovation performance. For a more accurate view of the innovation performance the indicator could be scaled to a measure of the country's resources available. There are several options available to achieve such scaling, for example the population, the GDP of the country, or the RD&I budgets of the country.

Our view is that the GDP of the country is the most appropriate measure for scaling the patent numbers within the context of this study. GDP provides a more accurate view on the resources that a country could mobilise than population because it takes into account differences in the productivity of the country. Compared to RD&I budgets it is more practical as data on relevant RD&I budgets for the scope of SET Plan Key Actions (KA) for non-EU members are not available. In our opinion GDP is also more appropriate to use than RD&I budgets because improved innovation performance can in theory be achieved with reduced RD&I spending on clean energy innovation (i.e. when the increased productivity of RD&I investments more than offsets the decline in RD&I

[14] Zachmann and Kalcik (2018). Export and Patent Specialization in Low Carbon Technologies.
[15] OECD (2019). Patent Indicators.

budgets), which in the long term will likely have permanent and negative structural effects on the innovation system of a country.

Table 1 List of patent indicators discarded for detailed assessment

Indicator	Description and rationale	Reason for discarding
Cumulative number of inventions and 'knowledge stock' concepts	In addition to measuring the number of inventions per year, the cumulative number of inventions could also be used as a measure of innovative performance. This way, year-to-year fluctuations have less of an impact and a more gradual picture is created. A refined version could be to use the concept of knowledge stock, in which older inventions are depreciated to account for decreasing value as patents mature and get closer to their expiry date.	Reporting cumulative invention numbers makes it more difficult to identify recent trends, while recent trends would be most informative for measuring progress within the context of Mission Innovation and R&I policy in general.
Number of patent citations	The number of citations of a country's inventions provides an indication of the quality of the inventions and could potentially be a clearer measure of actual innovation performance.	As patent citations only build up after patents have been filed / granted, the time lag between the inventive activity and the citation may become very large. Additionally, patent citation statistics are only recently available in PATSTAT and the meaning of the numbers is not yet fully clear.
Renewals	During the period that a patent is in force, patent holders need to pay periodic[16] "renewal fees", which increase over time, to maintain the patent's validity. If the patent holder is not willing to pay the fee, then the invention is released into the public domain. This indicator estimates the time-sensitive value of a patent.	A patent might not be renewed for several reasons such as change in the firm's strategy and external shocks. Also, technologies become obsolete, but at different rates per sector. Hence, renewals are not a representative measurement of innovation among different technologies.
Number of claims	Each individual patent includes a bundle of inventive components, each reflected in a claim, hence the number of claims can be used as an indication of the legal scope of a patent.	Some applicants inflate the number of claims, thus the relationship between the claims and the scope becomes less reliable and the value of the indicator is degraded

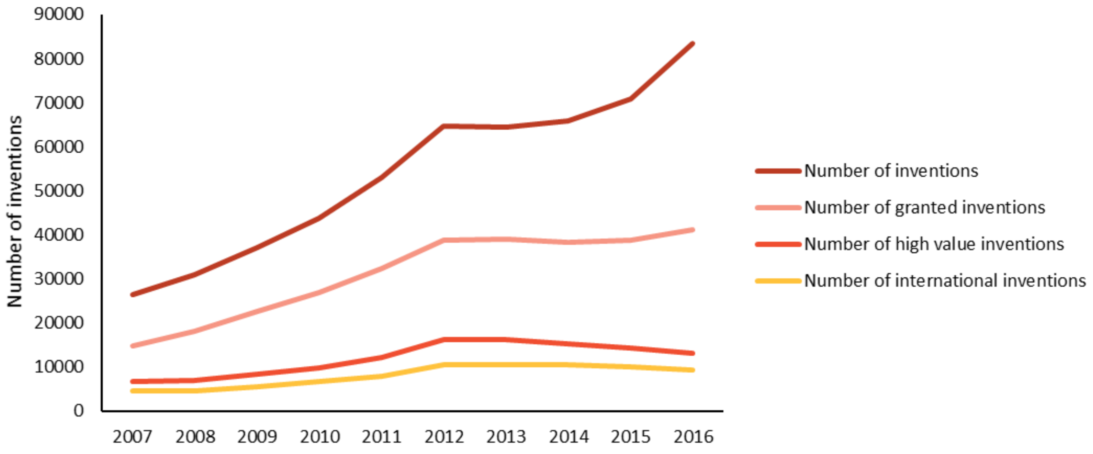
2.3 High-level assessment of potential indicators for composite indicator

In this section we assess the merits of the different potential patent indicators for inclusion in the composite indicator by extracting them for recent patents (2007-2016)[17]. In the previous section we identified six potentially relevant patent indicators, four of which we were able to analyse in more detail based on provided JRC data. Number of inventions, high value inventions, international inventions and granted inventions are considered in this section, while patent specialisation and patent collaboration are discussed again in Section 2.4.

[16] Usually the renewal fees are paid every year, though this depends on the country. For instance in the U.S the renewal fees should be paid every 3.5, 7 and 11.5 years after the grant.
[17] This study relies on data provided by the Joint Research Centre (JRC). JRC Patent data are based on EPO PATSTAT database 2019 autumn version (JRC update: December 2019).

For a first impression on how these indicators and their values relate to each other, we look at the global totals across all SET Plan KAs (see Figure 1). It shows that the global number of inventions related to SET Plan KAs has tripled between 2007 and 2016, from values around 25,000 inventions per year to values above 80,000 inventions per year. The number of granted inventions has increased in a similar fashion with values increasing from around 15,000 in 2007 to values above 40,000 in 2016. For the number of high value and international inventions, the growth is slightly less pronounced with values doubling instead of tripling between 2007 and 2018. From 2012/2013, growth stagnated for a few years for all indicators, with a slightly declining trend continuing for high value and international inventions.

Figure 1 Total inventions globally across all SET Plan KAs



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

The share of total inventions that are high value, international or granted is shown in Table 2. High value inventions (i.e. only counting applications filed at multiple patent offices) are between 15 and 25% of total inventions, indicating that a large share of patents are only filed locally. On average (considering cumulative values between 2007 and 2016) 15% of all applications are considered international (i.e. filed in a foreign country, treating EU28[18] as one country), indicating that the high value inventions indicator includes a significant number of inventions which include applications at multiple EU patent offices but not outside the EU. The number of inventions granted is generally between 50% and 60% of total inventions, indicating that up to 50% of filed patents do not get granted. A further noteworthy observation is that each indicator shows a considerable decline in its share of total inventions between 2014 to 2016, while the values between 2007 and 2014 were relatively stable. For granted inventions this could be due to the additional time lag for the granting process, but for high value and international inventions there is no clear reason for this decline. Overall, the figures in Table 2 show that considering only high value, international or granted inventions leads to the exclusion of a considerable share of the inventions and may therefore significantly affect the picture on the innovation performance of countries.

Looking at the regional distribution of 'inventions' (see Figure 2), it is clear that China (2016 share: 63%), the EU (2016 share: 7%), Japan (2016 share: 11%), Korea (2016 share: 10%) and the US (2016 share: 6%) are the key countries in clean energy innovation with a combined share exceeding 90% of total global inventions (2016 share: 97%). The shares between these countries changed significantly during the past 10

[18] The dataset used for this initial indicator assessment still considered the UK as part of the EU.

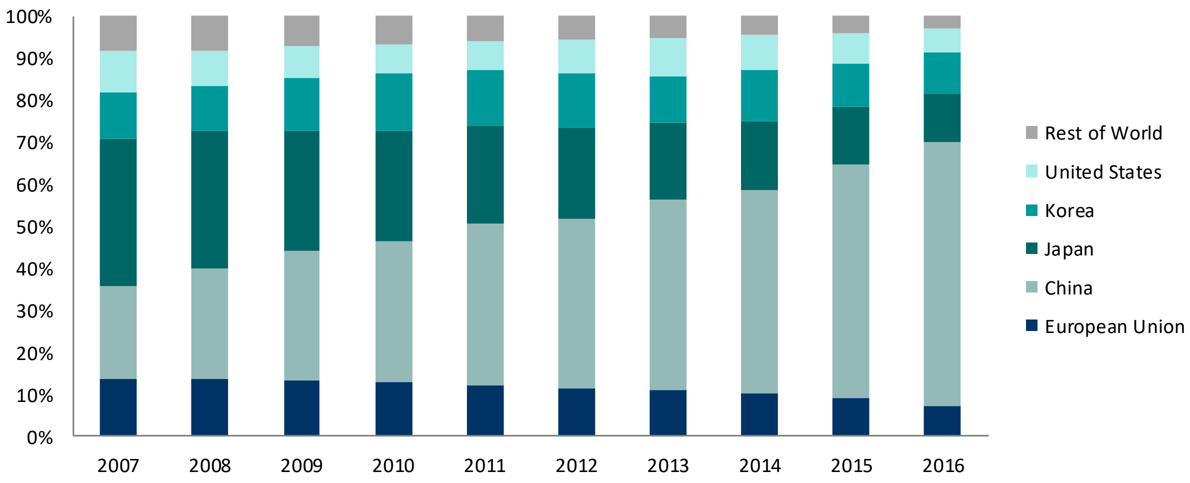
years, with China taking an increasingly large share of total inventions. During this time period, China's share increased from 22% to 63% while the EU, Japan and the US saw their share decreasing significantly.

Table 2 Share of total inventions globally across all SET Plan KAs

Indicator	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
No. high value inventions	26%	22%	22%	23%	23%	25%	25%	23%	20%	16%	
No. international inventions	17%	15%	15%	15%	15%	16%	16%	16%	14%	11%	
No. granted inventions	56%	59%	61%	62%	61%	60%	60%	58%	55%	49%	

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

Figure 2 Regional shares of global inventions across all SET Plan KAs



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

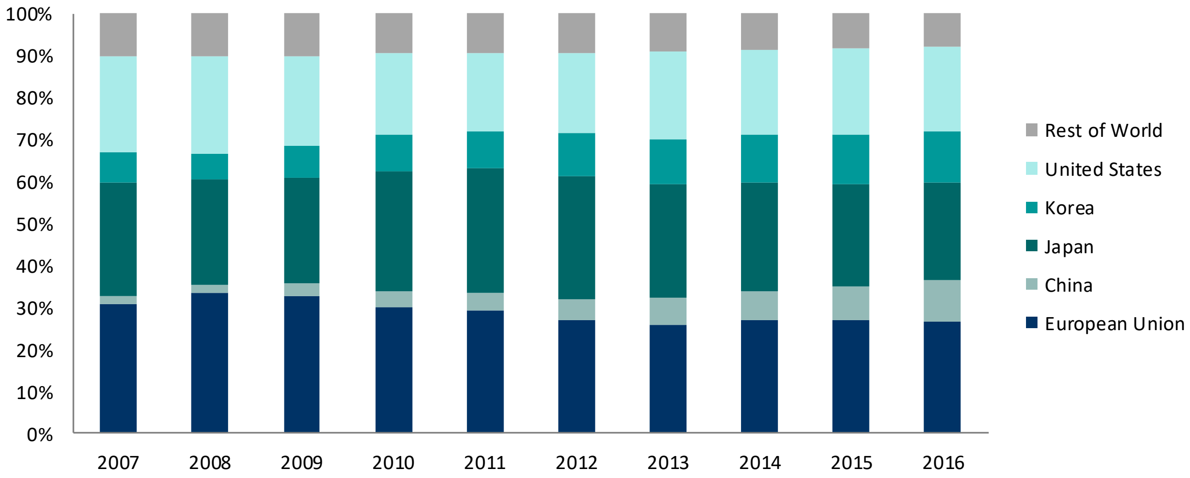
One of the most cited reasons for the increasing share of China and the stable share of Korea is that these countries implemented policies to increase the propensity to patent (see section 2.1). As a result, the higher number of inventions may not (fully/actually) represent improved innovation performance.

The concept of high value inventions was conceived to address this issue by only considering patents filed at multiple patent offices and thereby excluding many inventions that have limited value and only including applications at the local patent office. The regional shares of high value inventions are presented in Figure 3 and show a markedly different picture than the total number of inventions. In particular the Chinese share decreases to less than 10% of the global total compared to China's 63% share of total global inventions. The shares of the other world players all increased (from 2007), with the EU reaching 27%, Japan 23%, US 20%, and Korea 12% of global high value inventions in 2016.

Considering only high value inventions also has its drawbacks, however, as innovators based in countries with smaller markets may be more inclined to file for patents abroad than innovators based in larger markets. In a market as big as China's, for instance, innovators may be less eager to file for a patent abroad as protecting their innovation in their home market may be enough. This could skew the results in favour of the EU and

Korea in particular as the countries in these regions have the smallest home markets among the big players. Furthermore, inventions for which patents are filed at the European Patent Office and a patent office of an EU Member State are also considered 'high value', which could further skew the results in favour of the EU.

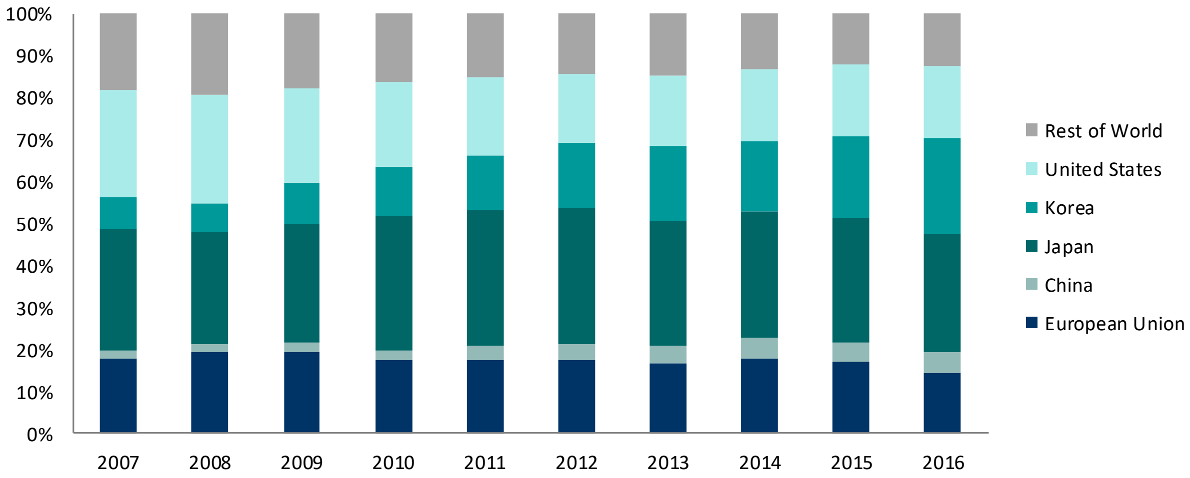
Figure 3 Regional shares of global high value inventions across all SET Plan KAs



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

A partial solution to this may be to only consider international inventions as this indicator treats the EU as one country and therefore excludes patents that are filed in another EU country but not outside the EU. The regional shares of international inventions are shown in Figure 4 and this shows that the EU share becomes much smaller with this approach (14% of international inventions in 2016 vs. 27% of high value inventions in 2016).

Figure 4 Regional shares of global international inventions across all SET Plan KAs

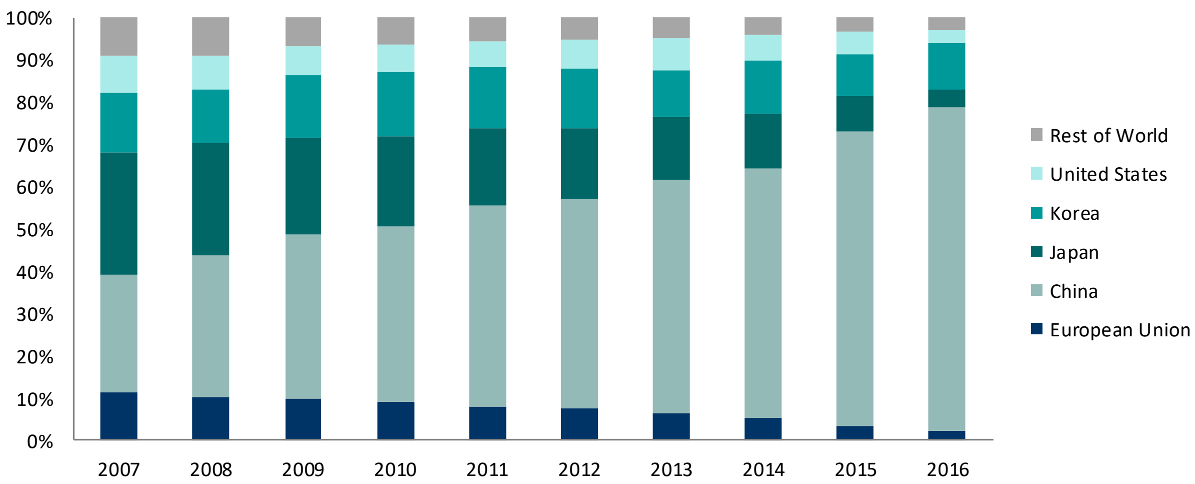


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

The figure also shows that Japan and Korea in particular have a larger share of international inventions compared to the share of high value inventions (i.e. in 2016 Japan had 28% international vs. 23% high value whilst Korea had 23% of international vs. 12% of high value), while China (5% international vs. 10% high value) and the US (17% international vs. 20% high value) actually have a lower share of international inventions than of high value inventions. The lower share for China and the US may seem counterintuitive as there is no clear reason to expect these countries to be affected differently than Korea by the most obvious difference between high value and international inventions (treating the EU as one country). Understanding the reason for the different impacts requires a deeper understanding on the exact approach for calculating these indicators. Box Box 3 provides a summary of the key reasons for different values on these indicators.

The final indicator that could offer a way to correct for differences in propensity to patent and quality of patents is granted inventions. The regional shares on this indicator are presented in Figure 5. The picture looks similar to the total number of inventions (Figure 2) with China taking a dominant share of granted inventions over the years, resulting in a share of 77% in 2016 which is even higher than China's share in total inventions (63%). For the EU, Japan and the US the opposite is true with global shares even lower than total inventions. Taking into account that there might be a higher propensity to patent and possibly a lower average quality of patent applications in China and Korea, these figures do not indicate that considering granted inventions addresses this issue but rather has an effect in the opposite direction.

Figure 5 Regional shares of global granted inventions across all SET Plan KAs



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

The reason for this phenomenon may be that while the policy stimulating a higher propensity to patent may lead to a lower average quality of patents, this policy is also supported by a less stringent patent granting process in these countries, in particular for patents filed by domestic applicants. Table 3 below provides an assessment of the share of inventions granted at the different patent offices, sub-divided into applications from domestic applicants and from international applicants. Due to the potential effect of different granting time lags between the patent offices, the years 2015 and 2016 have been excluded from the sample.

The overall share of inventions granted at each of the patent offices shows that the Chinese and Korean patent offices grant a relatively large share, at 73% and 65% respectively. The EU and Japanese patent offices grant the lowest share of inventions at 38% and 44% respectively. Additionally, the Chinese and Korean patent offices grant a substantially larger share of domestic inventions than of international applications. While these figures are consistent with the hypothesis that policies to stimulate patenting are supported by less stringent patent granting procedures, in particular for domestic applicants, there may be other reasons for these differences. The composition of the population of inventions at each office may be different for instance. Still, we consider it reasonable to conclude that measuring granted patents instead of filed patents does not resolve the issue of differences in quality of patents or propensity to patent. Taking into account the increased time lag for measuring granted inventions, we conclude that there is no added value of including granted inventions in the Clean Energy Innovation Index.

Table 3 Share of inventions from domestic, international and all applicants granted between 2007-2014 across all SET Plan KAs

Patent office	**Share granted**		
	Domestic applicants	*International applicants*	*All applicants*
European Union	38%	39%	38%
China	74%	65%	73%
Japan	44%	42%	44%
Korea	67%	53%	65%
United States	56%	67%	61%
Rest of World	61%	42%	52%

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

2.4 Conclusions on high level assessment of patent indicators and preselection of indicators to consider for the CEII

Based on the literature review and data assessment in the previous section, we draw preliminary conclusions and preselect a few indicators to consider for inclusion in the clean energy innovation index. The preselected indicators are analysed in depth in the next chapter.

We identified four indicators that can be considered as absolute measures of innovation performance: number of inventions, number of high value inventions, number of international inventions and number of granted inventions. For each of those, a higher value indicates a higher innovation performance, all else being equal. Additionally, two potentially useful indicators were identified that do not measure innovation performance per se, but offer insight into the functioning of the innovation system: patent specialisation and patent collaboration.

Among the four indicators that can be considered absolute measures of innovation performance there is strong variation in the results. Whereas China is dominant when considering the simple number of inventions or the number of granted inventions, other world players such as Japan, Korea, US and the EU lead when considering high value or international inventions. Hence, the selection of indicators strongly affects the view on innovation performance.

The first three indicators (number of inventions, high value inventions, international inventions) 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[19]. However, the

[19] 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.

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 as separate countries (in high value) or included in the EU as one country (in international) results in different results. 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.

The indicator on granted inventions is not an effective way of excluding lower quality patents from the sample. Given that the indicator also suffers from a longer time lag before data is complete, we do not see added value of including granted inventions in the CEII and do not analyse this indicator 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. As mentioned, we consider GDP a better scaling parameter than population because it accounts for differences in economic and innovation productivity per country.

We suggest reporting patent specialisation and patent collaboration as satellite indicators outside of the index to explore trends unaccounted for when considering only absolute invention numbers. Both indicators do not measure innovation performance per se and would therefore obscure the view on innovation performance if included in the CEII. However, we do believe that both indicators provide relevant insights that are not always clear when looking at the other indicators and therefore suggest to report them as satellite indicators, outside of the CEII.

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 preselected for potential 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.

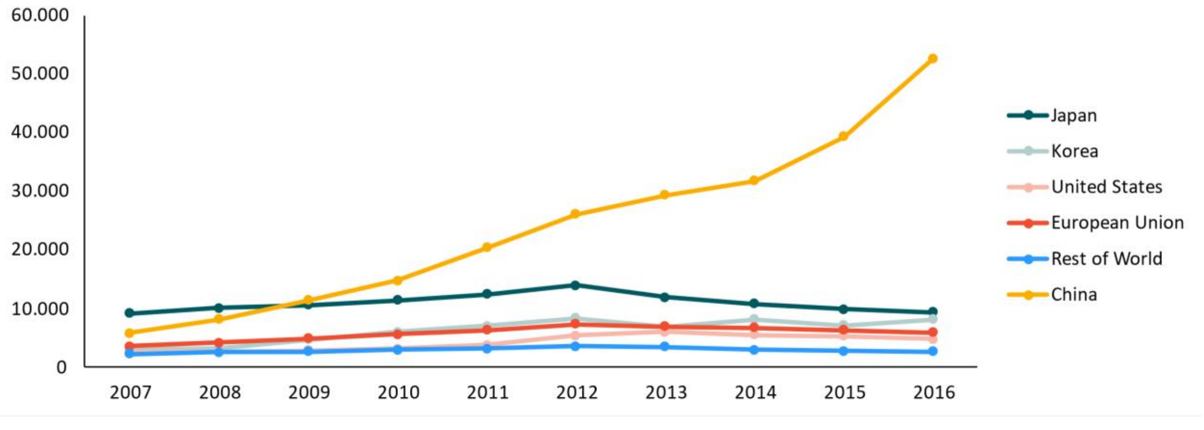
3.1 Main trends and developments

This section provides a high-level understanding of the main trends and developments for the three patent indicators of interest. First, the distribution across the world players for all in-scope technologies is analysed. Secondly, the trends and distribution across the SET Plan KAs is presented. Finally, the performance weighted 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 6 portrays the number of inventions across all SET Plan KAs by the main players in the world, namely Japan, Korea, United States, European Union and China. 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 6 clearly show that China is the dominant player when looking at the total number of inventions (without applying filters) and is extending its lead. In fact, China is the only world player for which the number of inventions exhibits an increasing trend. Hence, the increasing number of inventions within SET Plan KAs reported in the previous chapter can be attributed solely to China's increased patenting.

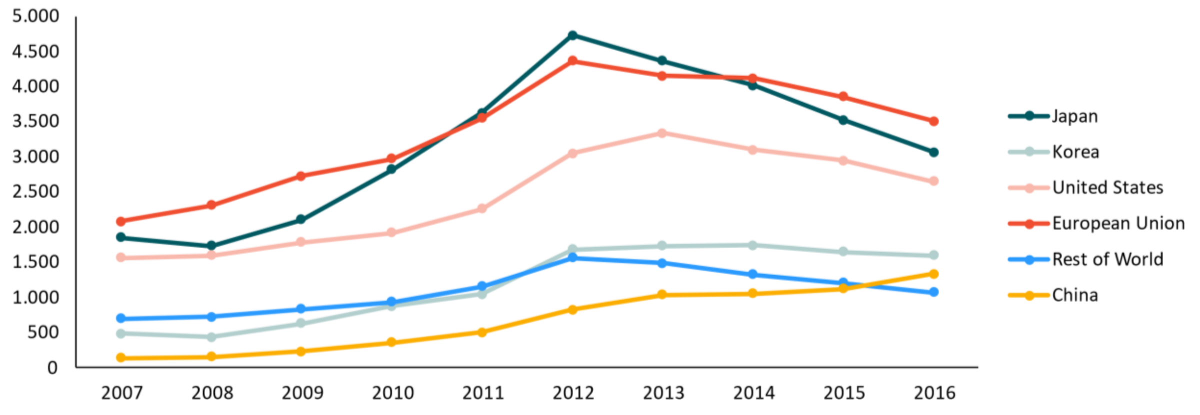
Figure 6 Number of inventions per region across all SET Plan KAs



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

Figure 7 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 has 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 show a leading position for Japan, the EU and US in particular, while Korea also surpasses China. In terms of volume, a similar trend can be observed for most regions, with a peak at around 2012 and slowly declining numbers of high value inventions afterwards.

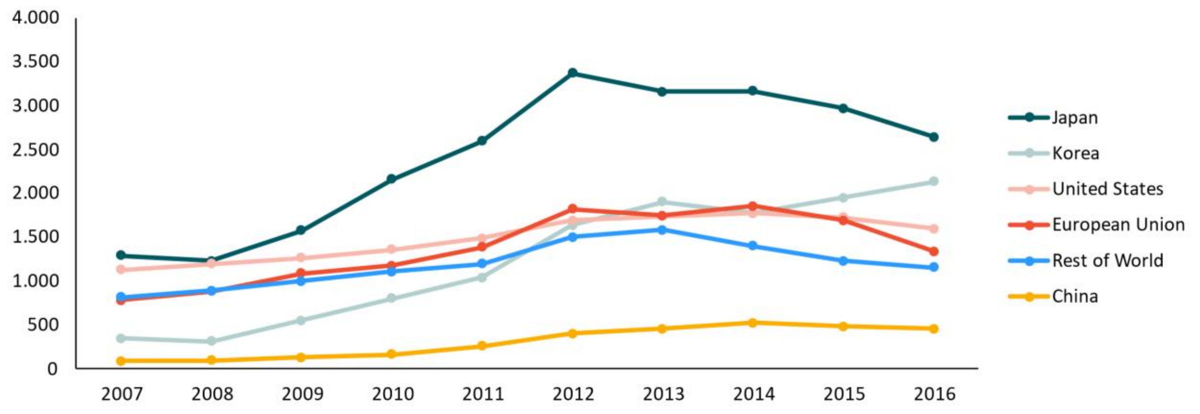
Figure 7 Number of high value inventions per region across all SET Plan KAs



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

Figure 8 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. Korea also shows a strong performance with an increasing number of international inventions during the whole period in scope, while, the numbers of the US, EU and Japan declined after 2014. Similar to high value inventions, China has a relatively low number of international inventions compared to total inventions and ranks lowest of all world players.

Figure 8 Number of international inventions per region across all SET Plan KAs

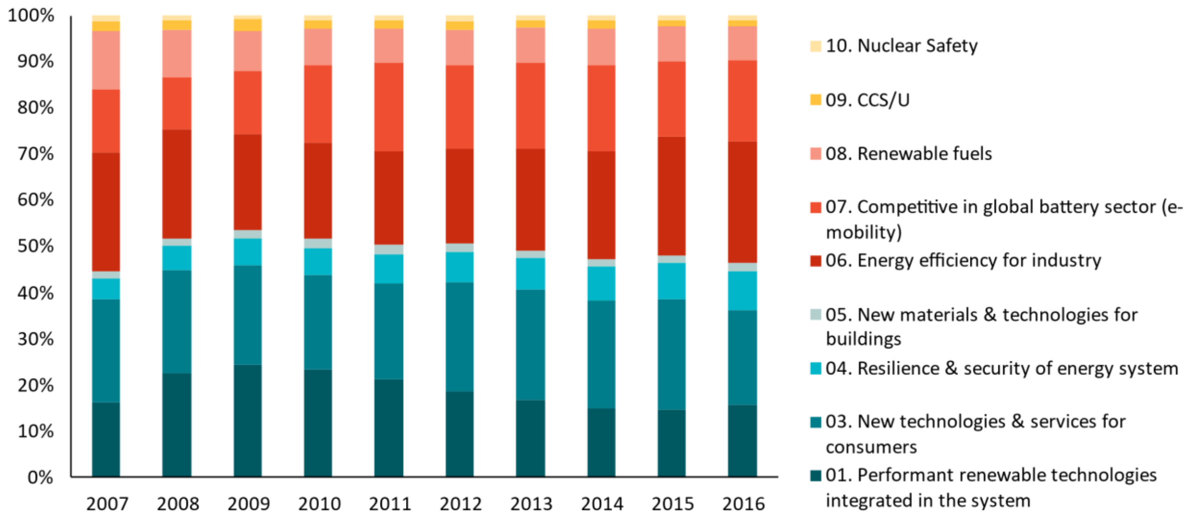


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.1.2 Trends in distribution of patents across SET Plan KAs

Figure 9 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 25% in 2010 to 17% in 2016.

Figure 9 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.

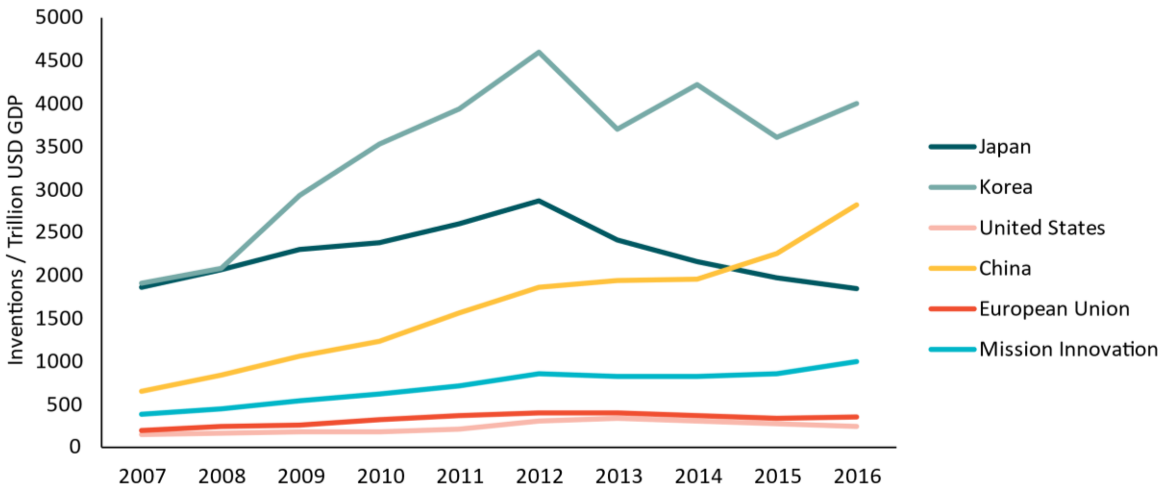
3.1.3 Patent trends normalised by GDP – World players

In this section, the performance of the world players is analysed by weighting the number of inventions by GDP (Trillion USD, PPP adjusted values)[20], thereby creating a better comparable performance metric. Figure 10 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 Korea and Japan have similar invention output per unit of GDP. The increasing trend in China's numbers is still noteworthy, showing strong performance improvement over the past decade. The US and EU, score relatively low on this indicator.

When considering only high value inventions (Figure 11), Korea and Japan show excellent performance compared to the other world players, while China scores particularly low. The EU and US score similar to the average performance of Mission Innovation member countries.

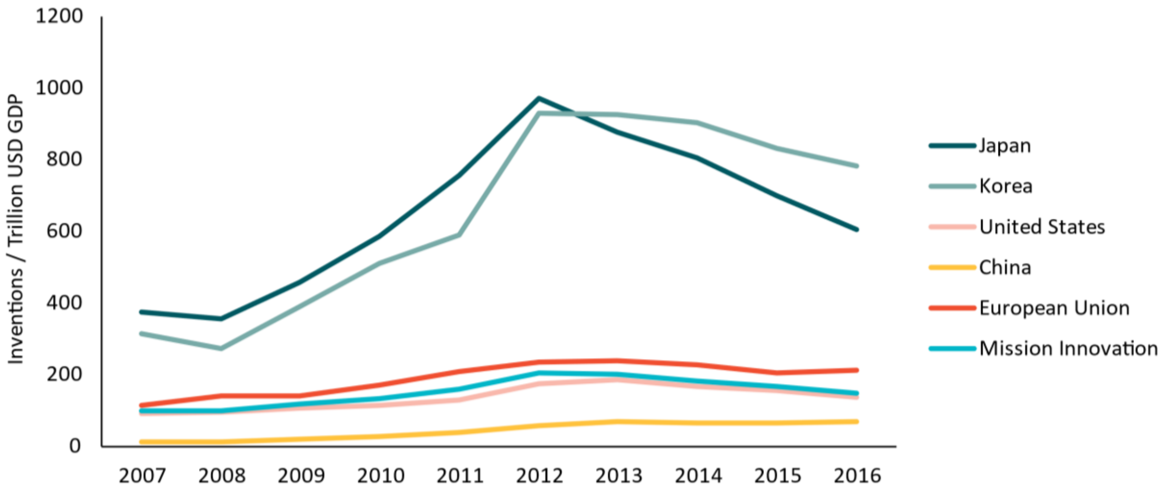
[20] World Bank (2019), Dataset on "GDP, PPP (constant 2017 international $)"; World Bank notes that "PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the U.S. dollar has in the 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 10 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

Figure 11 Number of high value inventions per unit of GDP across all SET Plan KAs

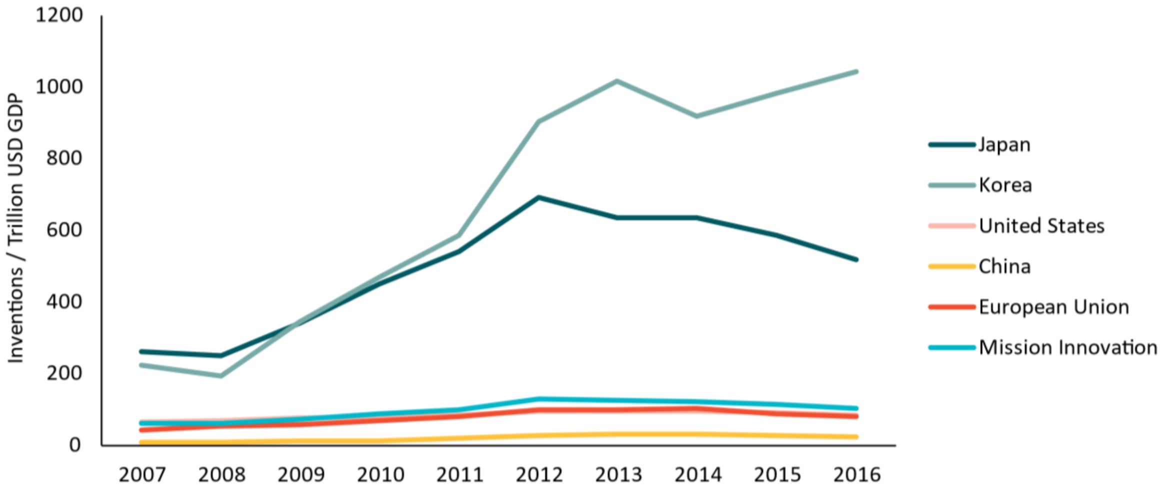


Data source (Inventions): Joint Research Centre (JRC) based on data from the European Patent Office (EPO)
Data source (GDP): World Bank

For international inventions (Figure 12) Korea shows a noteworthy performance, also outperforming Japan by a wide margin over recent years. The gap between the performance of the leading countries (Korea and Japan) and the average performing countries (US[21], EU) is wider than when considering high value inventions. 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[22], since it is more affordable and it has a large market to support the inventions.

21 Note that the US performance is hardly visible in the graph due to it overlapping with the Mission Innovation line in the first years (up to 2010) and with the EU line during the later years (from 2011 onwards)
22 China Power (2020). Are patents indicative of Chinese innovation?

Figure 12 Number of international inventions per unit of GDP across all SET Plan KAs



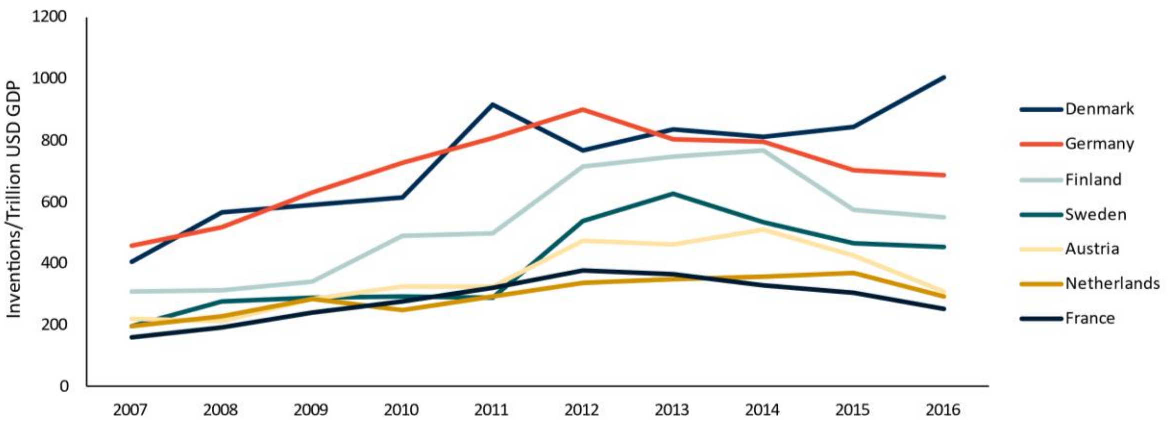
Data source (Inventions): Joint Research Centre (JRC) based on data from the European Patent Office (EPO)
Data source (GDP): World Bank

3.1.4 Patent trends normalised by GDP – EU27

Figure 13 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 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.

Figure 13 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

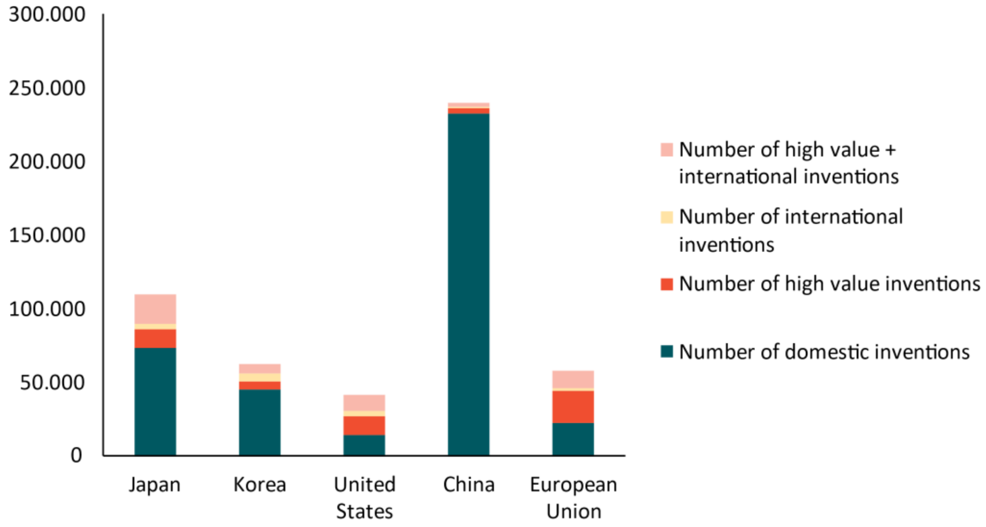
3.2 Patenting strategies per world player and SET plan key action

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 countries have very different strategies towards patenting (see Figure 14 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 14 Number of inventions per world player for all SET Plan KAs, broken down into types of inventions

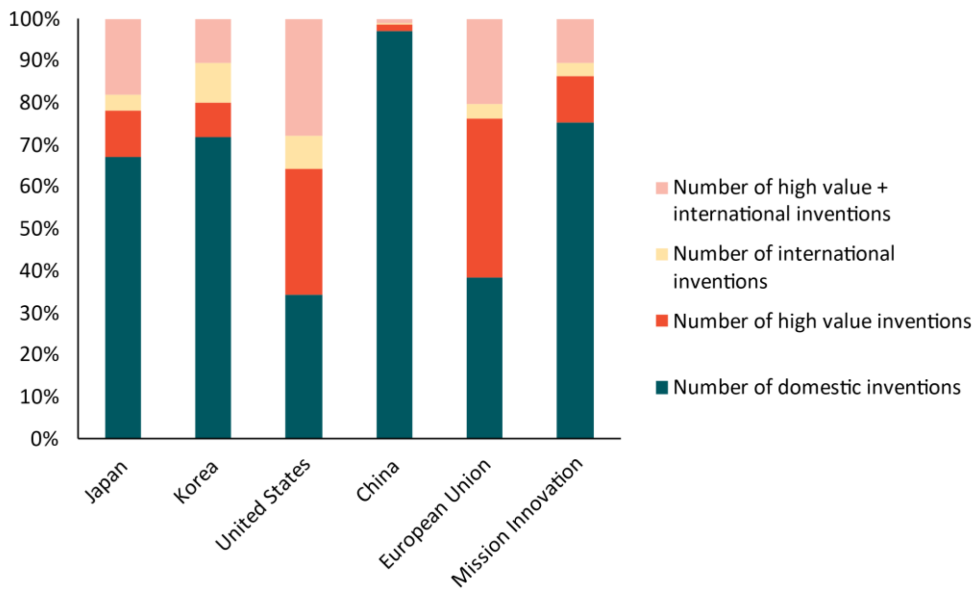


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.2.1 Distribution of invention types per world player

Looking at the distribution of invention types per world player (Figure 15), three distinct strategies can be distinguished. At one end, there is the strategy pursued by China which patents a lot of inventions but generally does not file the patent internationally (97% 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 the strategy pursued by the EU and US for which the majority of inventions are high value and/or international (less than 40% of inventions are domestic). 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 mentioned earlier. The last strategy that can be distinguished is the one employed by Japan and Korea which file significant numbers of patents both domestically and 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 15 Distribution of inventions per type for each world player

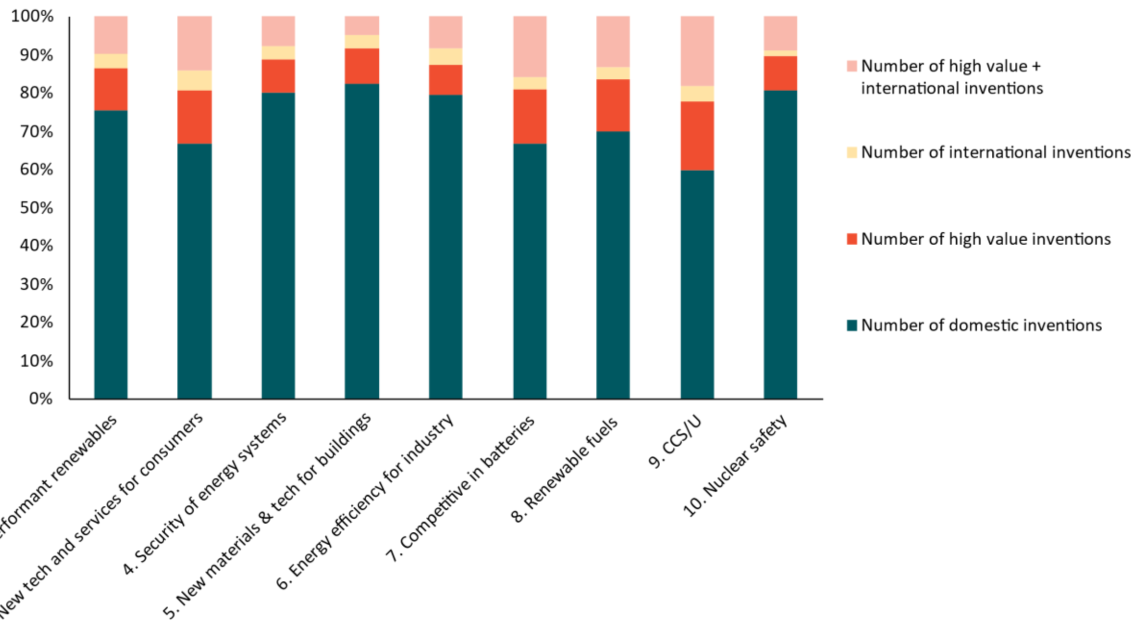


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.2.2 Distribution of invention types per SET Plan KA

The distribution of inventions per SET Plan KA (Figure 16) 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), renewable fuels (#8) 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 16 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)

It is important to note that the distribution of inventions per SET Plan KA is not simply the result of a stronger/weaker position of certain countries. It could for instance be the case that high shares of domestic inventions in specific SET Plan KAs are simply due to the large volumes of domestic inventions (in absolute numbers as well as a share of total inventions) in China. This could be a limitation for this analysis, given that the geographical distribution of inventions per sector is affected by the specific country contexts. However, the specificities of the technological field are also a reason for different patenting strategies. China, for instance, is highly specialised in New technologies and services for consumers (SET Plan KA #3 - see next section), for which it has a relatively large share of high value and international inventions, which is not the case for most of other KAs (for which domestic inventions are dominant in China). On the other hand, Korea, EU and US which are most specialised in Energy efficiency for industry (SET Plan KA #6), also have relatively high shares of high value and international inventions, in which this KA has one of the lowest shares.

3.3 Key developments by SET plan key action

Around 80% of inventions[23] for which patents were filed between 2007-2016 pertained to four of the nine SET Plan KAs[24]:

- 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 include ICT aiming at the reduction of own energy use and Energy efficient lighting technologies, among others;
- Energy efficiency for industry, which include 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;

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

[24] 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).

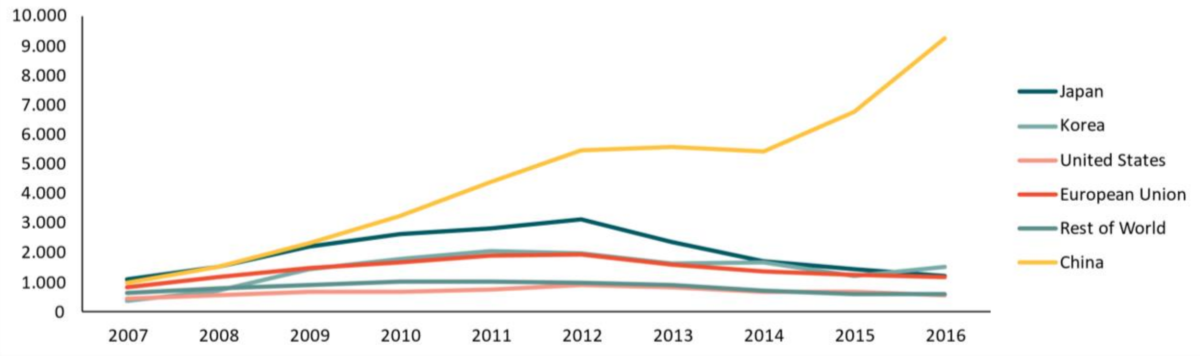
- and the Global battery sector (e-mobility), which includes battery technologies and electric vehicle charging technologies.

These SET Plan KAs are analysed in detail below, discussing the distribution of inventions across countries, country specialisation levels 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 SET Plan KA 1 'Performant renewable technologies' depend highly on the indicator selected. Considering the total number of inventions (Figure 17), China has become the dominant player with sharply increasing number of inventions in the most recent years, while the number of inventions for other world players remained stable or declined.

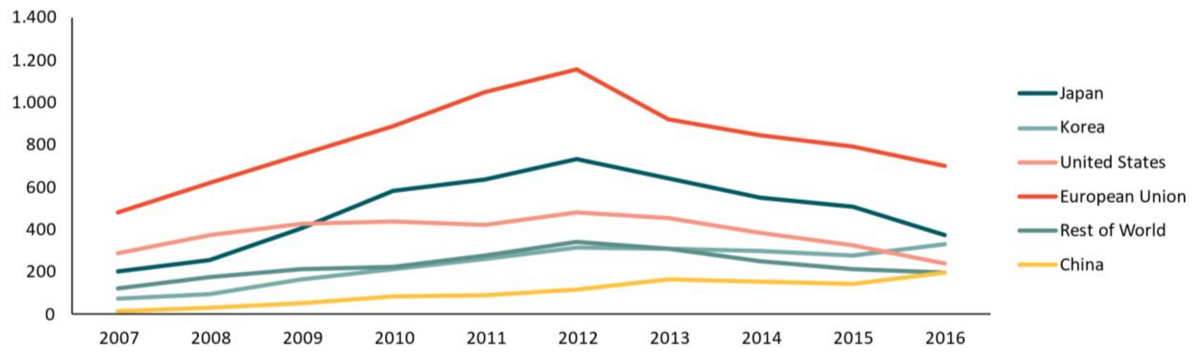
Figure 17 Number of inventions per world player for SET Plan KA 1. Performant renewables



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

Considering only high value inventions (Figure 18), a totally different picture emerges with the EU leading the field and China ranking lowest. The increasing numbers for China and declining numbers for most other world players is similar though, except for Korea which shows an increasing trend over the full time period.

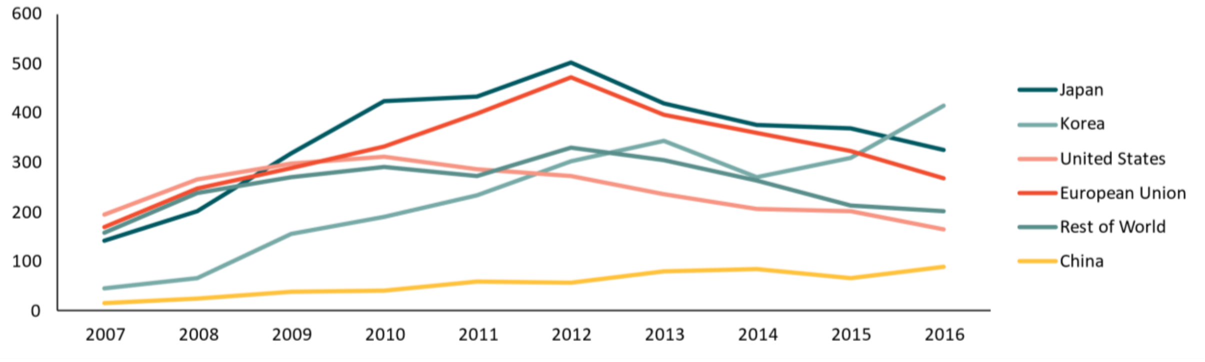
Figure 18 Number of high value inventions per world player for SET Plan KA 1. Performant renewables



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

Considering only international inventions (Figure 19), a more mixed picture emerges with Japan, the EU and the US leading initially (2007-2009) after which the US lost its lead position around 2010/2011 and Korea caught up with the leading world players in 2015/2016.

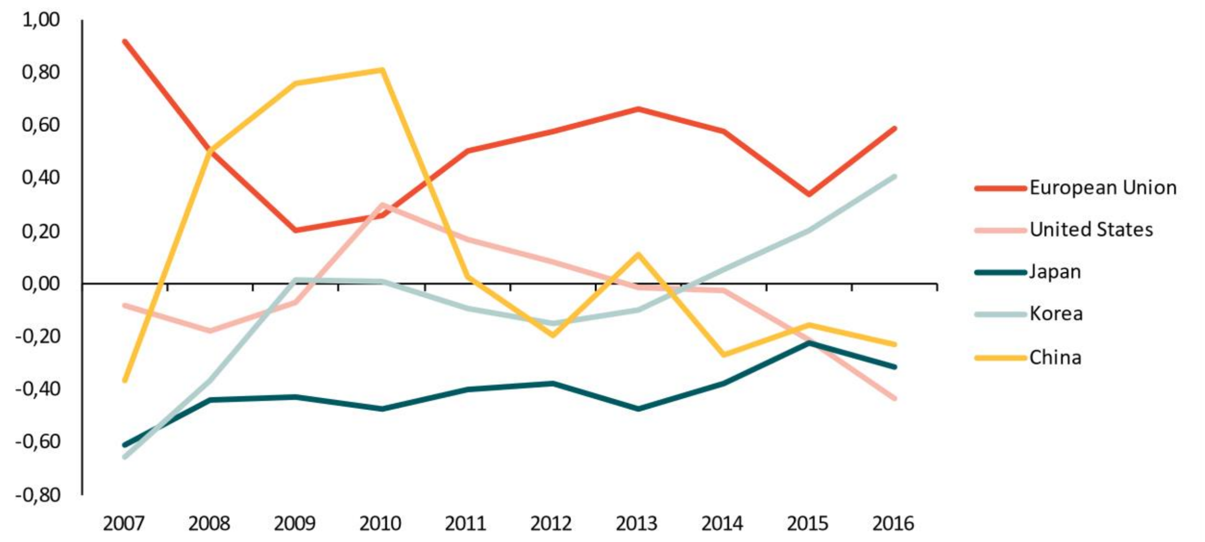
Figure 19 Number of international inventions per world player for SET Plan KA 1. Performant renewables



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

The development of patent specialisation levels for renewable energy technologies (Figure 20) shows that the EU maintained a high specialisation in renewables over the past decade whereas Japan had the lowest specialisation on renewables. Hence, the high share of Japan on (international) inventions on renewables Japan is a result of its strong aggregate performance across all SET Plan KAs, rather than specialisation in this specific action. Further noteworthy developments in terms of specialisation are that the US was not particularly specialised in renewables even in the years before 2010 when it was one of the leading world players. China showed a strong peak in renewables specialisation from 2008 to 2010, which coincides with the years when renewables deployment in Europe increased strongly and the Chinese companies were quick to capture market share in this growing market. Their efforts to develop a competitive industry can be clearly seen in this graph.

Figure 20 Patent specialisation per region for the SET Plan KA 1. Performant Renewables



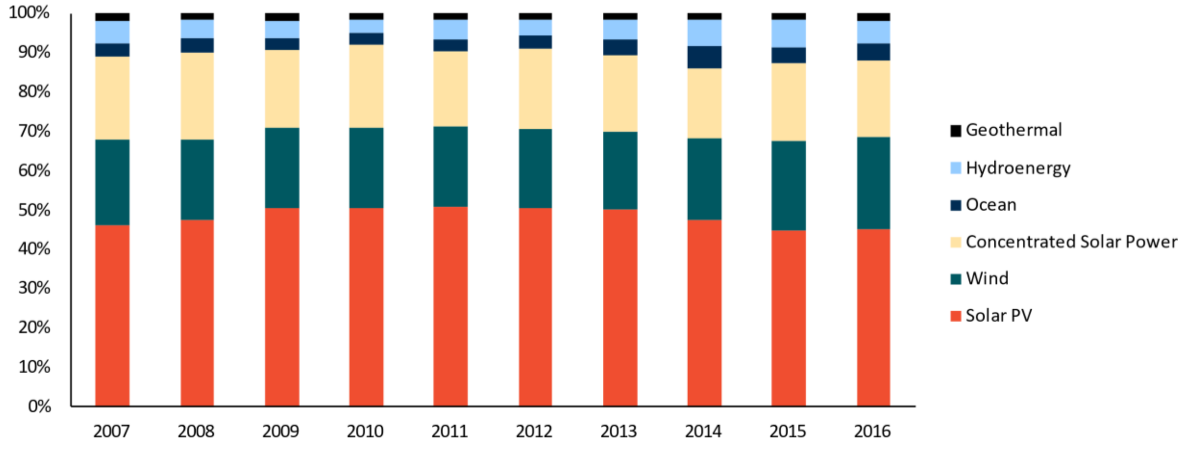
Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

The global distribution of inventions per technology under this SET Plan KA (Figure 21) shows that most inventions concern solar PV technology, which accounts for approximately 50% of the inventions, followed by wind (20-25%) and concentrated solar power (+/-20%). The remaining 10-15% of inventions are distributed across ocean, hydro 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 remained steady since 2010, fluctuating between 10,000 and 15,000 inventions per year, indicating that innovation continued even though renewables technologies have 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 21 Distribution of inventions per technology for SET Plan KA 1. Performant renewables

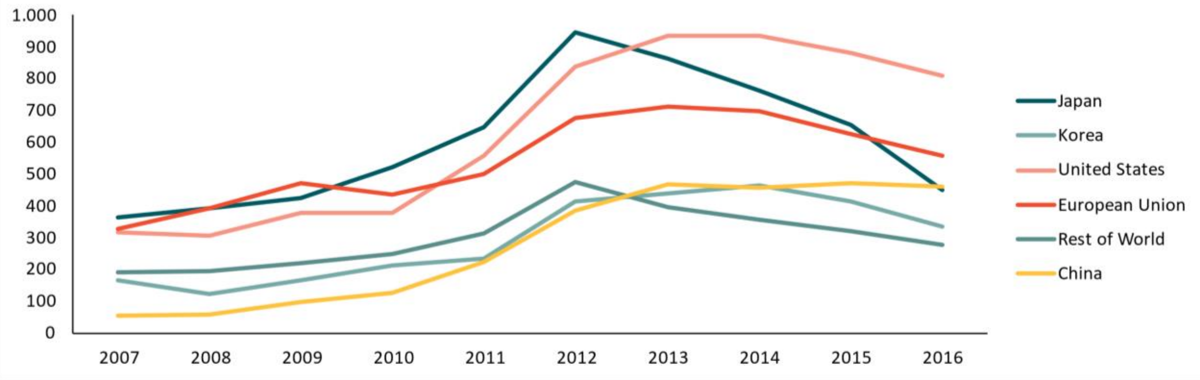


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3.2 New technologies & services for consumers

For SET Plan 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 22), a more mixed picture emerges with strong performance of Japan and the US in particular, while China scores relatively well for this SET Plan KA, compared to its relatively lower performance on high value inventions for most SET Plan KAs.

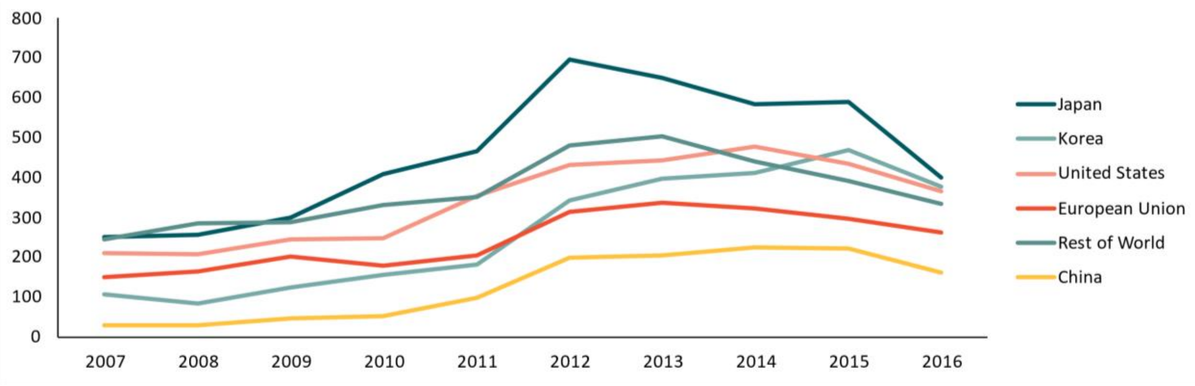
Figure 22 Number of high value inventions per world player for SET Plan KA 3. New technologies & services for consumers



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 23) show a particularly strong performance of Japan, with Korea also ranking much higher than on the other indicators. Furthermore, a relatively high share of international inventions are 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, compared to less than 10% on average across all SET Plan KAs, showing that the inventive activity for 'New technologies and services for consumers' are more distributed across the world.

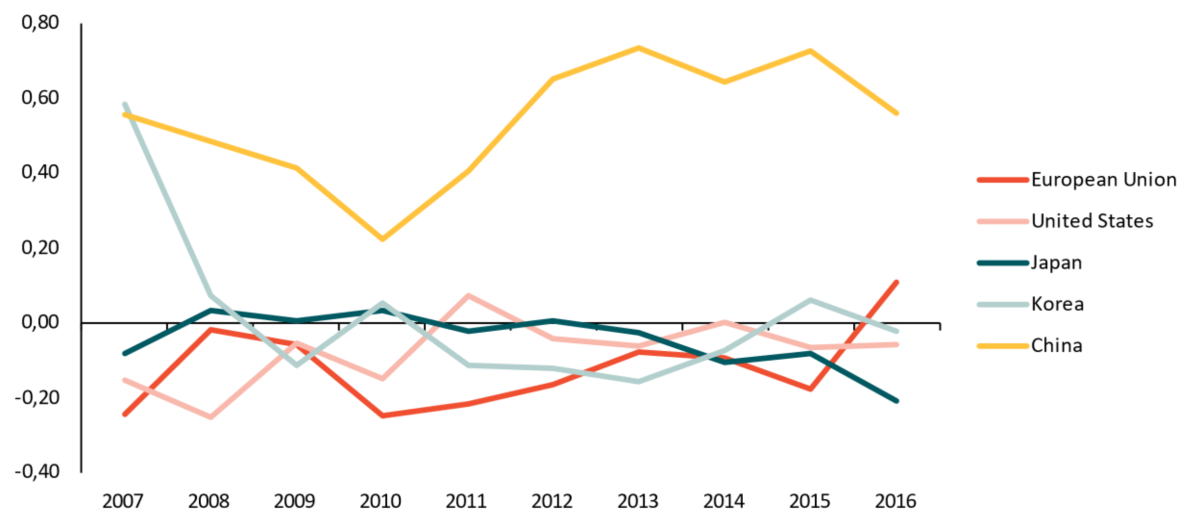
Figure 23 Number of international inventions per world player for SET Plan KA 3. New technologies & services for consumers



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

Among the world players, only China specialises in this particular SET Plan KA (see Figure 24), this sectoral performance being consistent with the relatively strong performance of China on high value inventions.

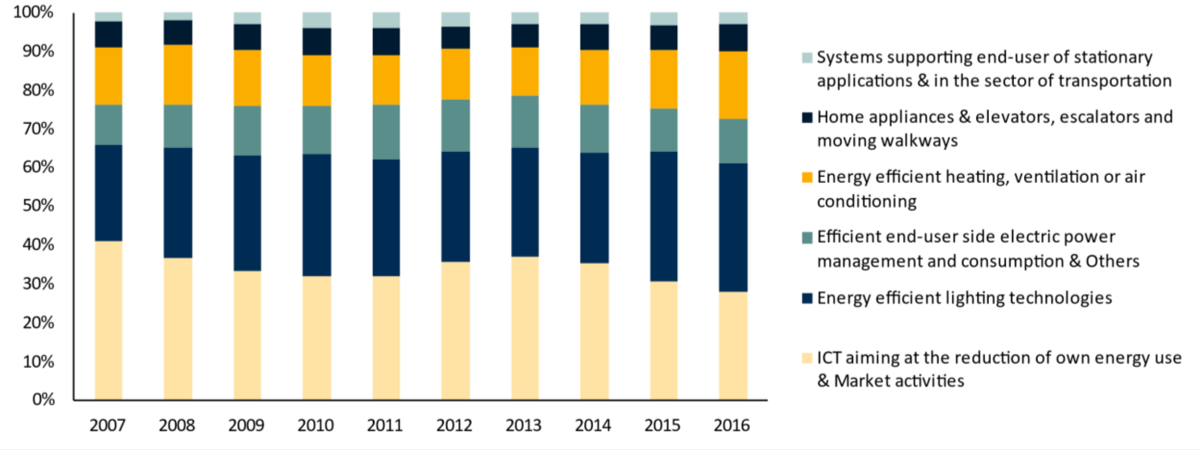
Figure 24 Patent specialisation per region for the SET Plan KA 3. New Technologies and Services for Consumers



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

Figure 25 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 approximately 50% of the high value and international inventions under this SET Plan KA.

Figure 25 Distribution of inventions per technology for SET Plan KA 3. New Technologies and Services for Consumers

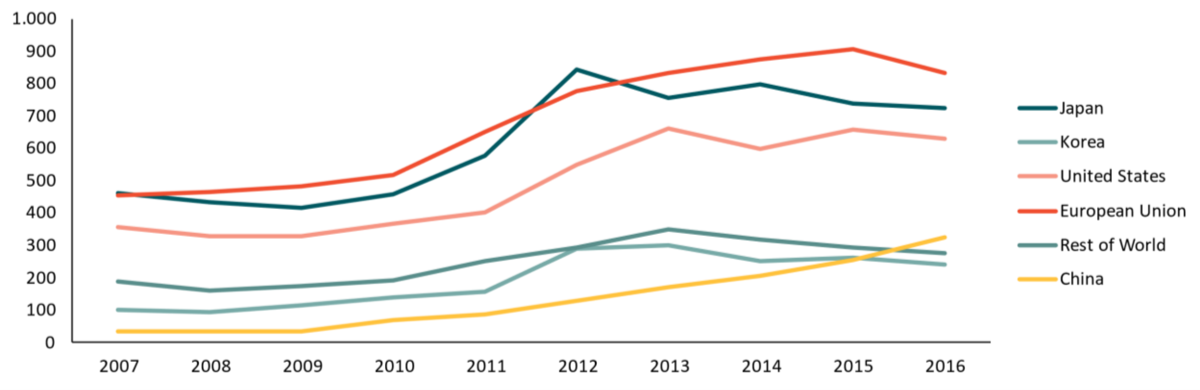


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3.3 Energy efficiency for industry

For SET Plan KA 6. 'Energy efficiency for industry', China also dominates the total number of inventions, accounting for 60-70% of global inventions per year from 2013 onwards. Considering only high value inventions (Figure 26) the EU and Japan are leading, with the US closely behind. China is rapidly catching up in recent years, already overtaking Korea.

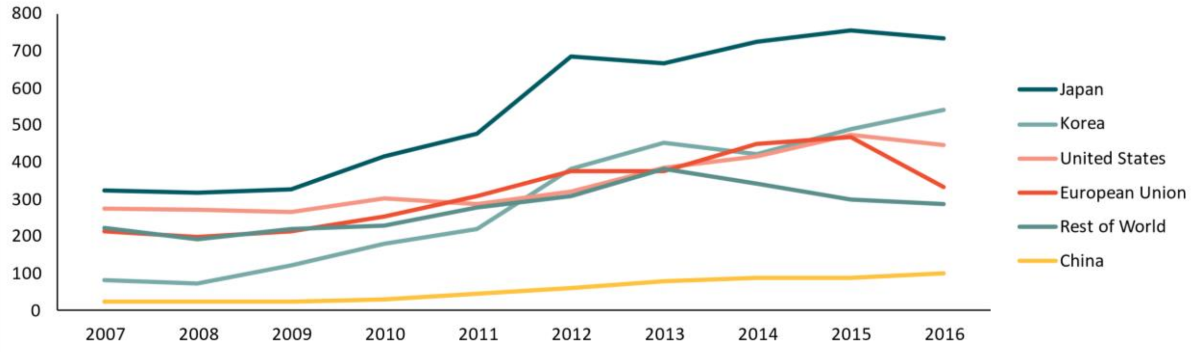
Figure 26 Number of high value inventions per world player for SET Plan KA 6. Energy efficiency for industry



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

When considering only international inventions (Figure 27), Japan has the strongest position, with Korea, the US and the EU following at a distance.

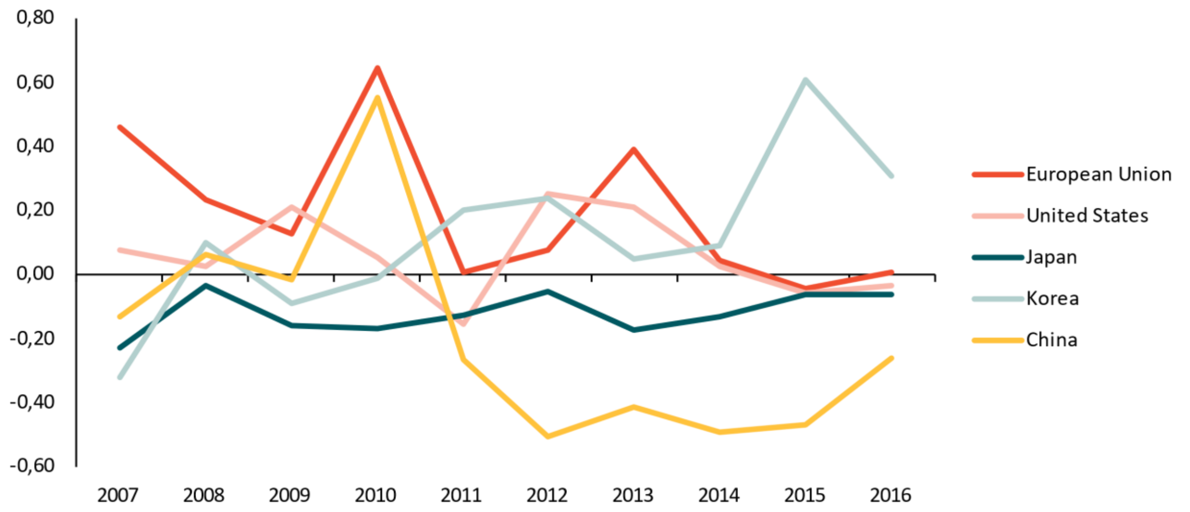
Figure 27 Number of international inventions per world player for SET Plan KA 6. Energy efficiency for industry



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

Korea is the most specialised world player within this SET Plan KA, whereas the EU reduced its initial specialisation in this field to an average level (see Figure 28).

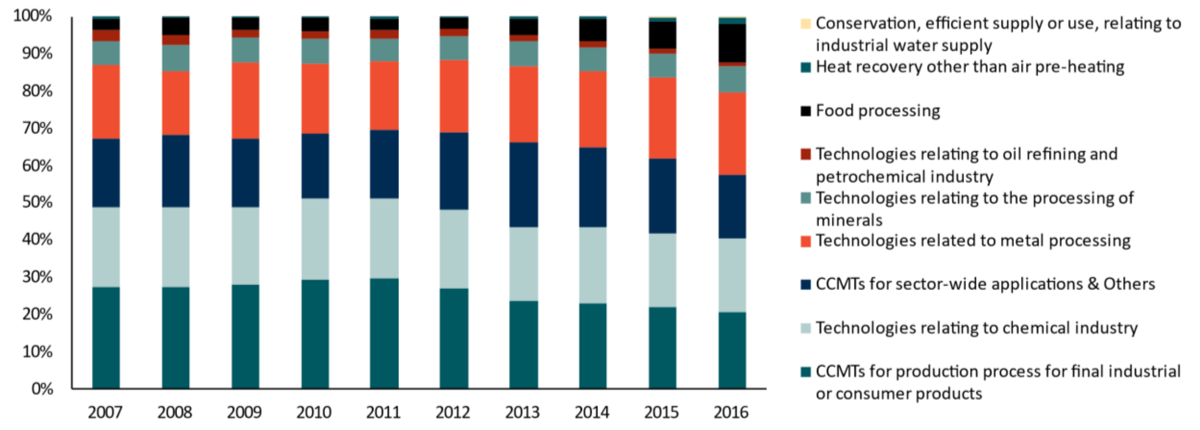
Figure 28 Patent specialisation per region for the SET Plan KA 6. Energy Efficiency for Industry



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 29) 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, CCMTs for sector-wide applications, technologies related to chemicals and technologies related to metal processing.

Figure 29 Distribution of inventions per technology for SET Plan KA 6. Energy efficiency for industry

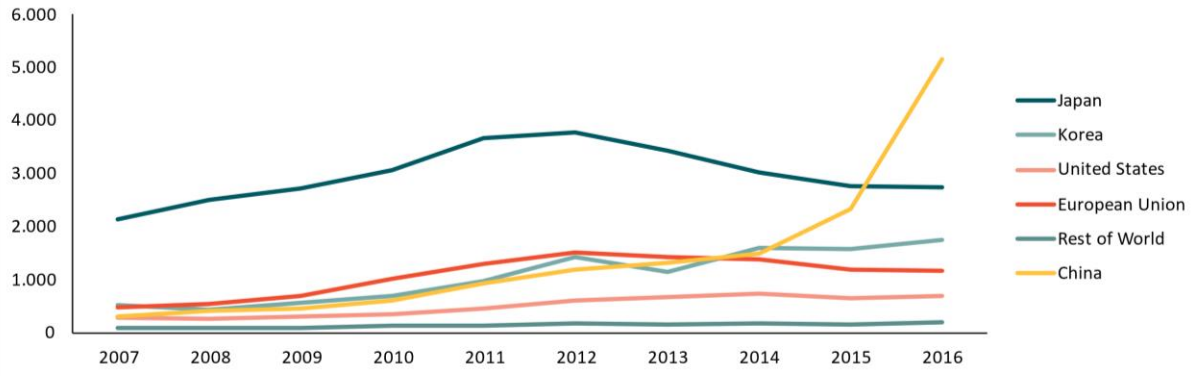


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.3.4 Competitive in the global battery sector

For SET Plan KA 7. 'Competitive in the global battery sector (e-mobility)', the total number of inventions (Figure 30) shows a different picture then 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.

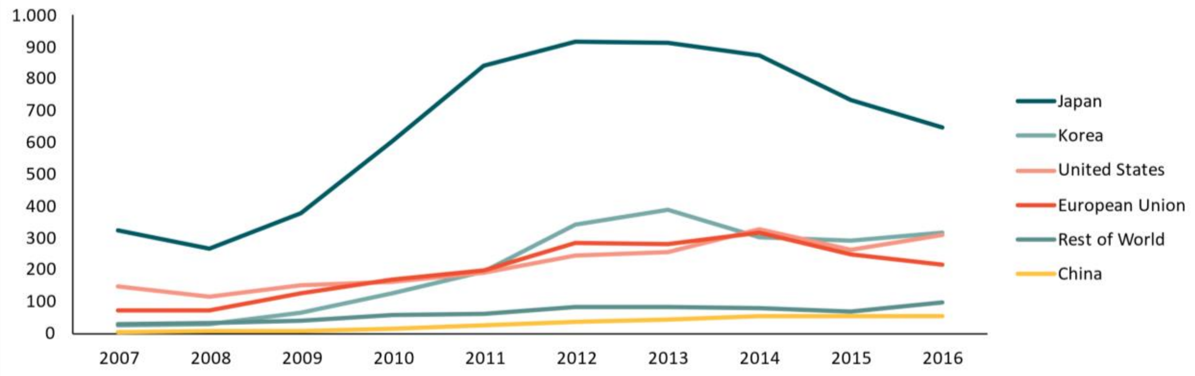
Figure 30 Number of inventions per world player for SET Plan KA 7. Competitive in the global battery sector (e-mobility)



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 31). For both indicators, Japan has the most inventions by a wide margin, accounting for 30-50% of high value/international inventions for each year.

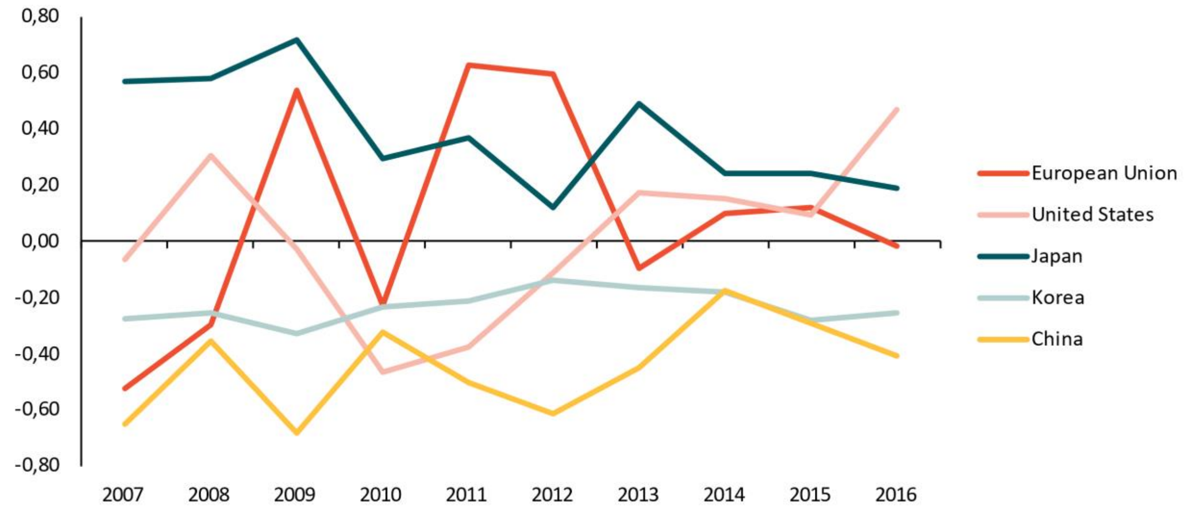
Figure 31 Number of international inventions per world player for SET Plan KA 7. Competitive in the global battery sector (e-mobility)



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

Specialisation in the battery sector remains particularly high for Japan across the full time period, with more intermittent specialisation for the EU and gradually increasing specialisation for the US (see Figure 32).

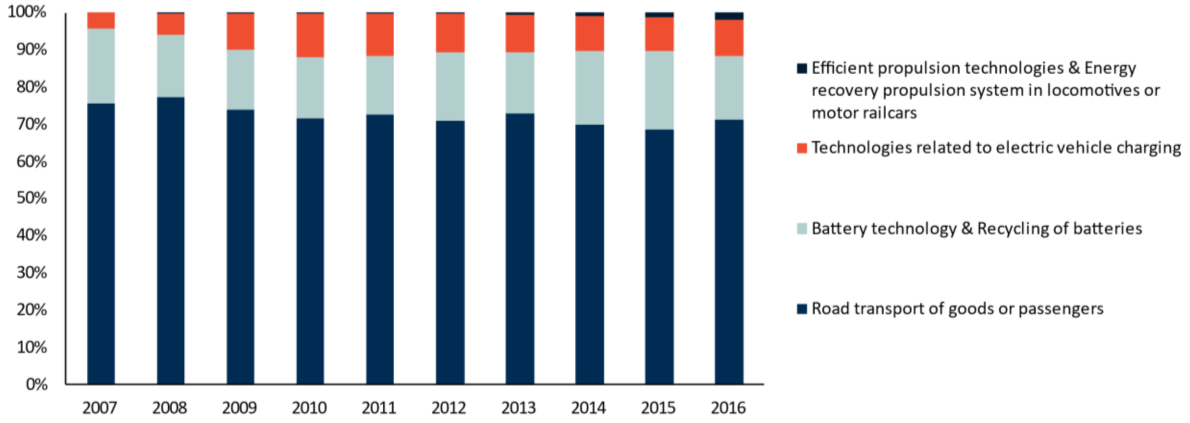
Figure 32 Patent specialisation per region for the SET Plan KA 7. Competitive in the global battery sector (e-mobility)



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

Within this SET Plan KA category, most of the inventions pertain to road transport technologies, which accounts for approximately 70% of all inventions in this SET Plan KA (Figure 33), with similar shares for high value and international inventions. Most of the remainder of the inventions related to the battery sector relate to either battery technology and recycling of batteries, or to electric vehicle charging.

Figure 33 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 SET Plan KAs are responsible for approximately 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 7-9% of the global inventions each (see Table 4). Key technologies within 'Resilience and security of the energy system' are enabler technologies for GHG emission mitigation. 'Renewable fuels' includes technologies such as fuel cells, biofuels and hydrogen technologies. The remaining SET Plan KAs are 5. 'New materials and technologies for buildings', 9. 'CCS/U' and 10. 'Nuclear safety', which capture less than 3% of the global inventions each, which corresponds to a total of 80-150 inventions annually.

Table 4 Overview of key features of other SET Plan KAs

SET Plan KA	Share of inventions[25] (2007-2016)	Key technologies	Most active world players
4. Resilience & security of energy system	7-9%	GHG emission mitigation enabler technologies	China (total inventions) EU (high value inventions) Japan (international inventions)
8. Renewable fuels	7-9%	Fuel cells Biofuels Other hydrogen technologies	China (total inventions) EU (high value inventions) Japan (international inventions)
5. New materials and technologies for buildings	2-3%	Integration of renewables in buildings	China (total inventions) EU (high value inventions)

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

			Korea (international inventions)
9. CCS/U	1-2%	N/A	China (total inventions) EU (high value inventions) US (international inventions)
10. Nuclear Safety	1%	N/A	China (total inventions) US (high value inventions) US (international inventions)

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

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 Korea (KR). Additionally, the patenting activity of the group of countries that are members of Mission Innovation (MI) are analysed.[26] We provide insights into the specialisation per region below, using the internal distribution of their inventions on the different SET Plan KAs. We also discuss the trends and developments per world player individually.

Table 5 (total inventions), Table 6 (high value inventions) and Table 7 (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 2016. While the overall pattern appears similar, with most inventions for SET Plan KA 1, 3, 6 and 7, there are some interesting differences. Firstly, for both SET Plan KA 3. 'New technologies and services for consumers' and SET Plan KA 7. 'Competitive in the global battery sector' the share of high value and international inventions is much higher than the share of total inventions, indicating that companies seek international patent protection for these products in particular. The opposite is true for SET Plan KA 4. 'Resilience and security of the energy system' and to some extent for SET Plan KA 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.

Comparing countries and regions, several observations already made earlier are confirmed such as the strong focus of Japan on the battery sector and the focus of the EU on renewables. Other insights are the lack of focus of China on batteries and renewable fuels, and the relatively high focus of the US on new technologies and services for consumers and carbon capture and storage/utilisation. In the following sections we discuss the trends for each world player in more detail.

[26] This includes most of the world players, except for part of the EU, and includes approximately 10 additional countries.

Table 5 Distribution of total inventions per SET Plan KA for each world player (2007-2016)

Actions	US	CN	JP	KR	EU	MI	*Global*
01. Performant renewable technologies integrated in the system	16%	19%	18%	23%	25%	19%	20%
03. New technologies & services for consumers	29%	17%	14%	18%	15%	17%	17%
04. Resilience & security of energy system	7%	12%	8%	6%	7%	9%	9%
05. New materials & technologies for buildings	2%	4%	2%	2%	4%	3%	3%
06. Energy efficiency for industry	20%	35%	21%	20%	18%	26%	27%
07. Competitive in global battery sector (e-mobility)	12%	6%	27%	17%	19%	15%	13%
08. Renewable fuels	10%	6%	7%	10%	11%	7%	7%
09. CCS/U	2%	1%	1%	1%	2%	1%	1%
10. Nuclear Safety	1%	1%	2%	2%	1%	3%	2%

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

Table 6 Distribution of high value inventions per SET Plan KA for each world player (2007-2016)

Actions	US	CN	JP	KR	EU	MI	*Global*
01. Performant renewable technologies integrated in the system	16%	16%	15%	20%	24%	17%	19%
03. New technologies & services for consumers	26%	42%	19%	25%	16%	21%	22%
04. Resilience & security of energy system	7%	6%	7%	4%	7%	6%	7%
05. New materials & technologies for buildings	2%	2%	1%	1%	3%	2%	2%
06. Energy efficiency for industry	20%	20%	19%	16%	20%	18%	20%
07. Competitive in global battery sector (e-mobility)	14%	10%	28%	22%	16%	20%	18%
08. Renewable fuels	10%	3%	8%	9%	10%	9%	9%
09. CCS/U	3%	1%	1%	1%	2%	2%	2%
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 7 Distribution of international inventions per SET Plan KA for each world player (2007-2016)

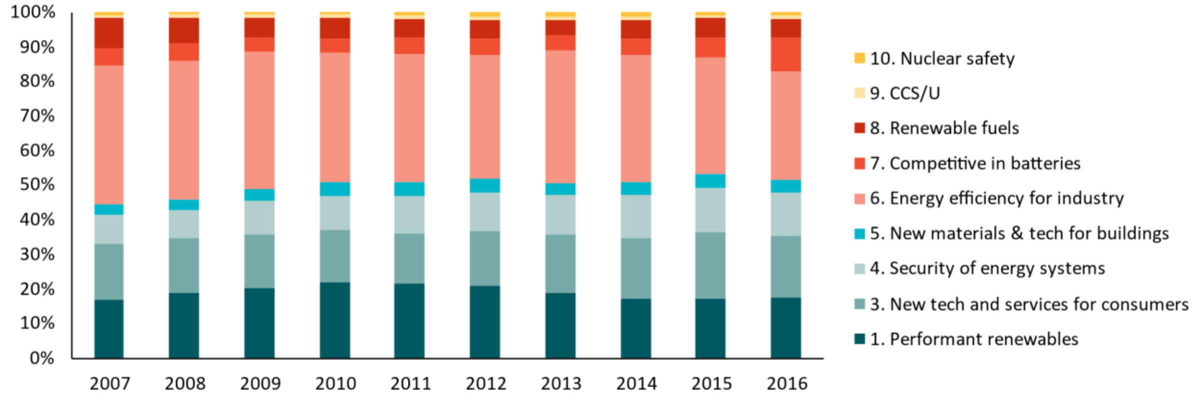
Actions	US	CN	JP	KR	EU	MI	*Global*
01. Performant renewable technologies integrated in the system	16%	18%	15%	19%	24%	16%	18%
03. New technologies & services for consumers	23%	42%	19%	21%	18%	20%	22%
04. Resilience & security of energy system	7%	6%	7%	8%	6%	6%	7%
05. New materials & technologies for buildings	2%	1%	1%	2%	2%	2%	2%
06. Energy efficiency for industry	23%	18%	22%	24%	23%	20%	23%
07. Competitive in global battery sector (e-mobility)	14%	10%	27%	17%	14%	19%	17%
08. Renewable fuels	10%	3%	7%	7%	10%	8%	8%
09. CCS/U	3%	1%	1%	1%	2%	2%	2%
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

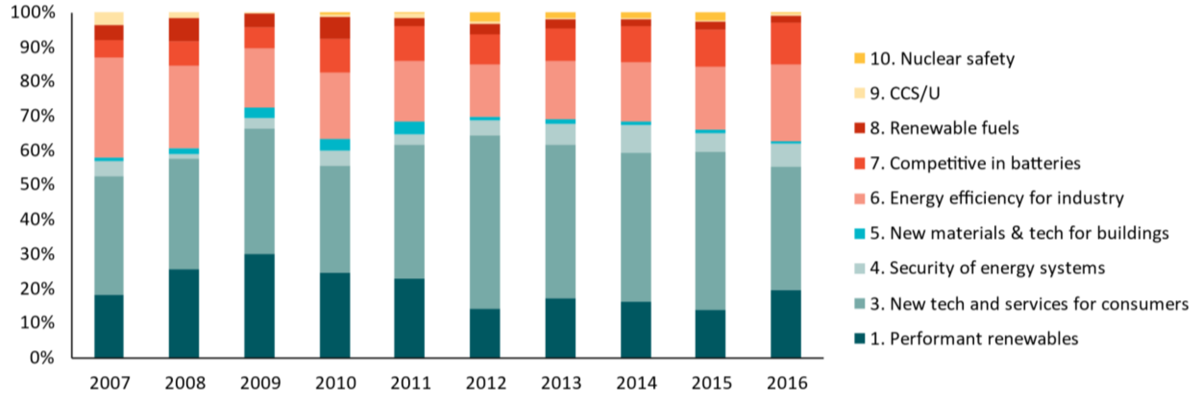
China experienced a significant increase in patenting activity for SET Plan KAs, growing its total number of inventions from 6,000 per year in 2007 to more 50,000 per year in 2016. Similar increases can be observed for high value inventions (130 to 1,300) and international inventions (85 to 450). China's distribution of total inventions across SET Plan KAs (Figure 34) is markedly different from international inventions (Figure 35) and high value inventions (graph not shown – similar to international inventions). For total inventions, SET Plan KA 6. 'Energy efficiency for industry' and 4. 'Security of energy systems' account 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'.

Figure 34 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 35 Distribution of international inventions across SET Plan KAs – China



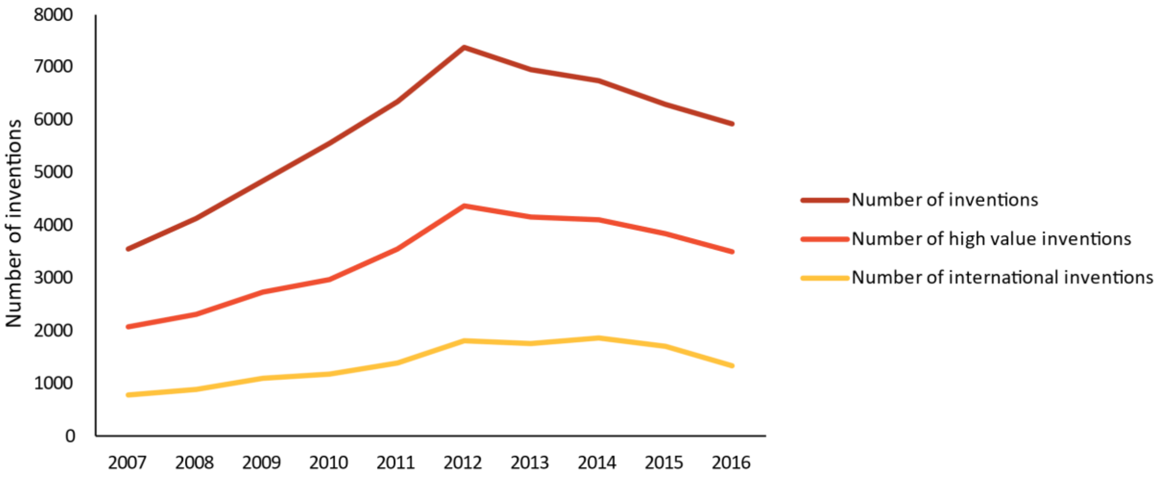
Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.2 European Union

The EU experienced strongly increasing patenting activity in SET Plan KAs from 2007 to 2012 with total inventions growing from 3,500 inventions to more than 7,000 (see

Figure 36). From 2012 to 2016 a slight decrease can be observed to approximately 6,000 inventions per year in 2015 and 2016. A similar pattern can be observed for high value inventions and to a lesser extent international inventions.

Figure 36 Total inventions by the European Union across all SET Plan KAs

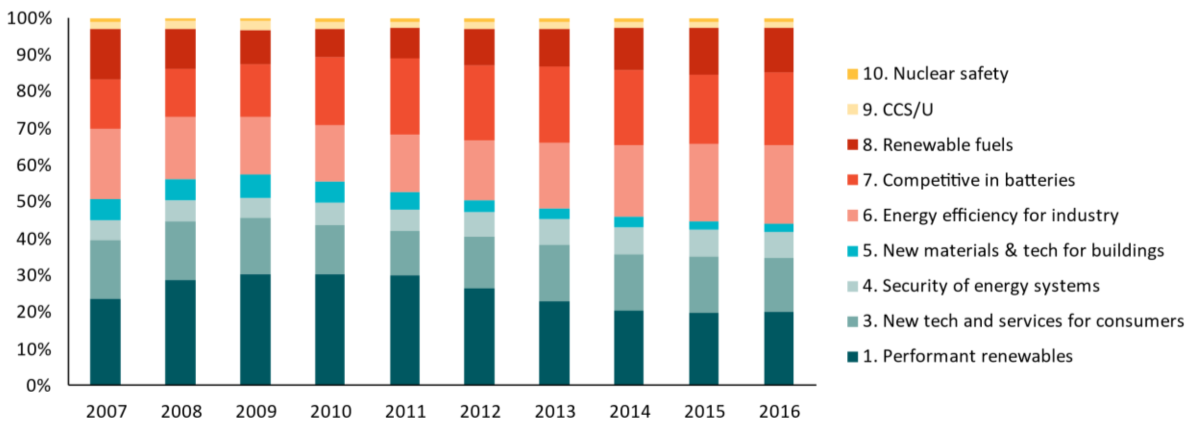


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

Compared to other regions, the EU has a strong focus on SET Plan KA 1. 'Performant renewables' with up to 30% of its total inventions and international inventions related to this action in the top years (see Figure 37 and Figure 38)[27]. Wind and Solar PV are the technologies with the largest number of inventions within this action, however the interest in the latter has decreased steadily since 2012. Furthermore, also for the EU a declining focus on performant renewable can be observed, down to 20% of total inventions in 2016.

Similarly, the EU dedicates a larger share of its inventions to SET Plan KA 8. 'Renewable fuels' than the global average. From the approximately 10% of the region's inventions that are for Renewable fuels, the largest interest is on Biofuels & fuel from waste. Within the same action, interest in Hydrogen technology & Application to transportation has grown rapidly over the last years, with almost three times the number of inventions in 2015 than in 2007.

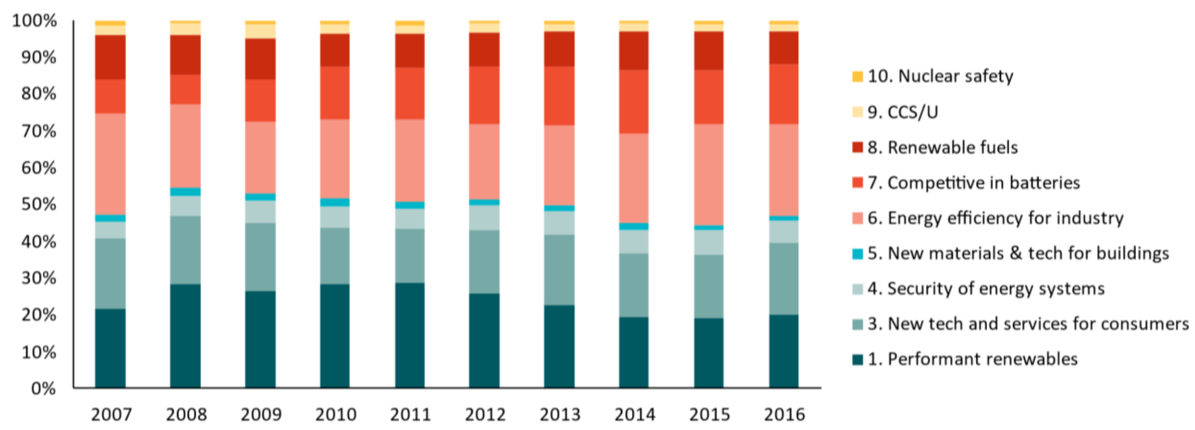
Figure 37 Distribution of total inventions across SET Plan KAs – European Union



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

27 The same applies for high value inventions.

Figure 38 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)

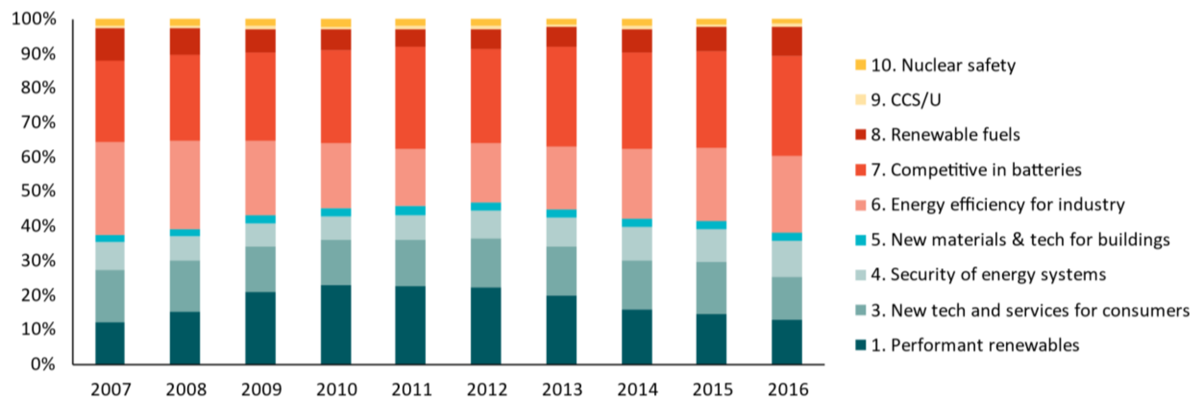
3.4.3 Japan

Japan had relatively stable patenting activity in terms of total number of inventions, with values fluctuating around 10,000 inventions per year for the full time period (2007-2016). Both high value inventions (1,800 to 3,000) and international inventions (1,300 to 2,600) increased significantly between 2007 and 2016. For all three indicators a slight peak took place in 2012.

As mentioned earlier, Japan has a very strong focus on SET Plan KA 7. 'Competitive in global battery sector' (see Figure 39 and Figure 40). With 25-30% 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 'Road transport of goods and passengers', followed by 'Battery technology & Recycling of batteries'.

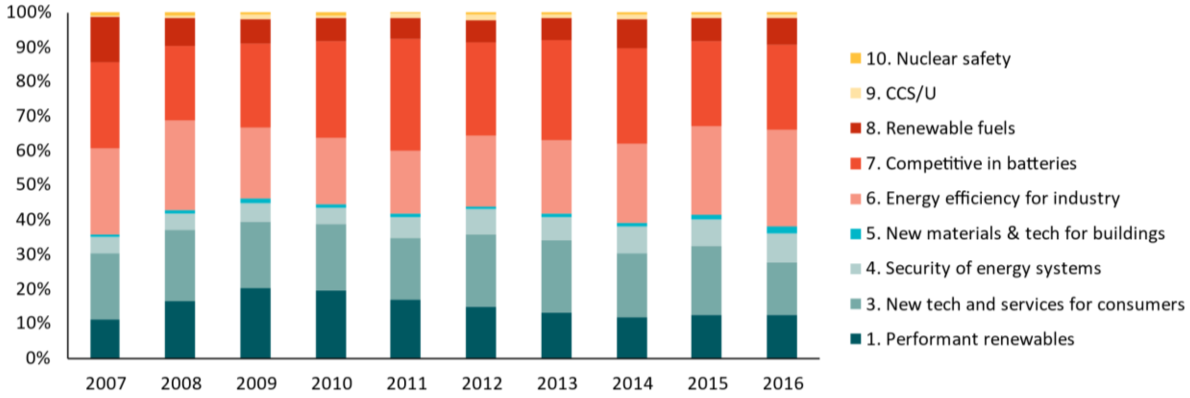
In contrast, when compared to other world players Japan had the least focus on SET Plan KA 1. 'Performant renewables', with only 15% of its inventions dedicated to this action. Despite this, Japan had significant patenting activity in Solar PV, which accounted for almost 70% of its inventions under this action.

Figure 39 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 40 Distribution of international inventions across SET Plan KAs – Japan



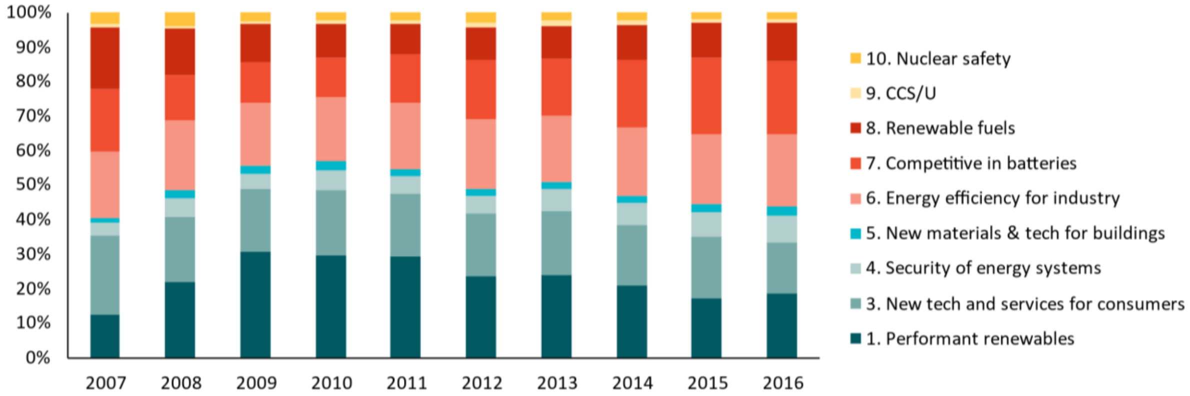
Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.4 Korea

Korea increased its patenting activity for SET Plan KAs considerably over the 2007 – 2016 time period, with a particularly sharp increase from 2007 to 2010 when the total number of inventions doubled from less than 3,000 to more than 6,000. Afterwards, the total number of inventions increased further to over 8,000 in 2016. A similar pattern can be observed for high value inventions (500 in 2007 to 1,500+ in 2016). For international inventions the increase is even more dramatic, growing from 350 in 2007 to more than 2,000 in 2016.

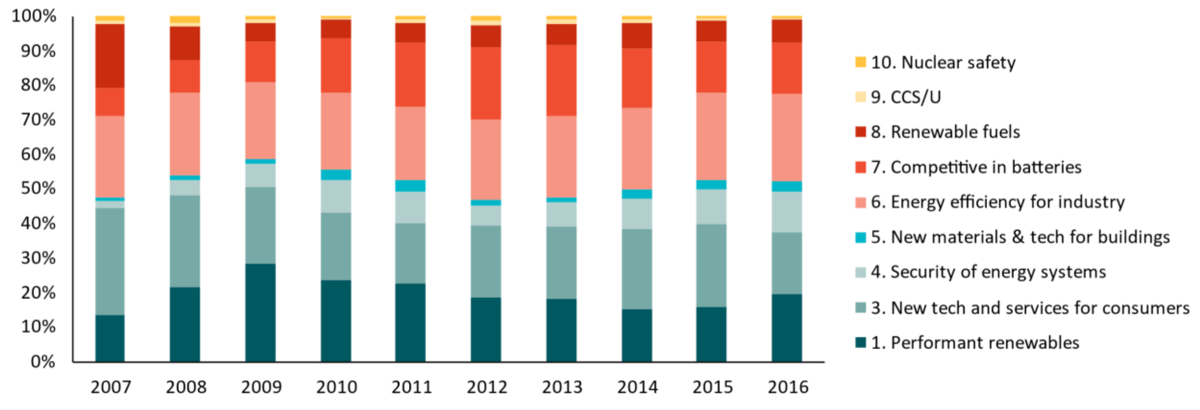
Korea's focus on specific SET Plan KAs fluctuated over time, without any clear trends emerging (Figure 41 and Figure 42).

Figure 41 Distribution of total inventions across SET Plan KAs – Korea



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

Figure 42 Distribution of international inventions across SET Plan KAs – Korea

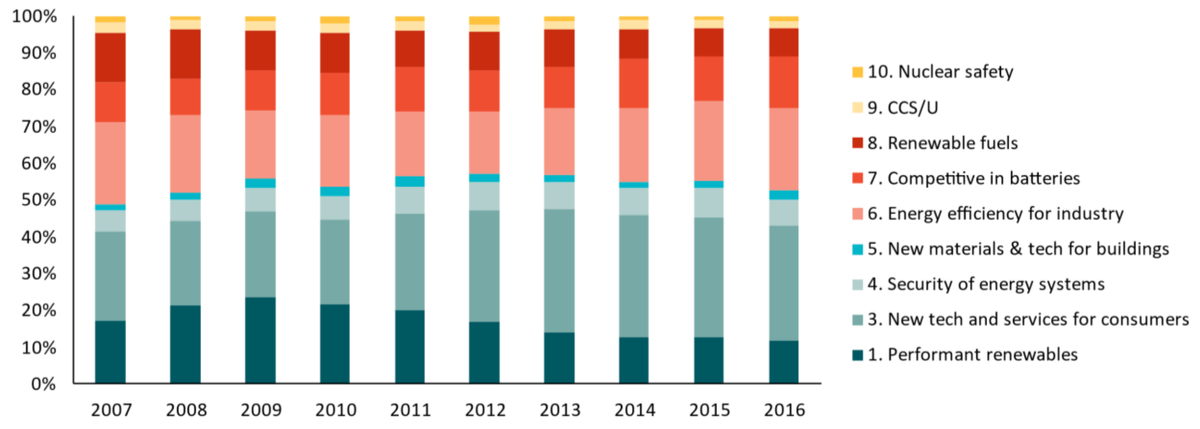


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.5 United States

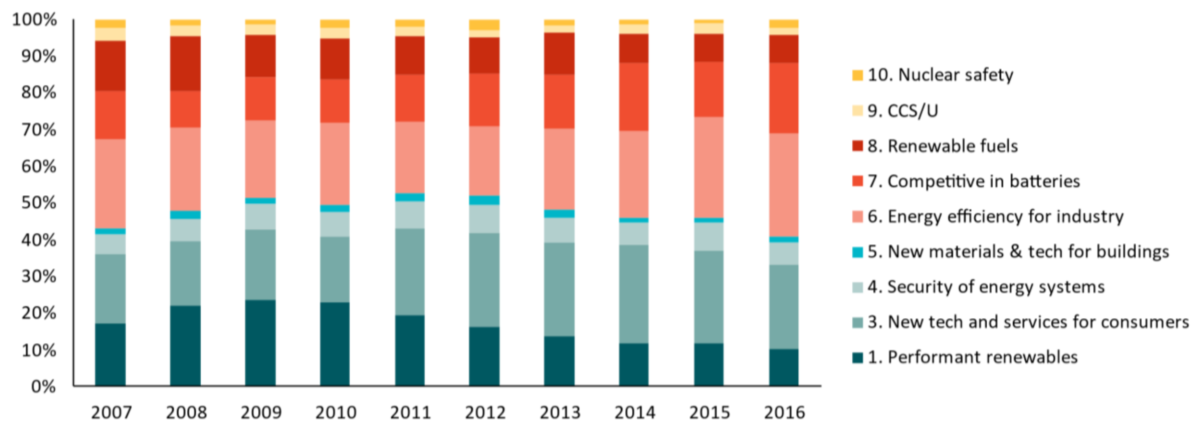
The United States increased its patenting activity in SET Plan KAs considerably since 2007, growing from 2,500 inventions in 2007 to approximately 5,000 inventions per year from 2012 onwards. During this time period, the US reduced its focus on SET Plan KA 1. 'Performant renewables', with a reduced number of inventions for almost all renewable technologies and for wind in particular. Meanwhile, the US strongly increased its focus on SET Plan KA 3. 'New technologies and services for consumers', with particularly large number of inventions for ICT aiming at the reduction of own energy use & Market activities. This trend is visible in all three indicators: total inventions (Figure 43), high value inventions (graph not shown), and international inventions (Figure 44).

Figure 43 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 44 Distribution of international inventions across SET Plan KAs – United States

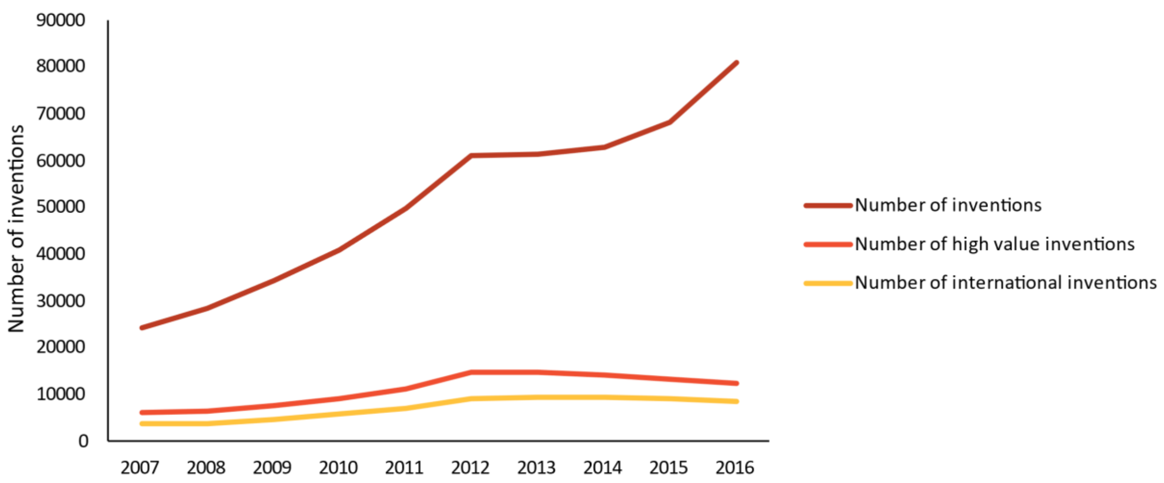


Data source: Joint Research Centre (JRC) based on data from the European Patent Office (EPO)

3.4.6 Mission Innovation

The number of inventions for the group of Mission Innovation members combined increased almost 4-fold between 2007 and 2016, from slightly less than 25,000 in 2007 to more than 80,000 inventions in 2016 (Figure 45). This is primarily due to the large growth in total inventions for China (+44,000). The growth stagnated from 2012 but picked up again from 2014 onwards. There was also significant growth in the number of high value inventions (6,000 in 2007 to 15,000 in 2013) and international inventions (<4,000 in 2007 to 9,000 in 2013), but the growth stagnated from 2012 onwards and the numbers declined slightly in the most recent years.

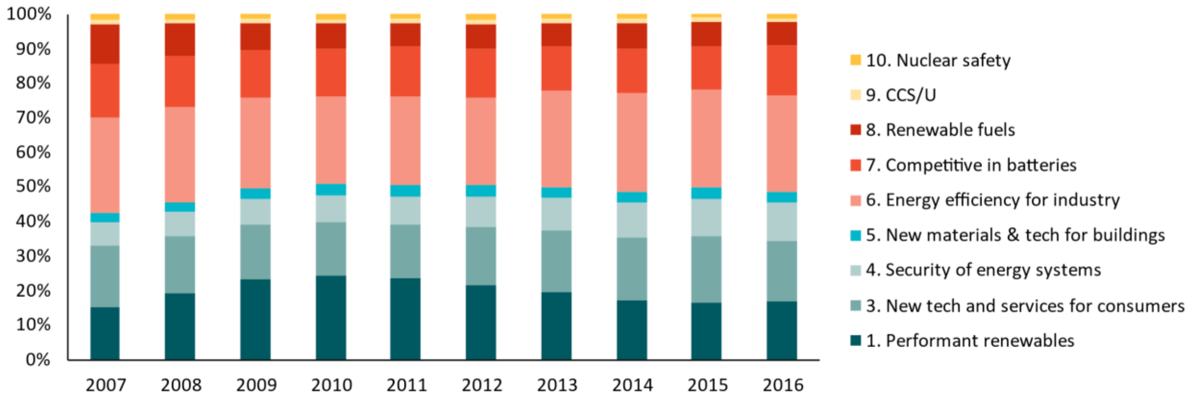
Figure 45 Total inventions by Mission Innovation countries across all SET Plan KAs



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

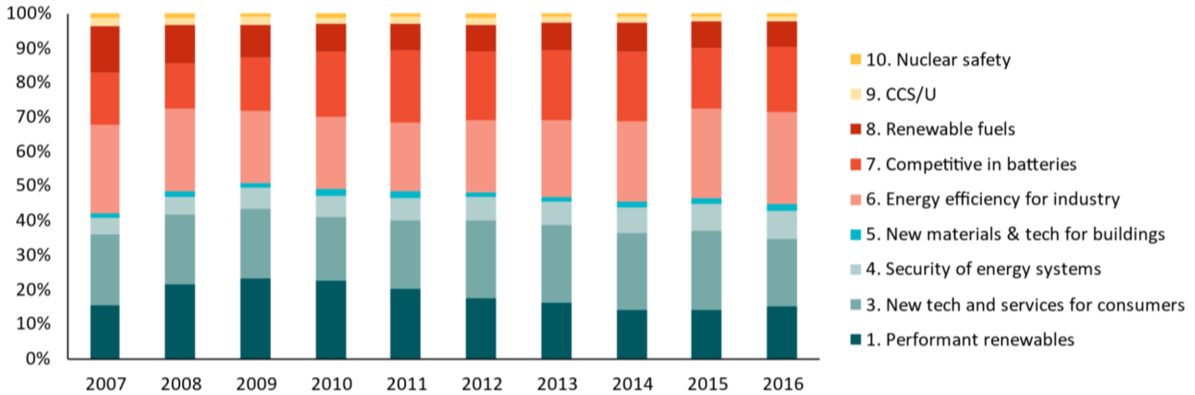
The distribution of inventions across SET Plan KAs shows a relatively stable picture (Figure 46 and Figure 47) with a peak for SET Plan KA 1. 'Performant renewables' around 2010/2011, a decreasing share for SET Plan KA 8. 'Renewable fuels', and an increasing share for SET Plan KA 3. 'Resilience and security of the energy system'.

Figure 46 Distribution of total inventions across SET Plan KAs – Mission Innovation members



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

Figure 47 Distribution of international inventions across SET Plan KAs – Mission Innovation members



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, we selected three potentially suitable 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 SET Plan KAs: China, EU, Japan, Korea and the US. Together, these countries/regions account for more than 90% of all inventions within the scope of the SET plan. China leads the total number of inventions with strongly increasing numbers over the past decade. A particularly high share of inventions from China only include a domestic patent application. The EU, Japan and the US are leading in terms of high value inventions, with slightly decreasing numbers since 2012/2013 for all three players. Japan and recently also Korea lead in terms of international inventions, with particularly strong growth for Korea. When scaling the numbers of inventions to GDP, Japan and 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, Netherlands and France.

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

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

The world players most specialised in these actions are the EU for renewables(KA 1), China for consumer technologies (KA3), Korea for industrial energy efficiency (KA6) and Japan for batteries (KA 7). The SET Plan KAs also differ in terms of international orientation, with patents for consumer technologies (KA3) and batteries (KA7) most often filed at multiple patent offices/countries, while patents for 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. Hence, we recommend including all three indicators in the CEII.

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

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