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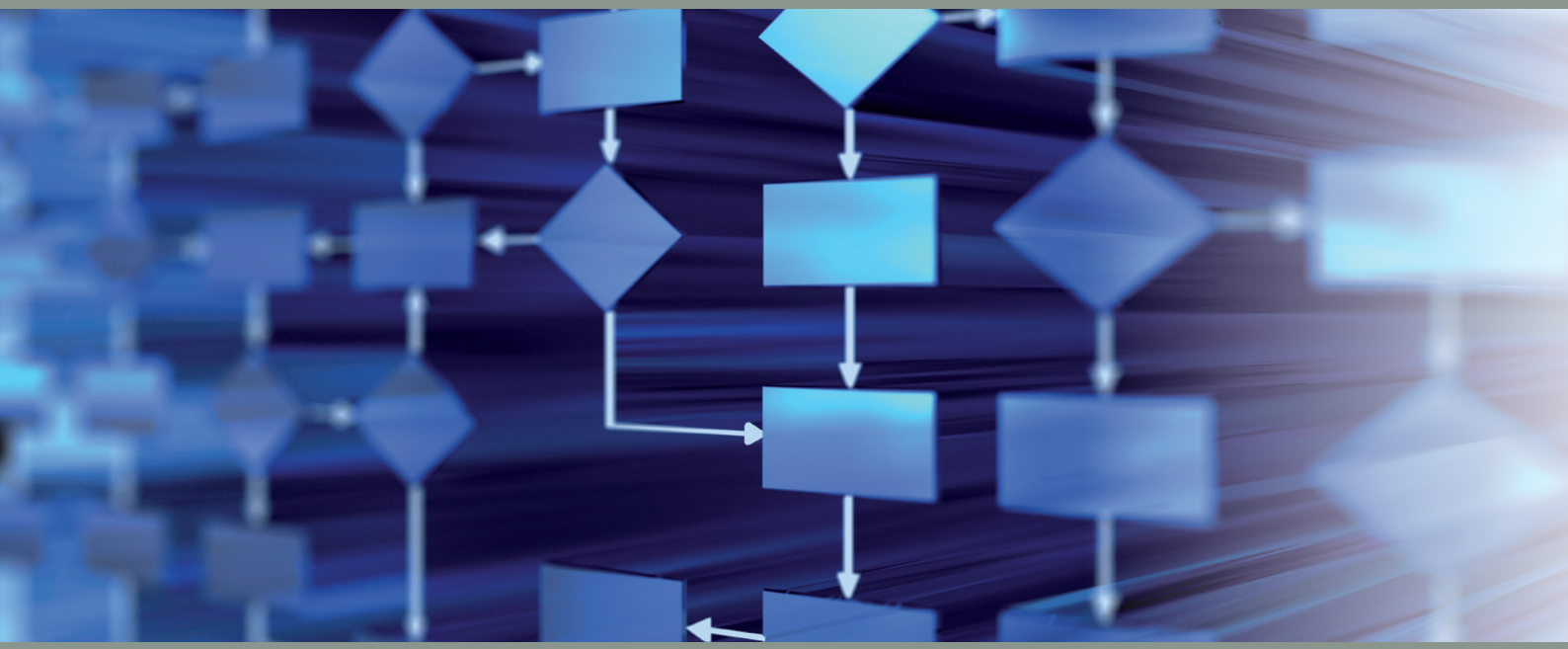

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Measuring innovation in energy technologies: green patents as captured by WIPO's International Patent Classification (IPC) green inventory

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Abstract

We analyze inventions in green energy technologies over the period 2005-2017. We use a novel dataset, making use of the IPC Green Inventory of the World Intellectual Property Organization (WIPO) to analyze four broad categories of green energy technologies including alternative energy production technologies, energy conservation technologies, and green transportation. We use these data to look at how patent families and PCT international patent applications have evolved in this field in recent years. We find that energy innovation-related patenting has first expanded exponentially up until 2013, both in terms of the total number of patent families and PCT international patent applications in green energy technologies. Yet this period of accelerated growth in the number of published green energy patents has been followed by a period of deceleration—even a slow decline. Although most green energy technologies have seen a downward trend in the annual number of patents published since 2012, the decline has been most pronounced in nuclear power generation technologies and alternative energy production technologies. The latter notably include renewable energy technologies, such as solar and wind energy, and fuel cells. In contrast, patents in energy conservation technologies and green transportation technologies have continued to grow, but at a slower pace.

Keywords: intellectual property, patents, energy, green innovation, green energy technology, sustainable development

JEL code: O33; O34; Q01; Q55

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The views expressed in this article are those of the authors and do not necessarily reflect the views of WIPO or its member states.

1. Introduction

At its best, innovation is not only a driver of growth but also a source of solutions to pressing societal matters. This is particularly true in the context of climate change and the corresponding need for new energy innovationand the scale-up and diffusion of resulting technologies.

Projections indicate that by 2040 the world will require up to 30% more energy than what it needs today (IEA, 2017). The largest contribution to energy demand growth—almost 30%—comes from India, whose share of global energy use is expected to rise to 11% by 2040. Overall, developing countries in Asia account for two-thirds of global energy growth; the rest comes mainly from Northern Africa and Western Asia, Sub-Saharan Africa, and Latin America and the Caribbean. Conventional approaches to energy supply are unsustainable in the face of climate change and to meet these increasing energy needs.[6]

With this in mind, the 2018 edition of the Global Innovation Index (GII) on the theme of 'Energizing the World with Innovation' details the requirements of the future energy innovation landscape (Cornell University, INSEAD and WIPO, 2018). It finds that higher levels of technological and non-technological innovation are required, on the supply side of the energy equation - including cleaner energy sources-, on the demand side - including smart cities, homes and buildings, energy efficient industries, and transport and future mobility, and in enabling technologies for the optimization of energy systems - including smart grids and new advanced energy storage technologies.

In this context, and to enable a better tracking of technological inventions, we use statistical analysis to identify the main trends in the field of green energy technologies. This working paper sets out the main methodological approaches taken, and the main results of this work. The analysis makes use of the International Patent Classification (IPC) Green Inventory of WIPO to characterize green energy inventions making use of WIPO's Statistics Database and the EPO Worldwide Patent Statistical Database (PATSTAT). The analysis covers the period 2005-2017.

Our results show that green energy technologies have been growing extraordinarily fast in the last decade. However, we also show that patent filings in the field have decelerated in recent years, and even declined for some technologies, notably alternative energy production technologies (i.e. renewable energy technologies) and nuclear power generation technologies.

Our research also finds that green energy technology patents are highly concentrated in a few origins. Only four countries, Japan, the United States of America (U.S.), Germany and China account for over 60% of all patent families and PCT international patent applications in green energy technologies. China has increased its number of filings for most green energy technologies exponentially over the past years.

The remainder of this paper is organized as follows. Section 2 describes the data and technical approach used in our analysis. Section 3 presents the results of the patent mapping of green energy technologies including a description of the main trends by origin by broad technology categories and for some specific technologies. Section 4 offers concluding observations.

[6] Sustainability is not limited to greenhouse gas (GHG) emissions. It also encompasses the use of limited energy resources (e.g., fossil fuels); the impact of the exploitation of energy resources; the impact of air pollution, especially in cities; and so on. See Dutta et al. (2018) for further elaboration.

2. Methodological approach

2.1 Data used

The core of this analysis rests on the identification of patent families and international patent applications via WIPO's PCT in green energy technologies as defined by WIPO's IPC Green Inventory, available at: http://www.wipo.int/classifications/ipc/en/green_inventory/.

The IPC Green Inventory was launched in 2010 by WIPO as an online tool for searching and retrieving patent documents related to green technologies in a number of fields, including alternative energy production, energy conservation, transportation, waste management and agriculture and forestry. The inventory was developed by the IPC Committee of Experts, and facilitates searches for patent information relating to Environmentally Sound Technologies, as listed by the United Nations Framework Convention on Climate Change (UNFCCC).[7] These green technologies are currently scattered widely across the IPC in numerous technical fields. The WIPO IPC Green Inventory makes it easier to retrieve patent information that covers green technologies.[8]

Table 1 provides the specific selection of IPC Green Inventory topics and sub-topics that are covered and analyzed in this working paper. Out of the full list of topics covered in the IPC Green Inventory, the topics Waste Management; Agriculture/Forestry; and Administrative, Regulatory or Design Aspects were excluded from this research.[9]

Our study employs two datasets. First, the WIPO Statistics Database was used for the analysis of PCT international patent applications. Second, WIPO's patent family database comprised of a combination of the EPO PATSTAT database together with PCT national phase entries stored in the WIPO Statistics Database, was used for the analysis of patent families. WIPO's patent family database provides comprehensive data up to 2015.[10]

Both datasets provide insights of patenting activity with different time dimensions: patent family data are available up to 2015, while data for PCT international patent applications are available up to 2017. On one side, PCT international patent applications may reflect higher quality inventions, as applicants are willing to bear higher filing costs, and data may be more comparable across origins as filing standars are somewhat harmonized. On the other, patent family data may be more comprehensive as they also include domestic-only filings, but the quality range of inventions may be wider.

A patent family is a set of interrelated patent applications filed in one or more countries or jurisdictions to protect the same invention. The study uses the WIPO patent family definition, on which families are based on "first filed" patent applications. Each first filing –an application without priority- forms a patent family. Subsequent filings, those claiming priority of other patent applications, are grouped into the family. An internationally-oriented patent family is defined as a patent family filed by residents in at least two different countries.

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[7] The International Patent Classification (IPC), established by the Strasbourg Agreement 1971, provides for a hierarchical system of language independent symbols for the classification of patents and utility models according to the different areas of technology to which they pertain. A new version of the IPC enters into force each year on January 1. For more information see http://www.wipo.int/classifications/ipc/en/.

[8] Similarly, the EPO has developed the "Y02" classification scheme, dedicated to climate change mitigation technologies, which enables a continuous and reliable flow of data on selected technologies and their application in the energy field. See for more information http://www.epo.org/news-issues/issues/classification/classification.html. This classification scheme is also applied in Box 1 in this Working Paper in which the EPO assesses patenting in smart grid technology.

[9] These topics were assessed as not being related to energy innovation and/or the IPC codes covered were deemed too general for analysis.

[10] 2016 data are available, but they are partial and incomplete, and are thus excluded from the analysis.

The date of reference for patent counts is the date of first filing. The origin of the invention is attributed to the first applicant in the first filing. Only patent families with at least one published application are considered for the analysis.

PCT international patent applications data covers "transnational patents" or those that sought international patent protection. However, it is important to highlight that PCT filings do not capture all "transnational patents". Notably they do not capture international patent families opting for the PCT rather than the Paris route. The share of PCT national phase entries in worldwide non-resident filngs was about 56% in 2017 (WIPO, 2018). The PCT is generally used by the world's major corporations, research institutions, and universities when they seek international patent protection.[11]

Table 1: IPC Green Inventory topics and sub-topics related to energy innovation[12]

Topic	Sub-topics
Alternative Energy Production	Bio-fuels Integrated gasification combined cycle (IGCC) Fuel cells Pyrolysis or gasification of biomass Harnessing energy from manmade waste Hydro energy Ocean thermal energy conversion (OTEC) Wind energy Solar energy Geothermal energy Other production or use of heat, not derived from combustion, e.g. natural heat Using waste heat Devices for producing mechanical power from muscle energy
Transportation	Vehicles in general (e.g. hybrid vehicles, electric propulsion) Vehicles other than rail vehicles Rail vehicles Marine vessel propulsion Cosmonautic vehicles using solar energy
Energy conservation	Storage of electrical energy Power supply circuitry Measurement of electricity consumption Storage of thermal energy Low energy lighting Thermal building insulation, in general Recovering mechanical energy
Nuclear power generation	Nuclear engineering (e.g. Fusion reactors, nuclear fission reactors, nuclear power plants) Gas turbine power plants using heat source of nuclear origin

Source: WIPO IPC Green Inventory

Patent families are analyzed for the period 2005-15, while PCT international patent applications are analyzed between 2007-17.

[11] See: http://www.wipo.int/pct/en/faqs/faqs.html

[12] See also Appendix A for a hierarchical figure of the different categories and sub-categories covered in this working paper, part of the WIPO IPC Green Inventory.

2.2 Method

IPC codes were extracted for the entire family portfolio and for PCT international patent applications; and these were then mapped to the IPC Green Inventory.[13]
If one patent family or PCT international patent application had more than one IPC code included in the IPC Green Inventory, all IPC codes were taken into account. Patents with at least one green energy technology IPC code were classified as green energy technology patents. The family or application is divided equally among all green energy technologies IPC codes (fractional counting). Only after the fractional counting were the IPC codes rounded at category level. This might lead to some over – or underestimation – of some green energy technologies as the different contributions of several technologies may not have the same weight.

3. Discussion of results

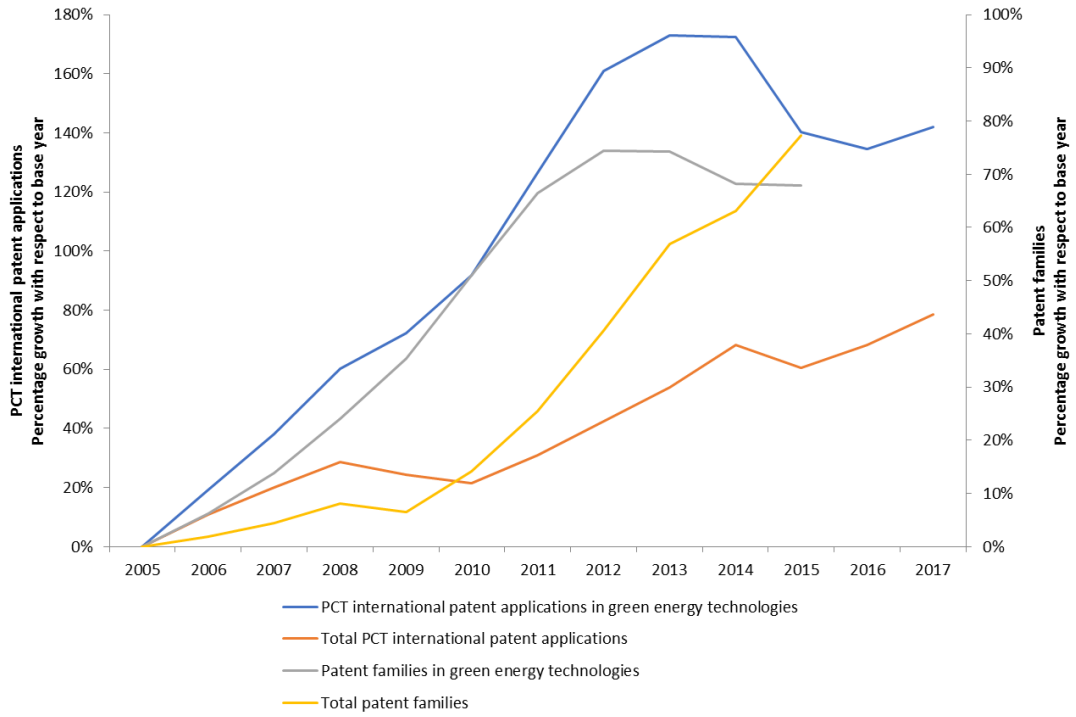
3.1 Green energy technologies accelerated growth and slow decline

Patenting in green energy technologies has been growing extraordinarily fast. The total number of patent families in green energy technologies almost doubled between 2005 and 2013. The number of PCT international patent applications almost tripled in the same period. Patent families went from 65,105 in 2005 to 113,457 in 2012, growing annually at 8.3%. PCT international patent applications passed from 6,546 in 2005 to 17,880 in 2013 growing 13% each year.

PCT international patent applications in green energy technologies grew 173% by 2013 relative to the 2005 levels, while all PCT international patent applications grew only 54% in the same period. An impressive growth is also observed in green energy technology patent families. These grew 74% by 2012 relative to the 2005 levels, while all patent families grew by 41% (Figure 1).

[13] Cooperative Patent Classification (CPC) codes were extracted for applications in the portfolio that did not have IPC codes and these were also mapped to the IPC Green Inventory. The CPC lookup was only applied to PATSTAT data. Only about 1.2% of all WIPO patent families in the anlaysis contained at least one application that had CPC codes but which did not have IPC codes.

Figure 1: Total patent families and PCT international patent applications vs. patent families and PCT international patent applications in green energy technologies



Source: WIPO Statistics Database, WIPO based on PATSTAT and WIPO IPC Green Inventory

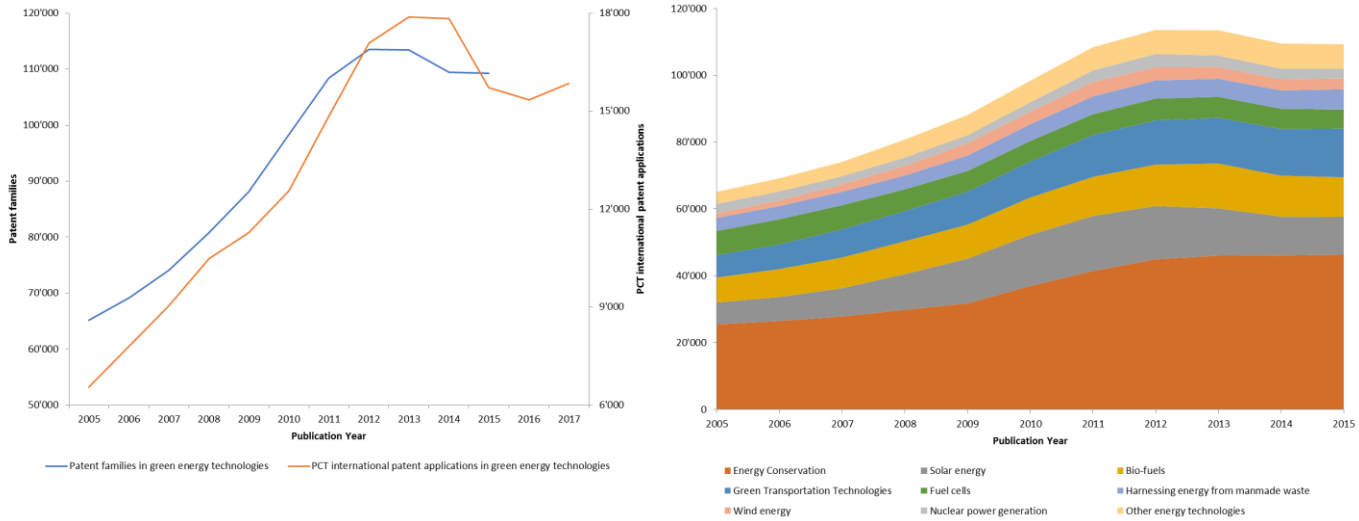
However, this accelerated growth has been followed by a period of deceleration, even a slow decline. The number of published green energy patent families peaked in 2012 — with the underlying invention usually happening about 18 months before the patent publication. Hence the peak of inventive activity was around 2010. Since then, a decrease in the absolute number of patent families has been observed every year until 2015 — a reduction from peak to bottom by 3.8%, from 113,547 families in 2012 to 109,266 in 2015. Moreover, 2015 has been the first year where the growth rate of the total number of patent families was higher (77%) than the growth of green energy patent families (68%) relative to the number of filings in 2005.

Similarly, published PCT international patent applications peaked in 2013, followed by a decrease of 11.4% between 2013 and 2017— dropping from 17,880 to over 15,840, an annual decrease of 3% (Figure 2).

Figure 2: Green energy patent filings waning

Number of patent families and PCT international patent applications in green energy technologies, 2005–2017

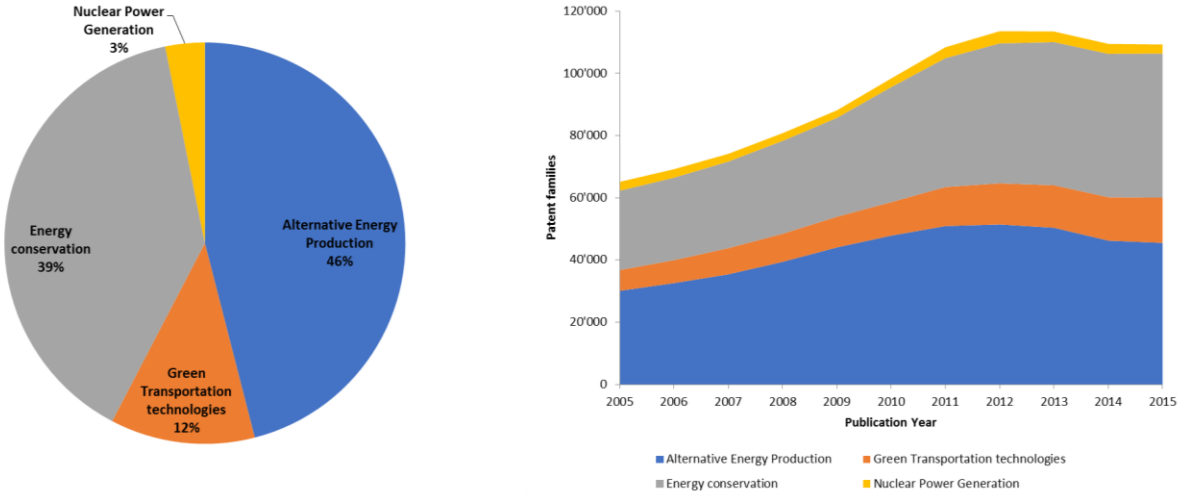
Total number of patent families in green energy technologies, 2005–2015



Source: WIPO Statistics Database, WIPO based on PATSTAT and WIPO IPC Green Inventory (left); and WIPO based on PATSTAT and WIPO IPC Green Inventory (right).
Note: All patent data refer to published applications.

With regard to patent families, although most green energy technologies have seen a downward trend in the annual number of patents published since 2012, the decline has been most pronounced in nuclear power generation technologies and alternative energy production technologies. The latter notably include renewable energy technologies, such as solar energy, wind energy, and fuel cells. In contrast, patents in energy conservation technologies and green transportation technologies have continued to grow, but at a slower pace (Figure 3).

Figure 3: Green energy patent filings by category, 2005-2015



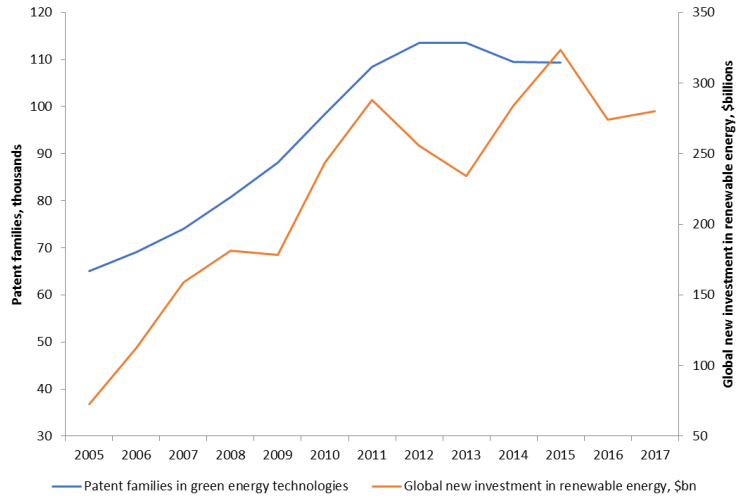
Source: WIPO based on PATSTAT and WIPO IPC Green Inventory

An analysis conducted by the EPO for the GII 2018 confirms the above-mentioned slowdown for smart-grid technology (see Box 1).[14]

A similar mixed story can be observed in global private-sector investment in green energy sources. In the period 2004–17, the world invested USD 2.9 trillion in renewable energy sources (Frankfurt School-UNEP Centre, 2018).[15] The period 2004–10 was characterized by a boom in investment, with a compound annual growth rate (CAGR) in investments equal to 32%. In contrast, in the period 2011–17, these investments have stagnated.[16] The levels of investment recorded in 2017 are 2% higher than those registered in 2016, but remain 13% lower than the record set in 2015 of USD 323.4 billion of new investment in renewable energy (Figure 4).

The 2018 *Global Landscape of Renewable Energy Finance* also highlights waning growth in annual investments in renewable energy in 2016 (IRENA and CPI, 2018).[17]

Figure 4: Green energy patent filings and global new investment in renewable energy, 2005-2017



Source: WIPO based on PATSTAT, WIPO IPC Green Inventory (patent families); and Frankfurt School-UNEP Centre/BNEF, 2018

[14] Saha and Muro (2017) also observed a decrease in the number of cleantech patents granted by the United States Patent and Trademark Office (USPTO). Between 2014 and 2016 the number of cleantech patents granted in the U.S. declined by 9%. However, one most keep in mind that granted patents relate to patents filed years earlier.

[15] Investment data are based on the output of the database of Bloomberg New Energy Finance (BNEF), a database of investors, projects, and transactions in clean energy. It includes projects, investments, and transactions from start-ups, corporate entities, venture capital and private equity providers, banks, and other investors. The following renewable energy projects are included: wind, solar, biomass and waste, biofuels, geothermal and marine projects, and small hydro-electric damns of less than 500 megawatt (MW). The aggregate renewable energy investment figure of USD 2.9 trillion over the period 2004–17 excludes large hydro-electric projects of more than 500 MW. More details on the methodology and definitions used in the BNEF database for the estimation of investments in green energy sources are available in Frankfurt School-UNEP Centre, 2018.

[16] CAGR was equal to –0.5% in this period. However, it is important to note that renewable energies deployment keeps growing while the costs of renewable energies keep decreasing.

[17] "Investment" is a financial commitment represented by a firm obligation, for example by means of a Board (or equivalent body) decision, backed by the necessary funds, to provide specified financing through debt, equity or other financial instruments. More information on the methodology is available in IRENA and CPI, 2018. See also Chapter 3 for IRENA's contribution to the GII 2018, 'Innovation Driving the Energy Transition'.

A slowdown can also be observed in the growth of green energy-related patents. WIPO's *World Intellectual Property Indicators 2017* showed that — first and foremost — patent applications in energy-related technologies in categories such as solar energy, fuel cells, wind energy, and geothermal energy significantly increased, up until 2013 (WIPO, 2017a). Since then, however, patent applications in the field of energy-related technologies have declined.

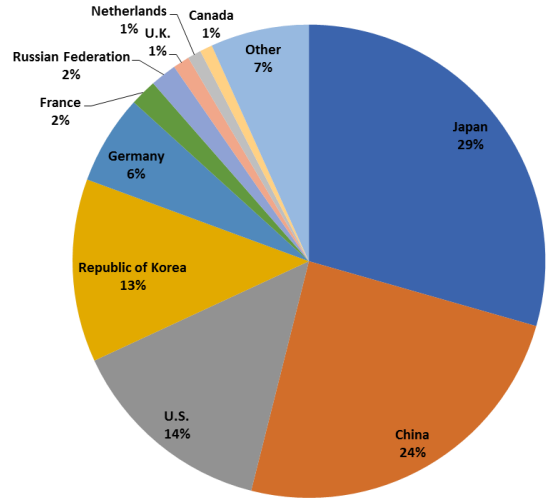
3.2 Distribution by origin and changes

Green energy technology patents are highly concentrated in a few origins. Only four countries (Japan, the U.S., Germany and China) account for over 60% of all green energy technology patent families and PCT international patent applications (Figure 5). Japan, China and the U.S. were the top 3 origins for patent families in the period 2005-15, accounting together for 68% of all filings. Japan, the U.S. and Germany together accounted for 61% of all PCT international patent applications in green energy technologies in the period 2007-17.

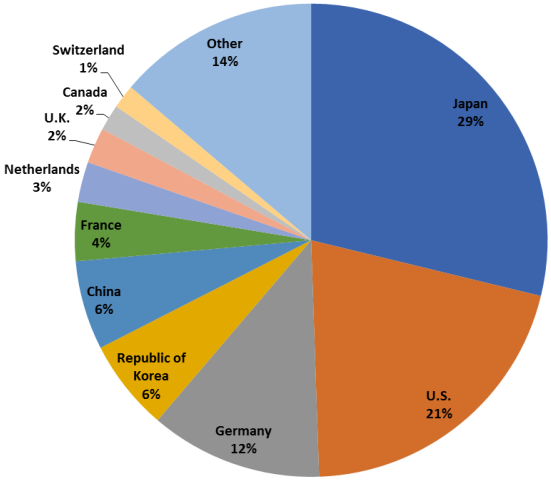
The growth of Chinese filings in green energy technologies has been extraordinary. Over the period 2005-15, Chinese origins increased from over 2,800 in 2005 to more than 45,700 in 2015, growing on average at 25.5% each year. With regards to internationally-oriented patent families, China increased its number of families by 15.7% on average each year in 2005-15. Even if at lower volumes, Chinese origins of PCT international patent applications in green energy technologies also grew by 24.7% each year over the period 2007-17.

Figure 5: Green energy patent filings by origin

Patent families in green energy technologies by origin, 2005–15



PCT international patent applications in green energy technologies by origin, 2007–17



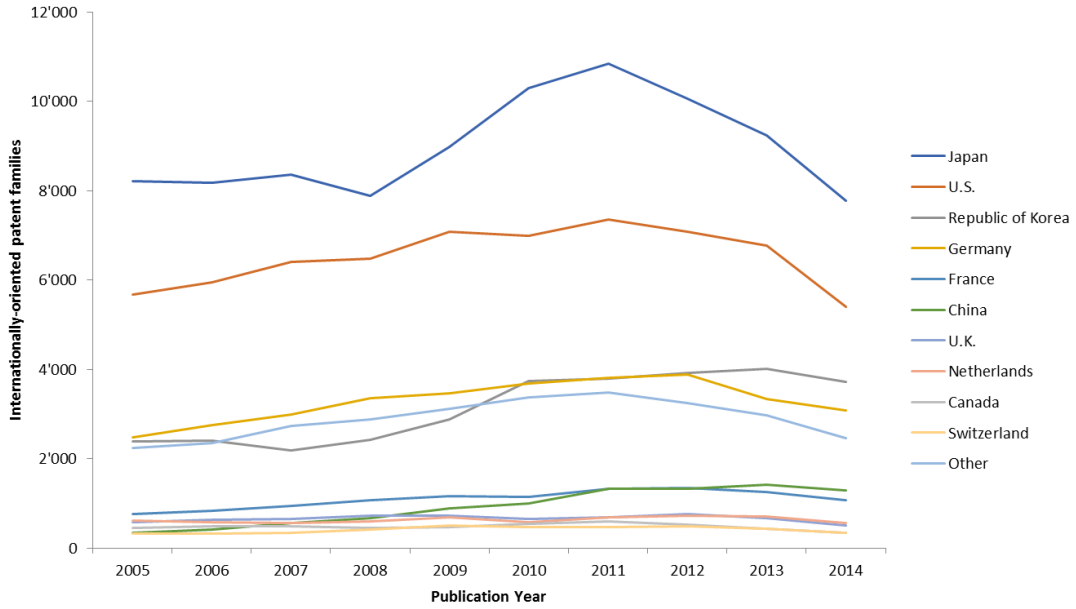
Source: WIPO based on PATSTAT and WIPO IPC Green Inventory (left); and WIPO Statistics Database and WIPO IPC Green Inventory (right)

China is the second top origin with regards to green energy patent families, but the volumes of PCT international patent applications and internationally oriented patent families of Chinese origin remain more modest. While China accounted for 24% of all green energy patent families in the period 2005-15, it only represented 6% of all PCT international patent applications in the period 2007-17 (Figure 5). Moreover, China also only accounts for 3.2% of internationally oriented patent families in 2005-15, while Japan and the U.S. remain the

top origins. This suggests that the extraordinary growth in the number of Chinese patent families in green energy technologies mostly refer to those filed at home.

A decline in internationally oriented patenting activity is observed for the world leading inventors of green energy technologies, Japan and the U.S., since 2011 (Figure 6). Both countries account for 53.4% of all internationally-oriented patent families in the field. In the period 2005-11 the number of internationally-oriented patent families increased annually on average by 4.7% for Japan, and 4.4% for the U.S. Since, patenting activity has declined in both countries, by 10.5% every year between 2011-14 for Japan, and by 9.8% for the U.S. These decreases are higher than what is overall observed for internationally-oriented patent families over the same period, equaling a decrease of 8.2% on average every year.

Figure 6: Internationally-oriented patent families in green energy technologies by origin, 2005-2014



Source: WIPO based on PATSTAT and WIPO IPC Green Inventory

3.3 Distribution by technology and origin

Patenting activity in alternative energy technologies has been decreasing in recent years. However, they still account for the largest share of all green energy technologies. Alternative energy production technologies, as defined by the IPC Green Inventory comprise solar energy technologies, bio-fuels, fuel cells, wind energy, hydro energy, geothermal energy, technologies for using waste heat, technologies for harnessing energy from manmade waste, among others (see Table 1).

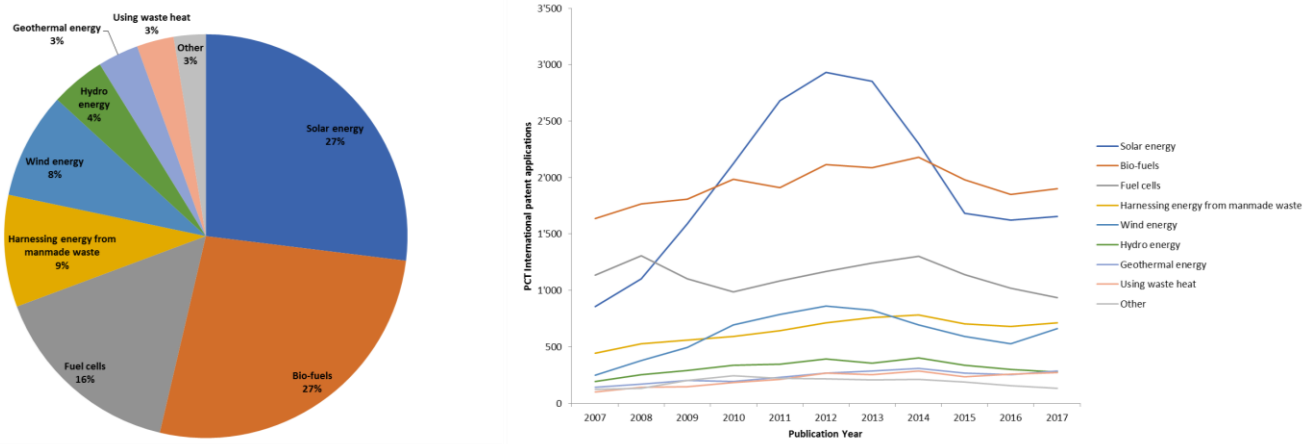
Alternative energy production technologies represent 46% of all patent families in green energy technologies in the period 2005-15; and 50% of all PCT international patent applications in the period 2007-17. In comparison to the growth of patent families and PCT international patent applications in all green energy technologies, alternative energy technologies grew faster every year up to 2010. Since then, they have grown at lower rates than all green energy technologies, and even declined since 2013. PCT international patent applications increased by 2.4% between 2016-17.
Patent families in alternative energy production technologies grew in the period 2005-2012. The number of families passed from over 30,000 in 2005 to over 51,000 in 2012, growing annually at 8%. PCT international patent applications in this category passed from over

4,800 in 2007 to over 8,900 in 2012, growing annually at 13%. This period of growth has been followed by decline both in the number of patent families and PCT international patent applications, but notably in the latter. Patent families have decreased by 11.5% in the period 2012-15, while PCT international applications have decreased by 23.5% in the period 2012-17.

For patent families, the story is mixed with regards to which alternative energy production technologies have contributed the most to the fast growth observed in the period 2005-12. Patenting activity of all technologies, with the exception of fuel cells, grew in the period, some at fast rates (solar, wind, hydro energy and geothermal energy), and others at more modest rates (harnessing energy from manmade waste). Patents in solar energy and wind energy show a mixed story. Accelerated growth was observed for wind energy technologies, increasing at 16.7% each year; and solar energy, growing at 13.6%. However, the same two technologies experienced important declines in the period 2012-15: 10.9% decrease each year for solar energy; and 6.4% decline for wind energy. In contrast, a slow decline is observed for fuel cells, hydro energy and bio-fuels; while other technologies keep on growing but at a slower pace (e.g. harnessing energy from manmade waste, and geo-thermal energy).

A similar mixed story is observed for PCT international patent applications (Figure 7). Patenting activities in all alternative energy production technologies increased in the period 2007-12, with an average of 13% each year. Solar energy and wind energy technologies show an accelerated growth of 28% each year in the period. In contrast, the period 2012-17 has been a period of decline for most technologies. PCT international patent applications in solar energy technologies decreased the most, equaling 11% less applications each year, followed by hydro energy (-7% each year) and wind energy (-5%).

Figure 7: PCT international patent applications in alternative energy production technologies by sub-category, 2007-2017



Source: WIPO Statistics Database and WIPO IPC Green Inventory
Note: " Other" include Integrated gasification combined cycle (IGCC) technologies; pyrolysis or gasification of biomass; ocean thermal energy conversion (OTEC) technologies; other production or use of heat, not derived from combustion (e.g. natural heat); and devices for producing mechanical power from muscle energy.

Regarding the origins of the inventions, Japan and the U.S. account for 49.3% of all PCT international patent applications in alternative energy production technologies in the period 2007-17. Among the top 10 origins, the most remarkable growth has been observed for the Republic of Korea, which has increased its number of applications by 19.3% each year in the period 2007-17; China with an annual growth of 18.7% ; and Denmark, with 11.8% growth each year. Both, the Republic of Korea and China have more than quadrupled their number of PCT international applications in alternative energy production technologies over the same period.

Patenting in green transportation technologies continues growing, even if it a slower pace. Green transportation accounted for 11.7% of all patent families in green energy technologies in the period 2005-15 and for 12% of all PCT international patent applications in green energy in 2007-17. In contrast to other green energy technologies, such as alternative energy production or nuclear power generation technologies, patents in green transportation continue growing. The number of families has more than doubled passing from 6,691 in 2005 to 14,534 in 2015. Similarly, the number of PCT international patent applications in green transportation has close to tripled, increasing from 812 in 2007 to 2,385 in 2017. Although patents in green transportation continue growing, a slowdown has been registered since 2012 for patent families, and since 2014 for PCT international patent applications. The latter has seen a resurge in the number of patent applications between 2016-17 equal to 15.4%.

Technologies for vehicles in general account for the largest share of green transportation patent families in 2005-15 (56.8%), followed by technologies for rail vehicles (24.8%), and technologies for vehicles other than rail vehicles (17.9%).[18] Within patent families for vehicles in general, the most important technologies are those for hybrid vehicles, accounting for 44.3% of all patent families in 2005-15, charging stations for electric vehicles (22.7%), and electric propulsion technologies with power supply external to the vehicles (18.4%).

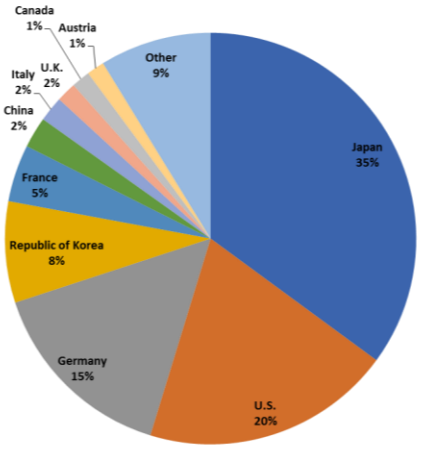
Three countries, Japan, China and the U.S. account for 63% of all patent families in green transportation technologies in 2005-15. Chinese patent families have growth by 28.6% on average every year in the same period. In absolute terms the number of patent families increased from 404 in 2005 to 4,979 in 2015, which is equal to more than 12 times the levels of 2005. The distribution by origin for internationally oriented patent families is slightly different. Japan, the U.S. and Germany account for 70% of all internationally oriented patent families in green transportation technologies in the period 2005-15 (Figure 8). Even if China is only the 6th most important origin, after Japan, the U.S., Germany, the Republic of Korea and France, it is the country with the highest growth in the period 2005-14, averaging 26.9% increase every year.

Internationally oriented patent families in green energy technologies have increased on average 6.4% each year in the period 2005-14. Only three technologies –electric propulsion with power supply external to the vehicle, charging stations for electric vehicles, and regenerative braking systems-, have increased at a faster pace (20.7% every year in the period; 11.5%; and 8.6% respectively).

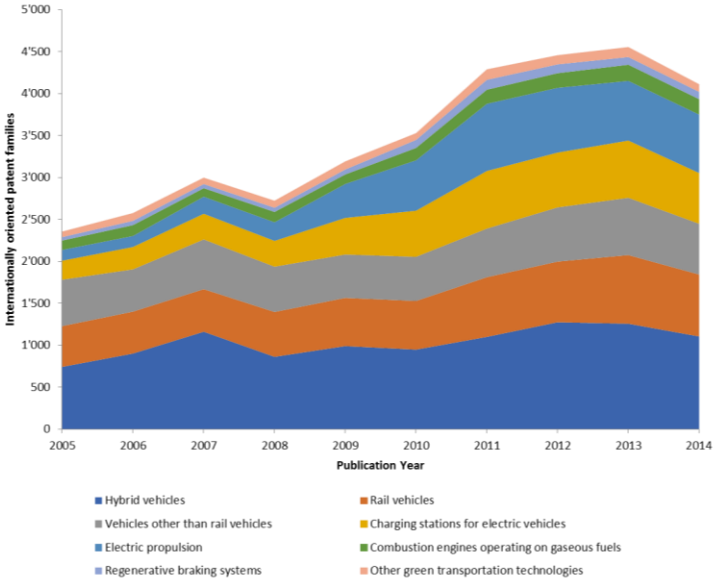
[18] The category “Vehicles in general” includes nine technologies: technologies for hybrid vehicles (e.g. Hybrid Electric Vehicles (HEVs); technologies for brushless motors; electromagnetic clutches; regenerative braking systems; electric propulsion technologies with power supply from force of nature (e.g. sun, wind); electric propulsion technologies with power supply external to the vehicle; combustion engines operating on gaseous fuels (e.g. hydrogen); power supply technologies from force of nature (e.g. sun, wind); and charging stations for electric vehicles.

Figure 8: Patent filings in green transportation technologies

Internationally oriented patent families in green transportation technologies by origin, 2005–15



Total number of internationally oriented patent families in green transportation technologies, 2005-15



Source: WIPO based on PATSTAT and WIPO IPC Green Inventory

Notes: Electric propulsion (right figure), refers to "Technologies for electric propulsion with power supply external to vehicle". Other green transportation technologies include: technologies for brushless motors; electromagnetic clutches; cosmonautic vehicles using solar energy; electric propulsion technologies with power supply from force of nature (e.g. sun, wind); marine vessel propulsion technologies; and power supply technologies from force of nature (e.g. sun, wind).

Filings in energy conservation technologies continue growing, representing 39% of all green energy technology patent families in the period 2005-15. The number of patent families in energy conservation technologies passed from 25,496 in 2005 to 46,343 in 2015, growing annually at about 6.2%. This category includes technologies in power supply circuitry (57.3% of all energy conservation patent families in the period 2005-15), low energy lightning (28.9%), thermal building insulation (7.6%), storage of electrical energy (6%) and the recovering of mechanical energy (0.1%).

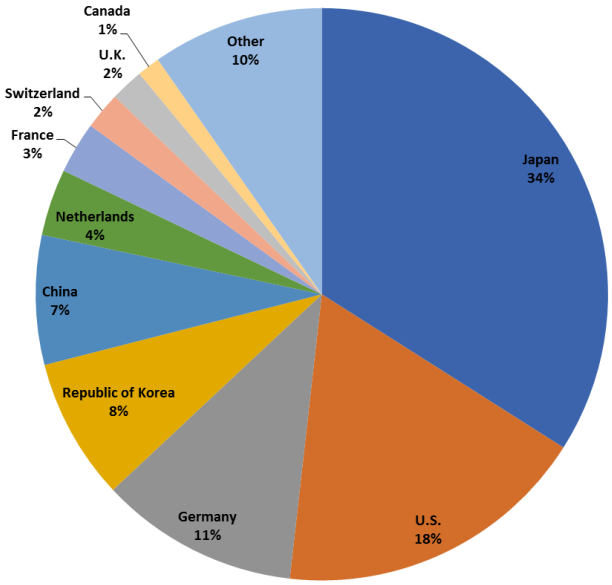
PCT international patent applications in energy conservation technologies grew steadily and more than doubled in the period 2007-2014. International applications passed from over 3,039 in 2007 to 6,541 in 2014, when a peak was achieved in the number of applications. The number of applications grew annually at 11.6% in this period. Since then, a decrease in the number of applications has been observed between 2014-17, representing a reduction of 6.2%.

As in the case of other green energy technologies, the origin of international patent applications of energy conservation technologies is highly concentrated in a few countries. Japan, the U.S. and Germany accounted for 63% of all PCT international patent applications in the period 2007-17. This concentration is very similar to the one observed for all green energy international patent applications (Figure 9).

All of the top 10 origins in energy conservation technologies, with the exception of the Netherlands, have seen their number of PCT international patent applications increase in the period 2007-17. The most remarkable growth is that of China, which increased its

applications annually by 29.6% in the period. China has been followed by the Republic of Korea (20% compound annual growth rate in the period 2007-2017), France (9.6%) and the U.K. (9.1%).

Figure 9: PCT international patent applications in energy conservation technologies, 2007-2017



Source: WIPO Statistics Database and WIPO IPC Green Inventory

Patent filings in nuclear power generation technologies represent about 3% of inventions in green energy technologies in the period 2005-15. The number of patent families in this technology category decreased over the period 2005-09 by 15%; to then increase between 2009-12 by 62%, to finally decrease once more between 2012-15 by 26%. As a consequence, the number of patent families in 2015 remained practically the same as in 2005. Internationally-oriented patent families have evolved in a similar fashion: a decrease was observed in the number of patent families between 2005-09, the levels peaked between 2009-12, and a further decrease was registered up to 2014. As a consequence, a total decrease of 38% is observed in the number of internationally-oriented patent families in the period 2005-14. This important decline could be a consequence of the delay in filing in subsequent offices after the first. PCT international patent applications in nuclear energy technologies also declined between 2007-10, to then slightly increase up to 2017. During the period 2010-17, the number of applications increased on average 6% every year.

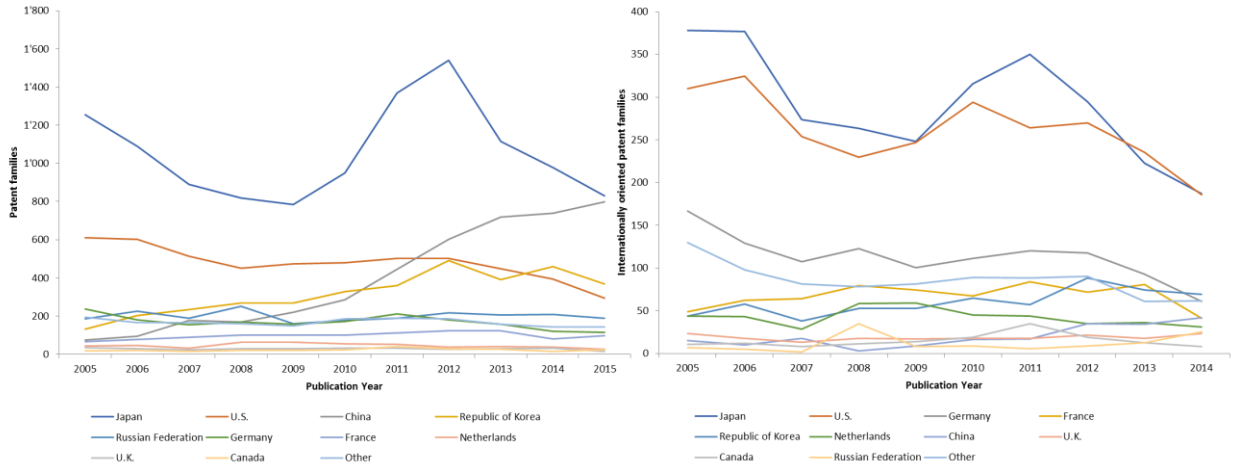
Relative to all other green energy technologies, nuclear energy patent families have decreased the most in the period 2012-15, 10% on average every year. Nuclear energy was the category with the second largest decline in the period 2013-17 with regards to PCT international patent applications, after alternative energy production technologies, decreasing on average 2% every year.

Japan, the U.S., China and the Republic of Korea together accounted for 76% of all patent families in nuclear energy technologies in the period 2005-15. The number of Chinese origins increased the most in the period, passing from 74 in 2005 to close to 800 in 2015, growing annually on average at 27% (Figure 10, left). Five of the top 10 origins, have decreased their number of patent families in the period: the U.K. (9% decrease every year on average), the U.S. (-7%), Germany (-7%), the Netherlands (-6%) and Japan (-4%).

Figure 10: Nuclear energy patent filings by origin

Patent families in nuclear energy technologies by origin, 2005–15

Internationally-oriented patent families in nuclear energy technologies by origin, 2005–14



Source: WIPO based on PATSTAT and WIPO IPC Green Inventory

Japan, the U.S. and Germany together accounted for 67% of all internationally-oriented patent families in nuclear energy in 2005-15. Chinese applications were only equal to 2% of total, but China was the origin that increased the most in 2005-14, growing annually on average by 2%. The top 3 origins were also the ones that decreased the most in the period: Germany decreased by 11% on average each year, Japan by 8% and the U.S. by 6%. With respect to PCT international patent applications, the U.S., Japan and France together accounted for 63% of all patent applications in the period 2007-17. The most important increases in the number of applications were registered for China (28% growth on average each year), and the Republic of Korea (27%).

3.4 Decomposition with focus on particular technologies

To understand further technology trends, we focus this section on two particular technologies: bio-fuels and charging stations for electric vehicles. Both technology areas have experienced important growth in the past decade and the origins of the patents have changed considerably lately, pointing to important transformations in both areas. Chinese applications have considerably increased in recent years in both technologies.

Bio-fuels

Patent families in bio-fuels represented 27.5% of all alternative energy production families in the period 2005-15. First filings in the technology area increased from over 7,400 in 2005 to over 13,300 in 2013, growing annually at 7.5%. Since then, the number of patent families on bio-fuels has decreased annually on average by 5.7% between 2013-15.

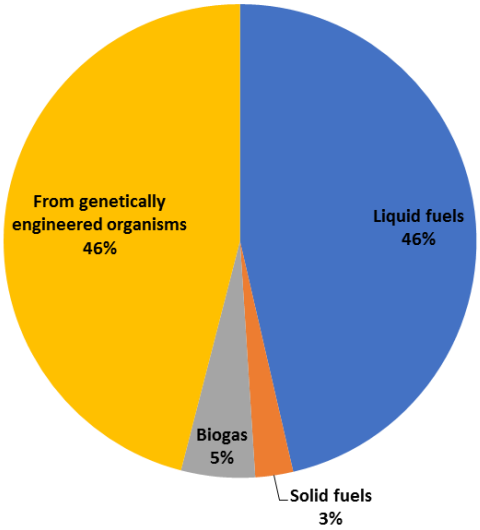
Bio-fuels accounted for 26.7% of all PCT international patent applications in alternative energy production technologies in 2007-17. The number of applications grew from over 1,600 in 2007 to over 2,100 in 2014, growing on average by 4.2%. Since then, the number of applications has declined by 4.5% each year between 2014-17.

Most PCT international patent applications on bio-fuels in the period 2007-17 were related to liquid fuels technologies (46% of all PCT international applications) and bio-fuels from

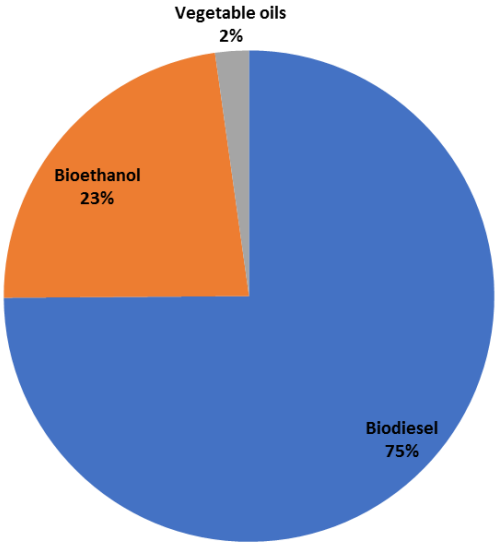
genetically engineered organisms (46%) (Figure 11). The largest share of liquid bio-fuels PCT international applications correspond to biodiesel (75%), followed by bioethanol (23%).

Figure 11: Bio-fuels patent filings, 2007-17

PCT international patent applications in bio-fuels



PCT international patent applications in liquid fuels technologies



Source: WIPO Statistics Database and WIPO IPC Green Inventory

The U.S. remained the most important origin of PCT international patent applications on bio-fuels in the period 2007-17, accounting for 36% of all. Japan was the second most important origin, but has experienced important decreases in the total volume of applications of 34% in the period, or 4% on average every year. In contrast, Chinese origins have increased by more than 7 times its volumes of 2007 by 2017, increasing its level of PCT international patent applications by 22% every year in the same period.

The importance of China as a leading global inventor in bio-fuels technologies is more marked when looking at patent families. Until 2009, most of these technologies originated in the U.S. and Japan, representing together on average 43% of all bio-fuels patent families in the period 2005-2009. Since then, China has seen rapid growth in bio-fuels patenting, becoming the top bio-fuel patenting economy by 2009. By 2014, their filings accounted for 55% of all bio-fuels filings worldwide.

Box 1. The evolution of smart-grid technology

Smart-grid technology is particularly important for the deployment of renewable energy sources, which smart grids integrate into existing power networks in such a way that shortages or surpluses due to fluctuating weather conditions can be offset by adjustments in conventional energy sources. This technology aims to optimize energy efficiency, reduce energy costs, and improve the reliability of energy supply.

As part of its initiative to make it easier to find sustainable technologies, the EPO has developed a dedicated classification scheme — Y02/Y04S[19] —for tagging patent documents relevant to climate change mitigation, adaptation, and smart-grid technology.[20] According to the latest patent data available, and following this methodology, between 2005 and 2011 the number of new patent families in smart-grid technologies has grown from 441 to 2,500. In the same time the number of internationally oriented smart-grid patent families increased six-fold, from fewer than 200 in 2005 to 1,168 in 2011.

In 2012 the trend changed. The growth of new smart-grid patent families has slowed considerably; the number of internationally oriented smart-grid patent families actually declined to 685 by 2014, following the general decline also observed for patented inventions in renewable energy technologies. There are two possible explanations. First, innovation in clean energy technology is often impacted by developments in oil and gas prices, which dropped considerably around the same time period. In other words, the attractiveness of investments in renewable energy technologies and resulting patented inventions might have decreased as fossil energies became cheaper again. Second, after a spurt in patenting growth, the technological foundations for smart-grid technology are in place. Attention is now turning to the deployment of smart-grid technology while overcoming social and economic obstacles.

High-income economies — such as the U.S. (which contributed 27% of the world's internationally oriented patent families), Japan (which contributed 26%), and the Republic of Korea (6%), as well as several European countries such as Germany (13%), France (4%), and Switzerland (4%) — contributed the most to internationally oriented patent families for smart-grid technologies (see Figure 12).[21] Between 2005 and 2010, inventions from middle-income economies amounted to 4% of total internationally oriented smart-grid patent families and came mostly from applicants of Chinese (2%) or Indian (1%) origin. In the following years, however, this share increased to almost 7% because of fast growing international patenting activity from China, mostly related to two sub-fields of in smart-grid technologies: *Electrical power generation, transmission or distribution* and ICT–*specific aspects*.

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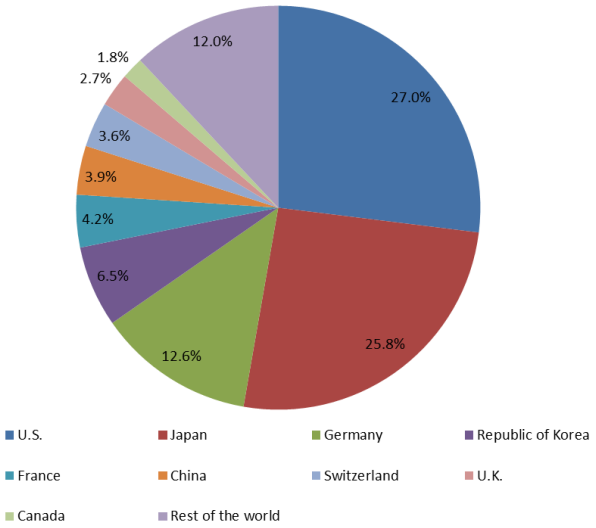
[19] For the EPO Y02/Y04S classification scheme, see http://www.epo.org/news-issues/issues/classification/classification.html.

[20] A 'smart grid' is an electrical grid that uses state-of-the-art information and communication technology to enable different components of the electricity network, such as electricity metres, substations, and power plants, to be connected and to interact with each other, exchanging data on current energy generation and consumption, or on power outages, in real time. The Y04S tagging scheme for smart-grid technologies consists of the following five elements:

- Electrical power generation, transmission or distribution
- Management or operation of end-user stationary applications (e.g., smart metering)
- Systems supporting end-user applications in transportation (e.g., electric vehicle operability)
- ICT-specific aspects
- Market-specific activities (e.g., energy trading and marketing).

[21] An 'applicant country' is the country of the first applicant in the first filing. If applicant country information was not available from the first filing, it was obtained from later patent family publications.

Figure 12: Number of internationally oriented smart-grid patent families by country of origin, 2005–2014.



Source: EPO, based on PATSTAT, spring 2018, available at www.epo.org/PATSTAT.

Source: This box was contributed by the EPO using the Y02/Y04S tagging scheme, as referenced in EPO, 2013.

Charging stations for electric vehicles

China is also becoming a world leader in the patenting of green transportation technologies in recent years. Figure 13 shows the evolution of patent filings of one specific technology within green transportation: charging stations for electric vehicles (EVs). This specific technology accounts for 22.7% of all patent families in transportation technologies for vehicles in general in the period 2005-15. The number of patent families for this technology increased by 16.2% on average each year in the period 2005-14, which is the second highest in the period just after electric propulsion technologies that registered an annual growth in filings of 19.5% in the same period.

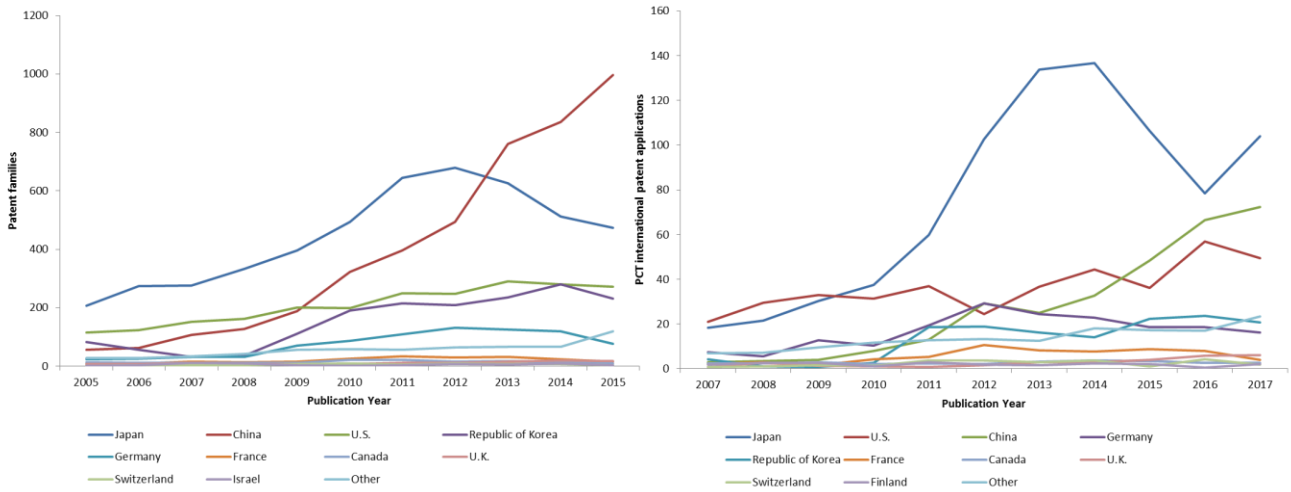
With regards to patent families, Japan and China together account for 59% of all patent families in charging stations for EVs in the period 2005-15. For PCT international patent applications, Japan, the U.S. and China together account for 70% of all applications in the period 2007-17.

China has experienced extraordinary growth in the number of patent families in this technology. It has multiplied by almost 18 times its number of patent families, passing from 56 in 2005 to 997 in 2015. This represents an average annual growth of 33.5% in the total number of patent families. No other country has experienced such growth, and it remains the second top origin for this technology in the period 2005-15. China accounts for 25.4% of all families, just after Japan (33.7%). It has effectively surpassed the number of U.S. families since 2010 and the number of Japanese patent families since 2013.

Figure 13: Patent filings in the green transportation technology "Charging stations for electric vehicles", by origin

Patent families in "charging stations for electric vehicles" by origin, 2005–15

PCT international patent applications in "charging stations for electric vehicles" by origin, 2007–17



Source: WIPO based on PATSTAT and WIPO IPC Green Inventory (left); and WIPO Statistics Database and WIPO IPC Green Inventory (right)

Chinese PCT international patent applications in technologies for charging stations for EVs also surpassed the number of U.S. applications in this technology area since 2015. China represents 14% of all PCT international patent applications in the period 2007-17. The number of applications has grown on average by 37% each year.

4. Conclusions

This paper uses statistical analysis to identify the main trends in the field of green energy technologies with the aim of better tracking technological inventions in this field. It makes use of the IPC Green Inventory of WIPO to describe the main characteristics and evolution of patent filings in four broad categories of green energy technologies: alternative energy production, notably renewable energy technologies; energy conservation technologies; green transportation; and nuclear power generation. It has informed and guided the preparation of the 2018 edition of the Global Innovation Index.

Our results show that green energy technologies have been growing very quickly in the last decade. However, we also show that patenting activity in green energy technologies have decelerated in recent years, and have even declined for some technologies, notably alternative energy production technologies and nuclear power generation technologies. But, why are these slowdowns or declines in green energy technologies taking place in the face of increased need for energy innovation? And what could explain the deceleration of patenting activities notably in alternative energy production technologies?

The reasons for green energy patenting slowdown are not entirely clear. Many factors could be at play. This slowdown could be a sign of existing obstacles in the diffusion of energy innovations, but also the presence of fewer subsidies and, possibly, diminished technological opportunities, signaling the maturity of basic technologies after a first wave of innovations. Specifically for photovoltaics (PV), the most recent *World Intellectual Property Report* 2017 of WIPO (2017b), showed that the shift in global value chain production — combined with the steep fall in prices — have put many traditional PV manufacturers in the U.S., Europe,

and elsewhere under competitive pressure, resulting in bankruptcies and acquisitions. This partly explains the decline in PV patent filings worldwide after 2011. However, the complete picture is more nuanced. Since 2011, patent applications have in fact continued to increase where most of the filings are observed (e.g. China, Japan, U.S.). With low prices that result in tight profit margins surviving firms have increased their their R&D investments in order to develop new technologies that are more cost competitive. Patenting among surviving firms has increased as a result.[22]

A lack of prioritization of green energy innovation as a result of declining oil and fossil fuel prices, which decrease the incentives to go green, could also play a role in the deceleration. Other aspects should also be accounted for. As renewable energies become mature, one can expect that the number of inventions and innovations deaccelerates. Moreover, deceleration could also signal failing technology adoption instead of diminishing opportunities for technological innovation. In other words, the green energy technologies required to curb emissions exist, yet the obstacles to their diffusion are manifold.

Innovation in green energy technologies might be moving towards technologies that enable more alternative energy production technologies, such as EVs or batteries. This is in line with some of the findings of this research: patent filings in energy conservation technologies and green transportation technologies continue to increase, even if at a slower pace.

Our research also finds that green energy technology patents are highly concentrated in a few origins. Only four countries, Japan, the U.S., Germany and China account for over 60% of all patent families and PCT international patent applications in green energy technologies. A decline in internationally oriented patenting activity has been observed for Japan and the U.S. since 2011, while a decline is observed for Germany since 2012. In contrast, the growth of Chinese filings in the field has been extraordinary in most green energy technologies. China is notably becoming a world leader in the patenting of green transportation technologies in recent years. However, our findings also suggest that the extraordinary growth in the number of Chinese patent families in green energy technologies mostly refer to those filed at home.

Finally, we hope that this research is a useful contribution of WIPO to the green energy innovation debate in relevant fora. To our knowledge it is the first time that the IPC Green inventory has been used for statistical analysis and the reporting of main green energy innovation trends.

[22] See Carvalho et al. , 2017; and de la Tour et al. , 2011.

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Appendix A: Hierarchical detail of IPC Green Inventory topics and sub-topics covered related to energy innovation

Topic	Sub-topics		
Alternative Energy Production	Bio-fuels	Solid fuels	Torrefaction of biomass
		Liquid fuels	Vegetable oils
			Biodiesel
			Bioethanol
		Biogas	
		From genetically engineered organisms	
	Integrated gasification combined cycle (IGCC)		
	Fuel cells	Electrodes	Inert electrodes with catalytic activity
		Non-active parts	
		Within hybrid cells	
	Pyrolysis or gasification of biomass		
	Harnessing energy from manmade waste	Agricultural Waste	Fuel from animal waste and crop residues
			Incinerators for field, garden or wood waste
		Gasification	
		Chemical waste	
		Industrial waste	Using top gas in blast furnaces to power pig-iron production
			Pulp liquors
			Anaerobic digestion of industrial waste
			Industrial wood waste
		Hospital waste	
		Landfill gas	Separation of components
		Municipal waste	
	Hydro energy	Water-power plants	Tide or wave power plants
		Machines or engines for liquids	Using wave or tide energy

Topic	Sub-topics			
		Regulating, controlling or safety means of machines or engines		
		Propulsion of marine vessels using energy derived from water movement		
	Ocean thermal energy conversion (OTEC)			
	Wind energy	Structural association of electric generator with mechanical driving motor		
		Structural aspects of wind turbines		
		Propulsion of vehicles using wind power	Electric propulsion of vehicles using wind power	
		Propulsion of marine vessels by wind-powered motors		
	Solar energy	Photovoltaics (PV)	Devices adapted for the conversion of radiation energy into electrical energy	Using organic materials as the active part
			Assemblies of a plurality of solar cells	
			Silicon; single-crystal growth	
			Regulating to the maximum power available from solar celles	
			Electric lighting devices with, or rechargeagle with, solar cells	
			Charging batteries	
			Dye-sensitised solar cells (DSSC)	
		Use of solar heat	For domestic hot water systems	
			For space heating	
			For swimming pools	
			Solar updraft towers	
			For treatment of water, waste water or sludge	
			Gas turbine power plants using solar heat source	
		Hybrid solar thermal-PV systems		

Topic	Sub-topics		
		Propulsion of vehicles using solar power	Electric propulsion of vehicles using solar power
		Producing mechanical power from solar energy	
		Roof covering aspects of energy collecting devices	
		Steam generation using solar heat	
		Refrigeration or heat pump systems using solar energy	
		Use of solar energy for dying materials or objects	
		Solar concentrators	
		Solar ponds	
	Geothermal energy	Use of geothermal heat	
		Production of mechanical power from geothermal energy	
	Other production or use of heat, not derived from combustion, e.g. natural heat	Heat pumps in central heating systems using heat accumulated in storage masses	
		Heat pumps in other domestic- or space-heating systems	
		Heat pumps in domestic hot-water supply systems	
		Air or water heaters using heat pumps	
		Heat pumps	
	Using waste heat	To produce mechanical energy	
		Of combustion engines	
		Of steam engine plants	
		Of gas-turbine plants	
		As source of energy for refrigeration plants	
		For treatment of water, waste water or sewage	
		Recovery of waste heat in paper	

Topic	Sub-topics		
		production	
		For steam generation by exploitation of the heat content of hot heat carriers	
		Recuperation of heat energy from waste incineration	
		Energy recovery in air conditioning	
		Arrangements for using waste heat from furnaces, kilns, ovens or retorts	
		Regenerative heat-exchange apparatus	
		Of gasification plants	
	Devices for producing mechanical power from muscle energy		
Transportation	Vehicles in general (e.g. hybrid vehicles, electric propulsion)	Hybrid vehicles, e.g. Hybrid Electric Vehicles (HEVs)	Control systems
			Gearings therefor
		Brushless motors	
		Electromagnetic clutches	
		Regenerative braking systems	
		Electric propulsion with power supply from force of nature, e.g. sun, wind	
		Electric propulsion with power supply external to vehicle	With power supply from fuel cells, e.g. for hydrogen vehicles
		Combustion engines operating on gaseous fuels, e.g. hydrogen	
		Power supply from force of nature, e.g. sun, wind	
		Charging stations for electric vehicles	
	Vehicles other than rail vehicles	Drag reduction	
		Human-powered vehicle	
	Rail vehicles	Drag reduction	
	Marine vessel propulsion	Propulsive devices directly acted on by wind	

Topic	Sub-topics		
		Propulsion by wind-powered motors	
		Propulsion using energy derived from water movement	
		Propulsion by muscle power	
		Propulsion derived from nuclear energy	
	Cosmonautic vehicles using solar energy		
Energy conservation	Storage of electrical energy		
	Power supply circuitry	With power saving modes	
	Measurement of electricity consumption		
	Storage of thermal energy		
	Low energy lighting	Electroluminescent light sources (e.g. LEDs, OLEDs, PLEDs)	
	Thermal building insulation, in general	Insulating building elements	For door or window openings
			For walls
			For floors
			For roofs
			For ceilings
	Recovering mechanical energy	Chargeable mechanical accumulators in vehicles	
Nuclear power generation	Nuclear engineering	Fusion reactors	
		Nuclear (fission) reactors	
		Nuclear power plant	
	Gas turbine power plants using heat source of nuclear origin		

Source: WIPO IPC Green Inventory