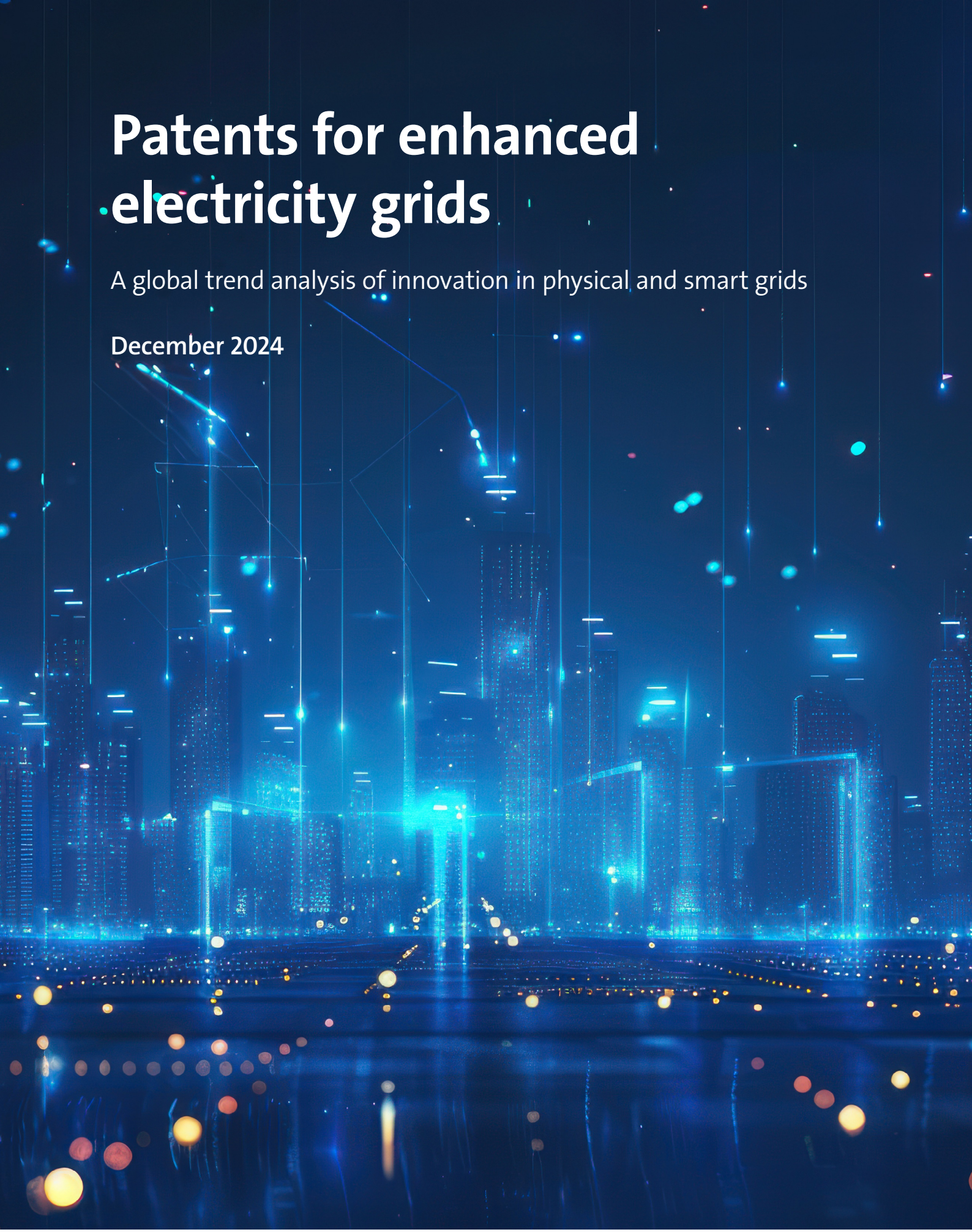
Patents for enhanced electricity grids

A global trend analysis of innovation in physical and smart grids

December 2024



Europäisches Patentamt
European Patent Office
Office européen des brevets

International Energy Agency

Executive summary

Electricity is at the core of ongoing energy transitions. Electricity demand has grown at twice the pace of overall energy demand over the last decade, and the growth of electricity consumption is set to accelerate further in the years ahead. To achieve countries' national energy and climate goals (which go beyond policies currently in place), the world's electricity use needs to grow 20% faster in the next decade than it did in the previous one. On the supply side, electricity grids will continue to incorporate more renewable resources with variable output and different geographical distributions to current grid layouts. At the same time, many countries face rising investment needs to update ageing grid infrastructure to make it fit for modern energy systems: roughly 50 million km of older transmission and distribution lines will need to be replaced around the world by 2050.

Modern, smart and expanded grids are therefore essential for successful energy transitions. Ensuring competitiveness, security and affordability while refurbishing, extending and optimising electricity grids to more flexibly connect sources of power supply and demand are technology innovation challenges, as well as investment and policy challenges. There are many opportunities for innovators to accelerate clean energy transitions with improved grid-related technologies and capture the economic value associated with the growing market for these solutions.

However, electricity grids are often the unsung heroes of energy transitions and their infrastructure is a familiar and uninspiring part of the landscape. At best they are taken for granted, and at worst their expansion is hindered by local opposition. There is a risk that if too little attention is paid to creating new products and services to reduce the costs and improve the performance of grid technologies – including by reducing the need for overhead lines and helping electricity customers monetise their consumption choices – then grids could become a bottleneck to the modernisation of energy systems.

As this report shows, researchers and innovators around the world are responding to the challenge. Over the past 19 years, patenting of electricity grid technologies has increased to levels roughly seven times higher than in 2005. Thanks to robust data on the technological, geographic and corporate distribution of this patenting activity, governments and innovators can track the trends and gaps that concern them. As a leading indicator of technological change, patent data complement other sources of information to yield actionable insights related to regional advantages, competitive weaknesses and strategic opportunities.

This study combines the expertise of the International Energy Agency and the European Patent Office and is the most comprehensive, global and up-to-date investigation so far of patenting in the area of key electricity grid issues and opportunities. The study identifies three groups of critical challenges technology can help address. While there is huge scope for making the power network "smarter" – a process that is already well underway and involves overlaying a network of communications systems on top of the network that transports the electricity itself – each of the three challenges can only be overcome with a mixture of hardware and software improvements. While patenting in smart grid technologies is a faster-moving area, the volume of patenting to enhance physical grids is not far behind and keeping up innovation efforts in this area will be crucial in the decades to come.

Key findings

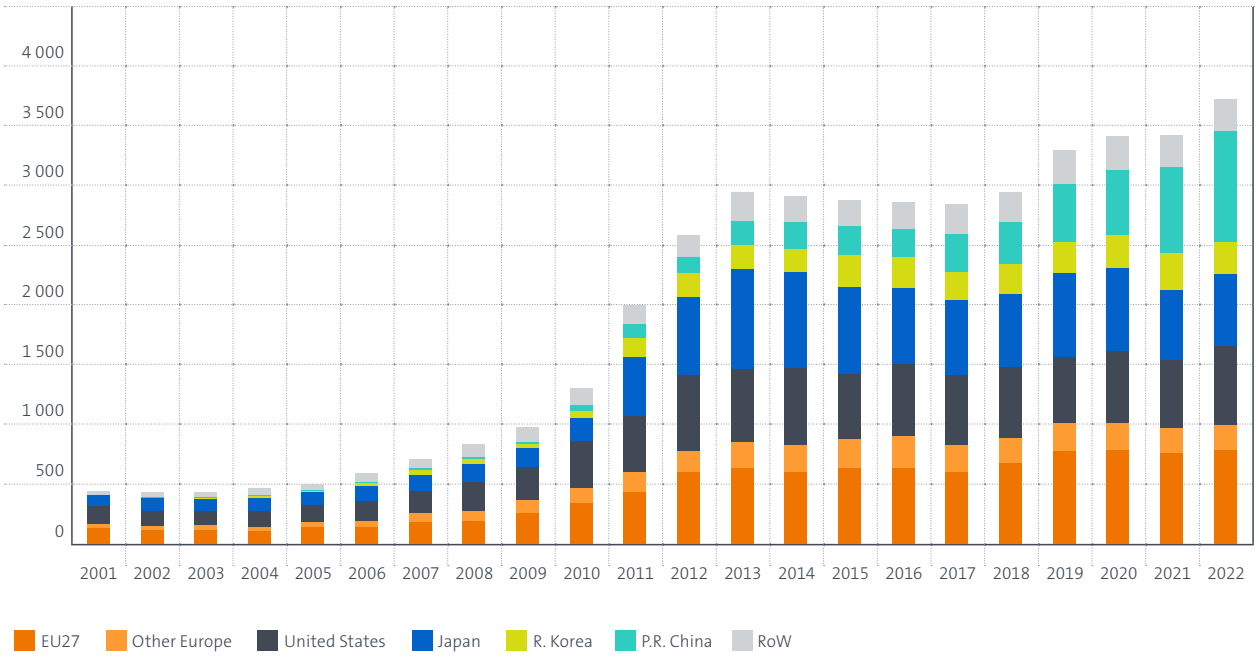
1. Grid-related patenting experienced a dramatic acceleration over the period 2009–2013. It has since stabilised in most major regions, with the exception of P.R. China; in 2022, the country overtook the EU for the first time, becoming the largest regional source of applications

Patenting activities in grid-related technologies grew at remarkable speed between 2009 and 2013. Over this period, the number of international patent families (IPFs)[1] related to grids increased at an average annual growth rate of 30% – well above the average rates of 12% for low-carbon energy technologies (EPO-IEA, 2021) and 4% for all technologies. This take-off phase reflects a period of intense industrial interest in a new suite of smart grid technologies, driven by the creation of policy-driven markets and standards for smart meters and electric vehicles, as well as the prospect of the swifter deployment of renewable energy sources of energy. The trend was also gathered impetus thanks to the emergence of software innovation as a major corporate strategy in this period. This expanded the scope of smart grid inventions being patented, resulting in 50% more physical grid patents containing smart grid elements in the period 2010–2022 than in the preceding decade.

This impressive growth mostly occurred in Europe, Japan and the US, and patenting activities remained stable at a high level afterwards in these regions. At the same time, steady progress has enabled P.R. China to gradually emerge as the new global engine of electricity grid patent growth, rising from 7% of the global total in 2013 to 25% in 2022. In that year, P.R. China became the world's top patenting region in this technology area for the first time.

Figure E1

Patenting trends by main world region (IPFs, 2001-2022)



Note: Calculations are based on country of IPF applicant, using fractional counting in the case of co-applications.

Source: author's calculations

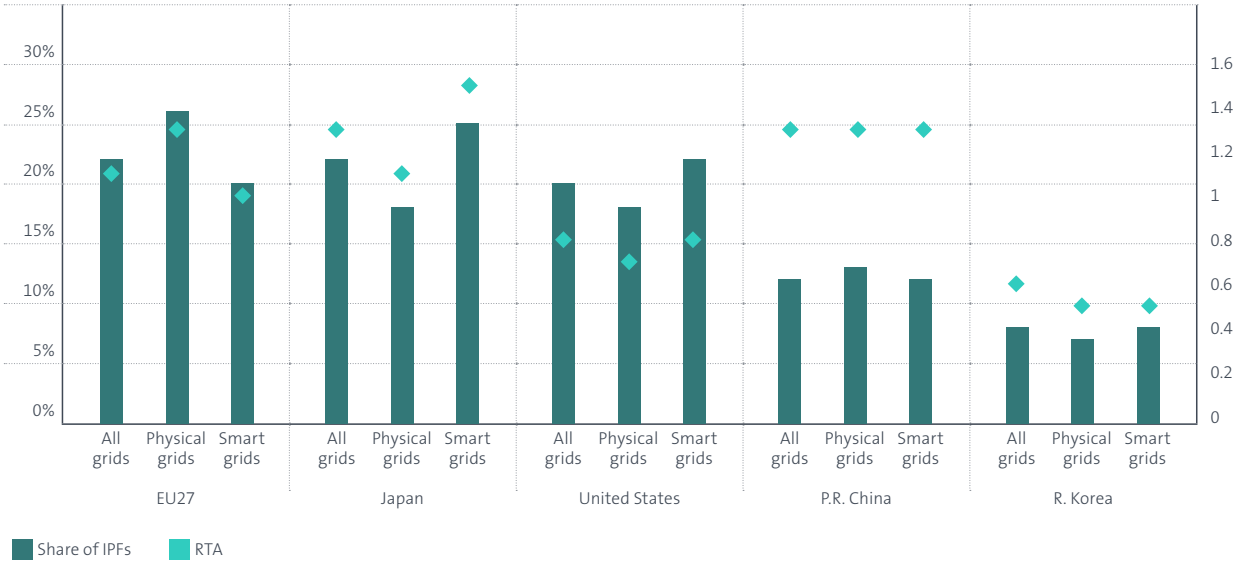
[1] Each IPF covers a single invention and includes patent applications filed and published at several patent offices. It is a reliable proxy for inventive activity because it provides a degree of control for patent quality by only representing inventions for which the inventor considers the value sufficient to seek protection internationally. The patent trend data presented in this report refer to numbers of IPFs.

2. The EU27 and Japan have led electricity grid patenting over the past decade

The EU27 and Japan each generated more than one-fifth of IPFs related to grids over the period 2011-2022, and they possess a relative technology advantage (RTA) in these technologies compared with non-grid technology areas.[2] Europe's contribution has drawn primarily upon expertise in physical grid technologies – Switzerland alone generated 5% of all grid-related IPFs – while Japan shows a stronger relative specialisation in smart grid technologies. Among other regions, the United States contributed 20% of patenting activities related to grids, but does not have any relative specialisation in the field. P.R. China's share of all grid-related IPFs between 2011 and 2022 was significantly lower, but shows a specialisation in both physical and smart grid technologies as high as that of the EU.

Figure E2

Share of international patenting and revealed technology advantage by main world region and main type of grid-related technologies (IPFs, 2011-2022)



Note: Calculations are based on country of IPF applicant, using fractional counting in the case of co-applications.

Source: author's calculations

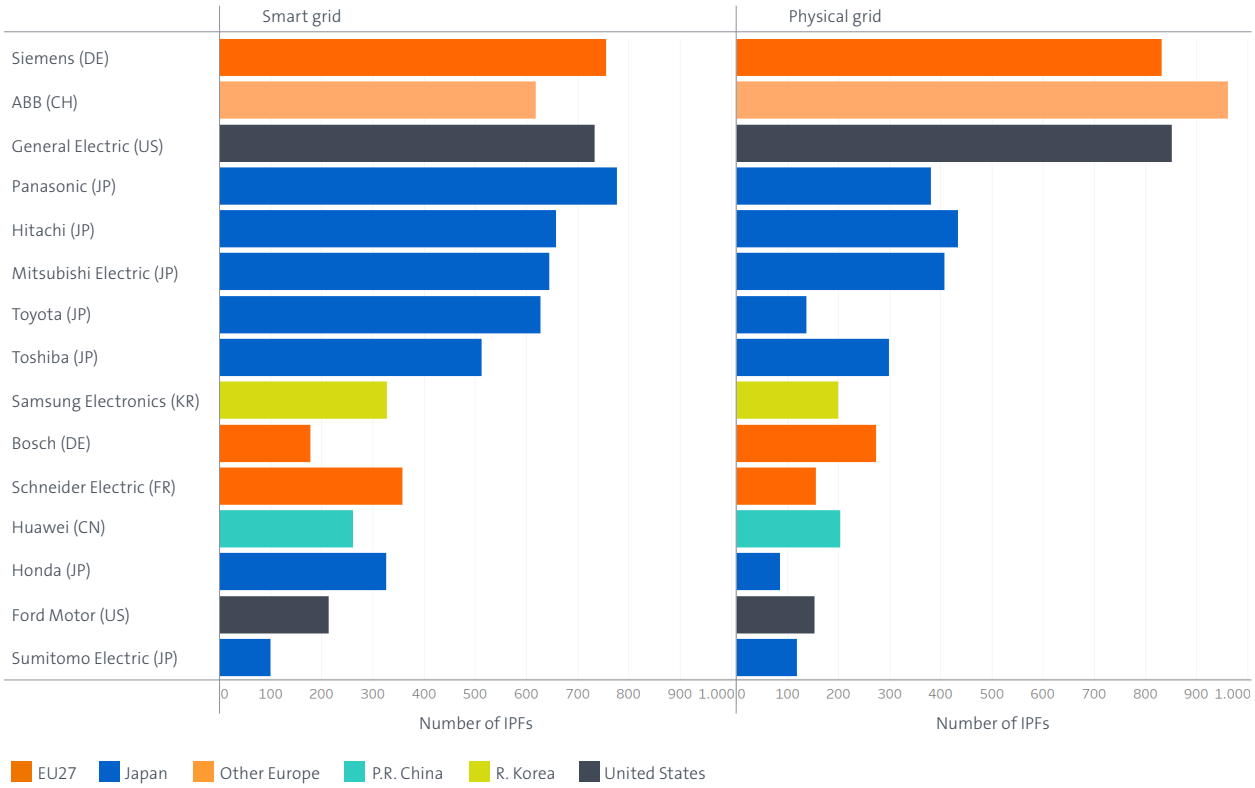
[2] The RTA index indicates a country's specialisation in terms of grid-related innovation relative to its overall innovation capacity. It is defined as a country's share of IPFs in a particular field of technology divided by the country's share of IPFs in all fields of technology. An RTA above one reflects a country's specialisation in a given technology.

3. Siemens, ABB and General Electric lead the ranking of electricity grid patent applicants, which is testament to their strengths in physical grid technologies in particular. They face strong Asian competitors when it comes to innovation in smart grids

The top 15 corporate applicants listed alone generated nearly one-third (31%) of IPFs in grid-related technologies over the period 2011-2022. Their cumulative share of IPFs is slightly higher in physical grid technologies (35%, compared to 31% in smart grids). Siemens, General Electric and ABB, three large conglomerates from Germany, the US and Switzerland respectively, lead the ranking. However, seven Japanese applicants feature too, all with a stronger specialisation in smart grids. The remaining top applicants include R. Korea's Samsung Electronics, France's Schneider Electric and P.R. China's Huawei, a telecom equipment company expanding into smart grids. Three automotive companies (Toyota, Honda and Ford Motor) feature in the ranking as a result of their strong contribution to innovation in smart EV charging.

Figure E3

Top 15 applicants in grid-related technologies (IPFs, 2011-2022)



Note: Applicants are ranked by total number of IPFs in grid-related technologies. Some of these may be relevant to more than one of the three subcategories shown; they are reported under each of these subcategories. The IPFs filed by ABB Grid have been consolidated under Hitachi.

Source: author's calculations

4. Smart grid innovation is driving the latest burst of electricity grid patenting. Although a great deal of attention is given to innovations helping customers control electricity demand, the largest smart grid patenting areas relate to control of larger grid-scale assets

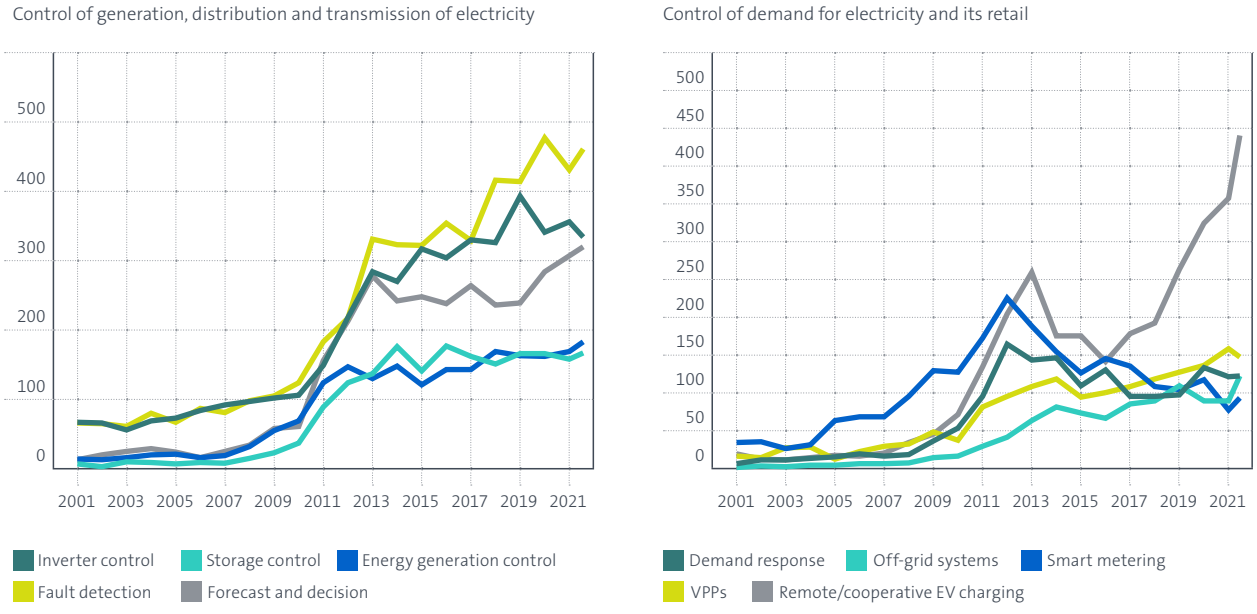
Smart technologies are being developed to address problems across nearly all aspects of electricity grids. Patenting activities in the control of grid-scale assets took off around 2010 and has kept increasing steadily since then. Japanese applicants have a strong lead in fields such as forecast and decision or remote control of inverters and electricity storage assets; the recent acceleration of patenting in fault detection has chiefly been driven by Chinese applicants.

Smart metering was the first customer-oriented field to show an increase in patenting, mainly in the US and Europe, but has shrunk significantly after a burst of activity during the period when they were first being rolled out. More generally, patenting trends tend to be more volatile on the customer side of smart grids, due to shorter product development times and the standardisation of protocols and interfaces for grid-connected equipment. As a result, it is important for innovators to secure intellectual property early in the development of new smart grid technology areas, as they may not enjoy long subsequent periods of incremental improvements.

A similar dynamic is seen in EV charging patenting, though this has returned to impressive growth since 2015 as new techniques for aggregation and remote control have emerged. The new growth phase coincides with a shift in patenting activities from equipment suppliers to OEMs, signalling the latters' increased strategic interest in mastering smart charging technology. Overall, Japanese applicants alone account for about one-third of IPFs in that field over the period 2011-2022, followed by US and European ones with about 20% each.

Figure E4

Growth of patenting in selected smart grid technologies (IPFs, 2001-2022)



Source: author's calculations

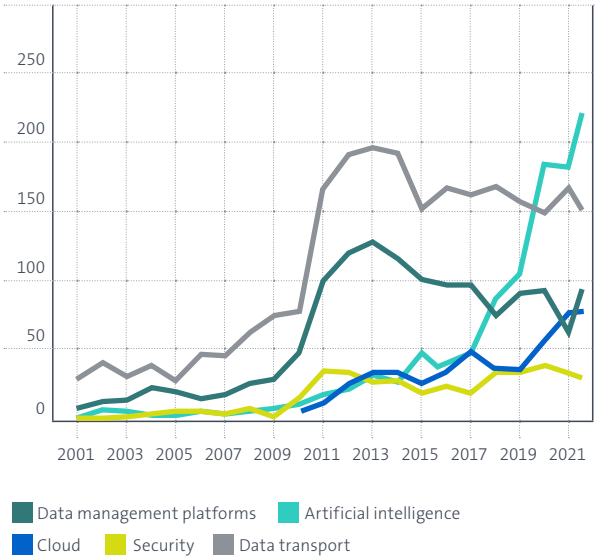
5. Grid-related AI patenting grew by over 500% in the five years to 2022, and is now the most active area of patenting among enabling digital technologies, led by the United States and P.R. China

The main area of AI-related IPFs is those to support forecast and decision, a category that boasts 39% of AI-related IPFs and drove rapid growth of AI-related electricity grid patenting from 2000 to 2022. AI is nonetheless applied in patents related to other areas of smart grids, in particular micro-grids and outage management. The US and China are the main patenting regions for these technologies, with 24% and 23% of AI-related IPFs respectively, followed by the EU27 countries with 18%.

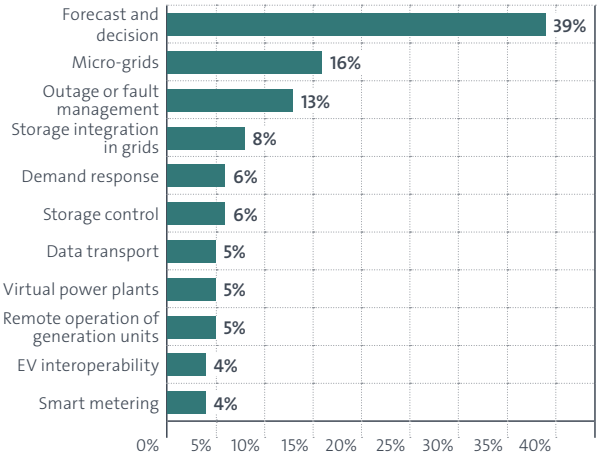
Figure E5

The growing impact of AI on innovation in smart grids

Patenting trends in selected enabling technologies for smart grids (IPFs, 2001-2022)



Smart grid technologies targeted by AI-related IPFs (2011-2022)



Note: The chart on the right shows the percentage of IPFs related to AI for grids that have also been identified as related to another category of smart grid technologies. Some of these may relate to two or more such categories; others may have no clearly identified relation to any of them.

Source: author's calculations

6. One-third of startups in electricity grid technologies hold a patent application, which is much higher than in other technology areas. These startups are mostly located in Europe and the United States

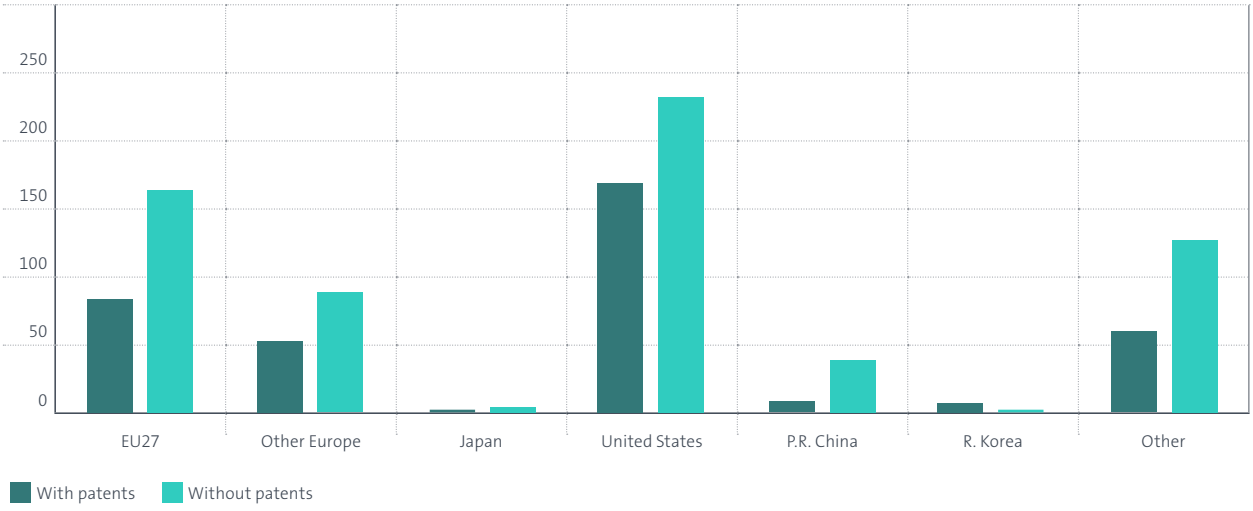
358 of the 1 085 startups identified for this report with activities relating to electricity grid technologies hold at least one IPF. This proportion is remarkably high, compared for instance with the estimated 6% share of all European startups that have a patent application. It is a positive indicator of fundraising capacity for grid-related startups, given the available evidence showing patent ownership has a positive impact of on startups' ability to attract VC funding (EPO-EUIPO, 2023).

Among smart grid technologies, one-third of startups are working on grid optimisation, and one-quarter on electricity trading. Other important areas include VPPs (20%) and meter hardware (14%). Contrary to expectations, around half of startups are developing hardware, a high-risk innovation path that typically requires patient investors and high upfront capital. Government attention should be given to the successes and difficulties encountered by these startups, to identify whether innovation ecosystems adequately support grid hardware entrepreneurs.

Most of the startups are located in the US and Europe, with each of those two regions contributing about 39% of the total, and 24% for the EU27 alone. By contrast, the small numbers of startups identified in P.R. China, R. Korea and Japan suggest a lesser role for venture capital in these countries' innovation ecosystems. Apart from these main regions, Canada (with 50 startups), India (30) and Israel (13) stand out for sizeable ecosystems of grid-related startups.

Figure E6

Startups in grid-related technologies: number of startups and patenting profile by main world region, 2011-2022



Source: author's calculations

The full report is available for download at:
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