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TRENDS IN WATER-RELATED TECHNOLOGICAL INNOVATION: INSIGHTS FROM PATENT DATA – ENVIRONMENT WORKING PAPER No. 161

By Xavier Leflaive, Ben Krieble and Harry Smythe (1)

(1) OECD Environment Directorate.

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Keywords: water pollution, droughts, floods, innovation, patent, green tech.

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Abstract

Innovation has a role to play to mitigate water-related risks and to support the provision of water services on which our well-being and sustainable development depend. Water-related innovation originate in a wide range of countries, with different levels of ambition. They disseminate at different scales globally.

This paper uses patent data to document trends in the invention of technologies to promote water security since 1990, focusing on the countries in which inventions are developed, where they might be commercialised, and in which subsectors they originate. The water-related technologies identified in the paper can be clustered into three categories: i) water pollution abatement; ii) demand-side; and iii) supply-side.

The paper describes a number of important trends that can inform a broader discussion on the factors that might hinder, or enhance, inventive activity to promote water security.

Keywords: water pollution, droughts, floods, innovation, patent, green tech

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Résumé

L'innovation a un rôle à jouer dans la gestion des risques liés à l'eau et la production des services d'eau et d'assainissement dont dépendent notre bien-être et le développement durable. De nombreux pays contribuent à l'innovation dans le domaine de l'eau avec des ambitions différentes. Ces innovations diffusent de manière inégales au niveau global.

Ce rapport utilise des statistiques sur les brevets pour renseigner des tendances dans les nouvelles technologies qui contribuent à la gestion de l'eau, depuis 1990. Il identifie les pays où les innovations émergent, ceux où elles sont commercialisées, et à quels sous-secteurs elles appartiennent. Il couvre trois ensembles de technologies : celles qui contribuent à la gestion de la pollution, de la demande ou de l'offre d'eau.

Le rapport décrit plusieurs tendances importantes susceptibles d'enrichir des discussions sur les déterminants qui encouragent ou freinent les innovations dans le domaine de l'eau.

Mots clé : pollution de l'eau, sécheresse, inondation, innovation, brevet, technologies vertes

Classification JEL : O13, O31, O38, Q25, Q55

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Executive Summary[1]

Water insecurity has been increasing in much of the world due to pressures from climate and demographic changes, as well as economic growth and development (OECD, 2013[1]). To respond to these challenges, countries must find innovative ways to address and finance improvements in water security. In some instances, this will entail greater investment in built and natural infrastructure. Technological advances are set to play a major role in achieving policy aims to reduce water risks.

This paper uses patent data[2] to explore trends in the invention of technologies to promote water security since 1990, focusing on the countries in which inventions are developed, where they might be commercialised, and in which subsectors they originate. The paper describes a number of important trends that can inform a broader discussion on the factors that might hinder, or enhance, inventive activity to promote water security.

The water-related technologies identified in the paper can be clustered into three categories: i) water pollution abatement; ii) demand-side (conservation of water in indoor use, in irrigation, in thermoelectric power production and in water distribution); and iii) supply-side (availability of water, through collection of rain, surface and ground-water; water storage; desalination of sea water). Between 1990 and 2016, water pollution abatement technologies accounted for over three quarters of water-related patents worldwide, while demand-side and supply-side technologies comprised 18% and 5%, respectively. Together, the three categories have accounted for about 1.3% of all patents globally.

Recently, the level of patenting of water conservation and availability technologies has been higher than the overall rate of patenting for all (non-water) environmental technologies, suggesting an increasing focus on the need for better management of water resources and an increasing interest in innovation for addressing water quality and quantity issues. Amongst demand-side (conservation) technology patenting, inventions to conserve water during thermoelectric power production have grown at an especially high rate, with more than 10 times more patents per year in 2012 and 2016 compared to 1990. Conversely, inventions in water distribution and conservation of irrigation water have grown slower than other demand-side technologies and total inventions. Another rapidly growing area of invention has been in water storage, albeit from a low base. This may reflect an increasing focus on the risks of drought, climate change-induced shifts in rainfall patterns, and other risks to water supply.

[1] OECD Working Papers should not be reported as representing the official views of the OECD or of its member countries. The opinions expressed and arguments employed are those of the authors. Working Papers describe preliminary results or research in progress by the author(s) and are published to stimulate discussion on a broad range of issues on which the OECD works. Comments on Working Papers are welcomed, and may be sent to the Environment Directorate, OECD, 2 rue André-Pascal, 75775 Paris Cedex 16, France.

[2] Patent data have a number of attractive properties compared to other alternatives: they are widely available, quantitative, commensurable, output-oriented and capable of being disaggregated. At the same time, not all innovations or inventions are patented, and measuring the number of patents by itself does not provide an indication of their relative importance and impact. See Haščič I., Migotto M. (2015) for a more detailed discussion of the relevance of patent data to measure environment-related innovation.

The five largest overall inventors of the world's water-related technologies, by patent count, are the US, Korea, Germany, China, and Japan, with about 70% between them. China and Korea have exhibited substantial growth in their share of world patenting, for water-related and all technologies, while Germany's share has steadily fallen. Korea, in particular, went from less than 1% of the world's water-related patents in 1990 to more than a quarter since 2009. The top inventor countries are also major potential markets for the technologies, reflecting partly the propensity of inventors to protect their inventions in their country of residence, but also the attractiveness of these markets to foreign inventors. Nonetheless, patent protection for water-related technologies is sought at about, or at a lower rate than, the rate at which patent protection is sought for all technologies in those countries.

The countries with the largest share of water-related patenting activity in all technology patenting activity include Saudi Arabia, Chile, Moldova, Colombia, Slovak Republic, Hungary and Mexico. For instance, in Saudi Arabia, roughly one out of every 15 inventions is water-related, compared to the world average of 1 in 77. This suggests that even if countries do not account for a major share of overall water-related technologies, domestic factors, including institutional settings and environmental pressures, can lead to a relative specialisation in water-related technologies compared to other technological domains. Indeed, despite accounting for a small share of the world's inventions in water security (about 1.2%), the most water-stressed countries have a pronounced relative technological advantage in those technologies, registering about 30% more patents than would be expected based on their share of overall patents. Conversely, the least water-stressed have a relative disadvantage. This suggests necessity is only one parent of invention, as a country's economic size and general propensity to innovate are also likely important factors giving rise to inventive activity.

The countries where water-related patent protection is most sought after (considered as a proxy for potential demand for water-related technologies) are also the biggest inventors, the US, Europe (lead by Germany), Japan, China, and Korea. This reflects the fact that i) a large share of inventions originate in these countries, and ii) these countries have potential importance as markets for water-related technologies. However, this is true for most types of technology. The most water-stressed countries tend to specialise in demand-side technologies and host about 50% more water-related patented technologies than they do other technologies. Conversely, the least water-stressed countries attract water-related technologies at a much lower rate than technologies overall. For countries in between the extremes of water stress, there is a negative relationship between water stress and the preponderance of water-related patents over all patents held in these countries. This suggests the attractiveness of a market for water-related technologies may be partly related to water stress, and partly to other factors, such as the size of a country's economy, the strength of its intellectual property regime, or the ease of registering a patent priority there.

There are a number of messages policy makers, inventors, and financiers can take from these findings. Policy makers can better target research and development spending and other policies to support invention by understanding how their own country ranks in specific subsectors and where relative technological advantage may or may not exist. Inventors can use this data to understand in which types of technologies patents are being successfully registered, which might indicate areas being targeted by other inventors. They can also learn in which markets other inventors are seeking protection for their inventions, indicating where inventions might be most readily commercialised. Financiers can explore which technology domains are producing inventions and the growth trends over time, to better understand their own portfolio and exposure to different subsectors and geographies.

Further analysis is required to separate the effects of water stress on the propensity to innovate and to seek patent protection in a particular country from other contributing factors and to better understand the determinants of innovation (including the role of environmental policies). The extent to which inventors actively target international markets or respond to local conditions, and the characteristics of inventor countries and companies also requires further inquiry.

The paper clearly confirms that water-related innovation is a vibrant industry globally. One pending issue is the pace of diffusion of innovation and their deployment in countries where they are needed. While a lot of attention is paid to the supply of new technologies, equally important is the enabling environment that stimulate demand for and the diffusion of innovation: robust water policies that make pollution costly and that signal the opportunity costs of using water when and where it is scarce drive the pace of technology diffusion.

Introduction

At least since September 2015 and the adoption of the 2030 development agenda, the global community acknowledges that water is a driver to sustainable development at local, national and global level. However, the world is not on track to meet its commitments as regards water management, and this comes at high costs for communities, the environment and economies globally.

More than 2 billion people lack access to safe drinking water and 4.5 billion people do not have access to safely-managed sanitation. FAO estimates that about 50 percent more food will be needed by 2050 to meet the requirements of a growing population with changing dietary patterns; this will require secured access to good quality water. Climate change only compounds the challenges related to water management, adding uncertainty to water availability and demand.

New technologies have a crucial role to play to ensure communities can benefit from water's myriad productive uses, maintain ecosystem services, and manage water-related risks. Innovation can capture fully the potential for water storage (for use during droughts and/or for power generation), conservation (for cost reduction and efficiency gains), and other beneficial uses. It can help to treat and recycle wastewaters and prevent pollution of ecosystems. It can help mitigate risks of floods.

Technological innovation in many fields helps to enhance water security, which the OECD defines as achieving an acceptable level of four distinct risks: the risk of too much water (flooding), of too little water (drought), of water of poor quality, and of degradation of freshwater ecosystems (OECD, 2013[1]).

This paper[3] analyses data from the OECD.Stat database, which identifies water security-enhancing inventions in a number of domains, broadly categorised as water pollution

[3] This paper extends on Dechezleprêtre, Haščič and Johnstone (2015), exploring a larger range of water-related technologies and using data from more recent years.

abatement, supply-side, or demand-side technologies, as listed in Table 1. The source of the underlying data – i.e. the EPO World Patent Statistical database - covers over 200 jurisdictions since 1990, including which types of water-related technologies are being patented, where technological invention is occurring, and where inventors seek patent protection.

Table 1. Water-related Technologies in OECD.Stat Database

	Technologies Included			
Water Pollution Abatement	Water and wastewater treatment	Fertilisers made from wastewater, sewage sludge etc.	Oil spill clean-up	
Demand-side (Conservation)	Indoor water conservation (faucets, showers, aeration, sanitation, home appliances, etc.)	Irrigation water conservation (drip irrigation, watering control, drought resistant crops)	Water conservation in thermoelectric power production	Water distribution (piping, leak prevention, monitoring, and detection)
Supply-side (Availability)	Surface, ground, and rain water collection	Water storage		

Note: See Annex B for full descriptions of technologies included and their associated patent codes.
Source: Haščič and Migotto (2015)

While these patents are likely to represent a significant share of water-related technologies, the search strategies employed to populate the OECD.Stat database may not cover all possible relevant inventions for two main reasons. First, there may be technologies that contribute to water security, but do not fit within one of the identified categories.[4] Second, some inventions may not be patented or patentable. For instance, this might be the case where inventors seek to avoid the disclosure of intellectual property required by a patent application or if the invention does not qualify for patent protection.[5]

This paper was developed as one of several background documents for the Roundtable on Financing Water[6]. This suite of documents is intended to support the discussion and development of policy recommendations on how to facilitate the development and diffusion of innovation that contributes to water security and sustainable growth.

[4] Notably, there is currently no search algorithm for desalination technologies in the OECD.Stat database. Previous work has used a separate search strategy to attempt to identify desalination patents (Dechezleprêtre, Haščič and Johnstone, 2015[3]). Other technologies might not be categorised as "water-related", yet still contribute to water security, such as flood protection infrastructure technology.

[5] See Annex A for further discussion on the advantages and disadvantages of using patent data as a measure of innovation.

[6] The Roundtable on Financing Water is a joint initiative by the OECD, the Netherlands, the World Water Council and the World Bank. For more information, please visit: http://www.oecd.org/water/roundtable-on-financing-water.htm.

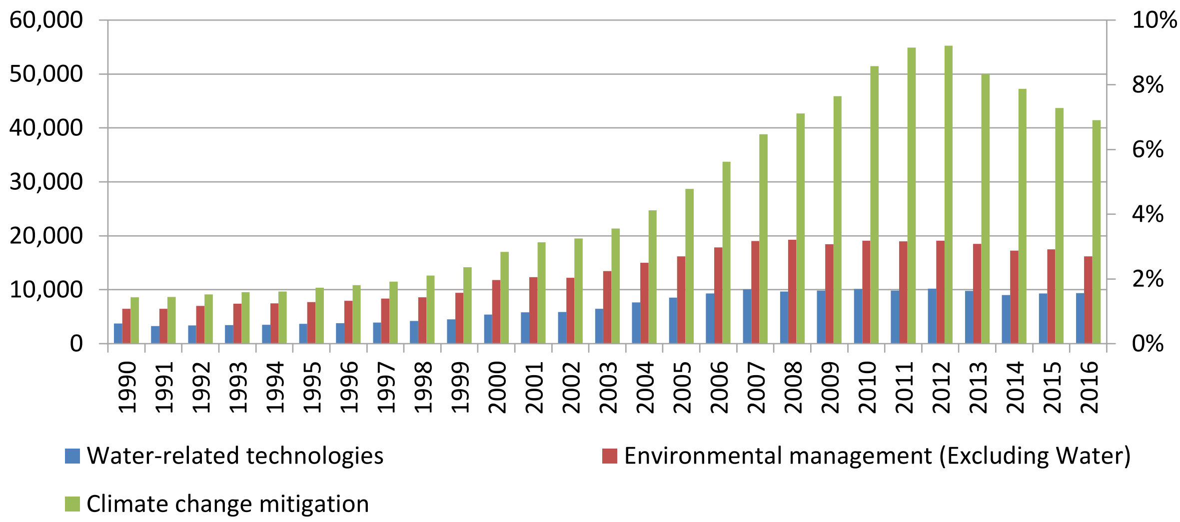
1. Trends in Water-related Technological Innovation

1.1. Water as a Share of Environmental Inventions

Overall, inventive activity related to the environment, measured as the number of patent priorities registered worldwide each year, has steadily increased until the early 2010s, tripling from 1990 to 2016 (Figure 1.1). It then stabilised and slightly declined in the last 3-4 years on record. The trend is similar for inventive activity related to climate change mitigation, although the rise during the first decade of the century was much faster.

In that context, water-related patenting increased steadily from 1990 to 2007 and then plateaued. It rose not as fast as other environmental technologies, but was less affected by the downturn in patenting activity in 2008-09.

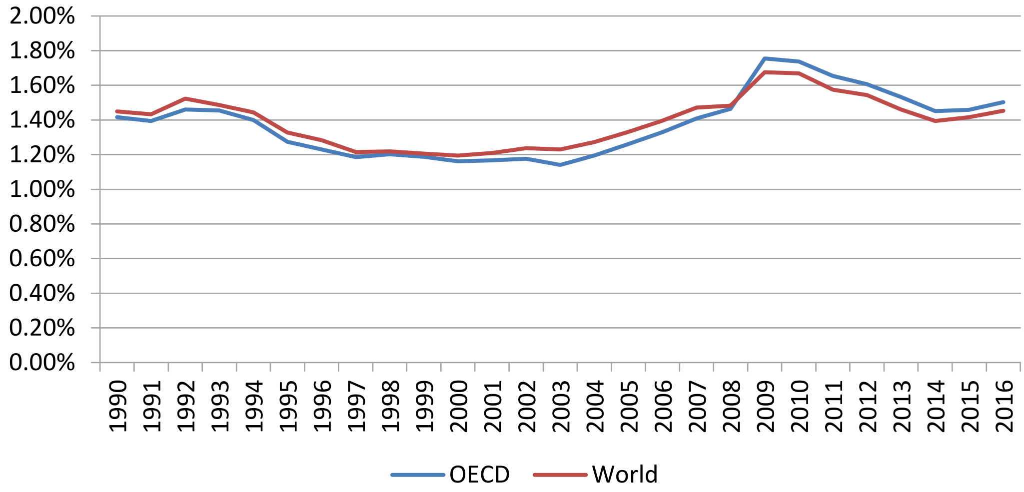
Figure 1.1. Total Patented Inventions by Year



Source: (OECD, 2020[2]).

Technologies identified by the OECD as contributing to water security (water pollution abatement and demand- and supply-side technologies) account for between 1.1% and 1.6% of total patented technologies, with an average of 1.3% over the period (Figure 1.2) and approximately 2/3 of other environmental patents.

Figure 1.2. Water-related Technology as a Share of Total Inventions



Source: (OECD, 2020[2])

During this period, the annual total inventive activity generally rose each year, from around 260 000 claimed patent priorities[7] in 1990 to 645 000 in 2016. Two exceptions to the trend are the years 2002 and 2008 to 2009, in which the total number of inventions fell relative to the previous year and to the overall trend.[8] As of 2016 worldwide patenting activity had not recovered to its peak of 682 000 in 2007. Inventors in OECD member countries recovered from the 2008 decline more quickly than their non-OECD counterparts, surpassing the 2007 peak during 2012 and growing further in 2016.

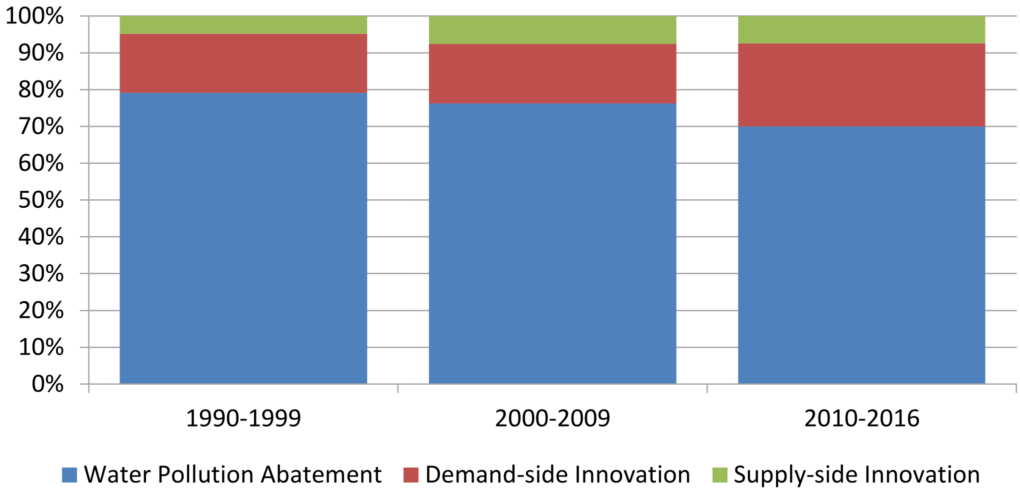
1.2. Clusters of Water-related Inventions

Inventions in water pollution abatement technologies accounted for the largest share of water-related inventions, but fell from over 80% in 2000 to just over 70% by 2016 (Figure 1.3). Over the same period, demand-side technologies grew from 15% to 25% of water-related inventions, while supply-side technologies ended up flat around 4%.

[7] See Annex A for definitions of key terms.

[8] Patenting tends to fall following financial and economic crises (World Intellectual Property Organisation, 2010[11]).

Figure 1.3. Shares of Water-related Inventions by Category

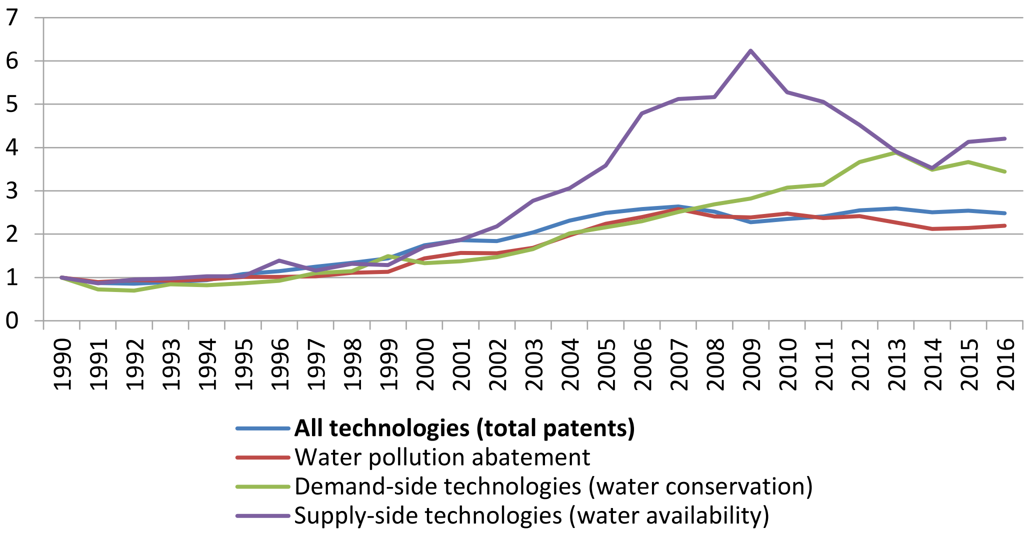


Source: (OECD, 2020[2]).

The overall level of patenting for all technologies has increased 2.5 times between 1990 and 2016 (Figure 1.4). In comparison, water pollution abatement technologies have grown marginally slower than overall invention, whereas technologies to manage water quantity (both demand- and supply-side) have grown faster.

Since 1990, the number of water pollution abatement patents filed annually has a little more than doubled, while demand-side technology inventions have increased 3.5 times. Patenting of supply-side technologies has also increased, albeit from a lower starting point and with greater annual variation. For instance, in 2009 five times more supply-side patents were filed than in 1990, while the 2016 figure was three times 1990 levels. This reduction in the growth of supply-side inventions roughly coincides with demand-side patenting beginning to grow at faster rate than overall inventive activity, suggesting a shift in focus from availability to conservation technologies.

Figure 1.4. Relative number of patented inventions by category and by year (1990 = 1)



Note: The annual number of patented inventions filed for each category have been normalised to one in 1990.
Source: (OECD, 2020[2]).

1.2.1. Water Pollution Abatement Technologies

Of the patented inventions classified as water pollution abatement technologies between 1990 and 2016, over 90% are related to water and wastewater treatment, with oil spill clean-up technologies accounting for between 2-7% and about 1% for fertilisers developed from waste water, sewage, sea slime, and other masses. The large share of water and wastewater treatment may be linked to the increasing prevalence and stringency of policies and laws designed to curb emissions. To the extent that these fertilisers recycle nutrients from wastewater, sewage and other waste, this can be considered an example of innovative circular economy approaches to waste management.[9]

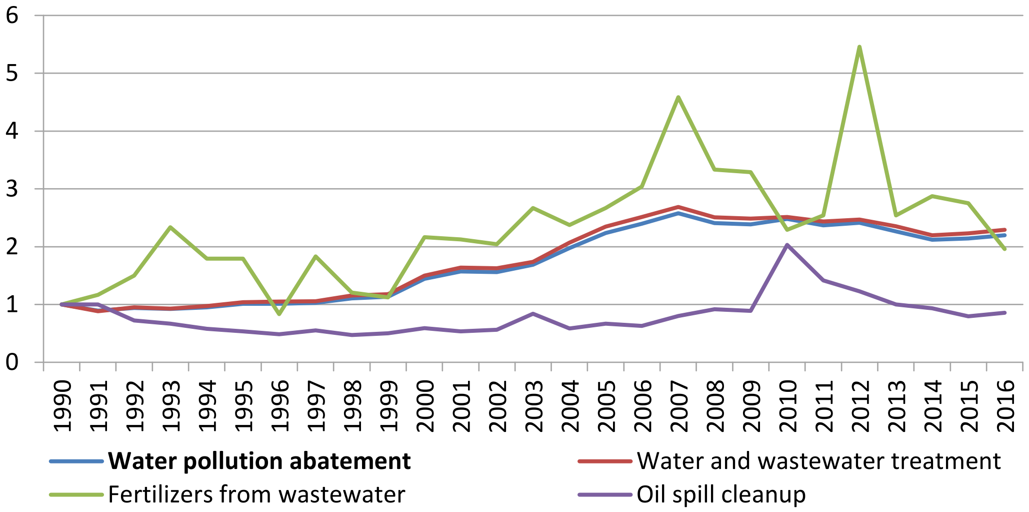
Fewer oil spill clean-up patents were registered than in 1990 in every year since, apart from the three years 2010-2012.[10] For water and wastewater treatment, the rate of patenting has been at least twice 1990 levels every year since 2004. The development of new wastewater fertiliser technologies[11] has varied from year to year (albeit from a generally low base), although patenting since 2000 has more than doubled 1990 levels, with 2012 seeing 5 times more patented inventions registered (Figure 1.6).

[9] A circular economy can be defined as "an industrial economy that is restorative by intention; aims to rely on renewable energy; minimises, tracks, and eliminates the use of toxic chemicals; and eradicates waste through careful design" (Ellen MacArthur Foundation, 2012[10]).

[10] 2010 was the year of the Deepwater Horizon explosion and oil spill in the Gulf of Mexico. Although, we do not directly identify that event as the cause of the increase in oil spill clean-up inventions, it is noteworthy that 163 patents were filed by US inventors in 2010 (42% of the world total and only one less than the global total for 2009), compared to an annual average of 24 the preceding decade (19% of global total). Some other major inventor countries also saw increases above trend, such as Norway, Russia, & the UK.

[11] Technologies to produce fertilisers from wastewater, sewage sludge, sea slime, ooze or similar masses.

Figure 1.5. Relative number of patented inventions in pollution abatement by year



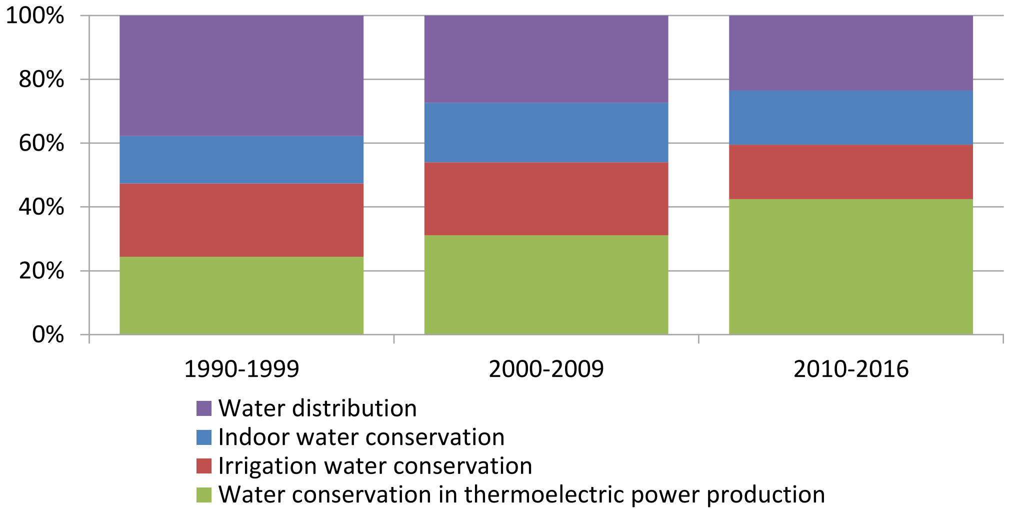
1990	
Technology	Number of Patents
Water pollution abatement	2963
Water and wastewater treatment	2744
Fertilizers from wastewater	24
Oil spill cleanup	195

Note: The annual number of patented inventions filed for each category have been normalised to one in 1990.
Source: (OECD, 2020[2]).

1.2.2. Demand-Side Technologies

Water distribution inventions comprised the largest share of demand-side technologies through the 1990s (around 40%); although by 2000, it had fallen to around 30% and reached a little over 20% by 2016. Conversely, conservation technologies in thermoelectric power generation grew from 15% in 1990, to comprise 30% of demand-side technology patents in 2000, surpassing distribution technologies to reach more than 40% by the end of the period (Figure 1.7). Conservation technologies (both indoor and irrigation) have fluctuated, but typically have each represented about, or slightly less than, 20% of demand-side technologies.

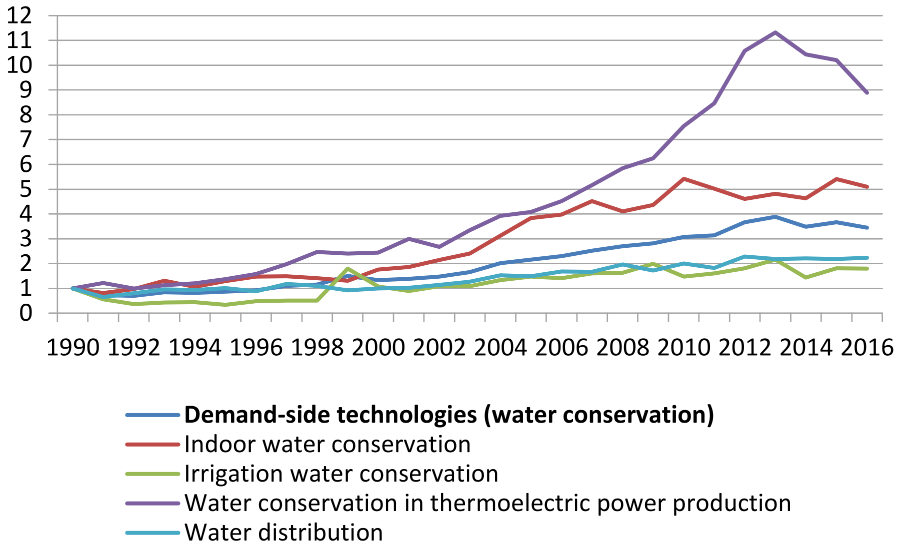
Figure 1.6. Demand-side Technologies



Source: (OECD, 2020[2]).

Inventions for water conservation in power production grew at a significantly higher rate than other demand-side technologies (Figure 1.8). In 2016, more than 10 times more patents than in 1990 were issued in this domain. Inventions in indoor water conservation also increased, with patenting activity up 4-fold compared to the start of the period. Distribution and irrigation conservation technologies have tended to grow more slowly than the averages for both demand-side technologies and for total invention, not quite doubling 1990 levels by 2016.

Figure 1.7. Relative number of patented inventions in demand-side technologies by year



1990	
Technology	Number of Patents
Demand-side technologies (water conservation)	626
Indoor water conservation	74
Irrigation water conservation	215
Water conservation in thermoelectric power production	96
Water distribution	241

Note: The annual number of patented inventions filed for each category have been normalised to one in 1990.
Source: (OECD, 2020[2]).

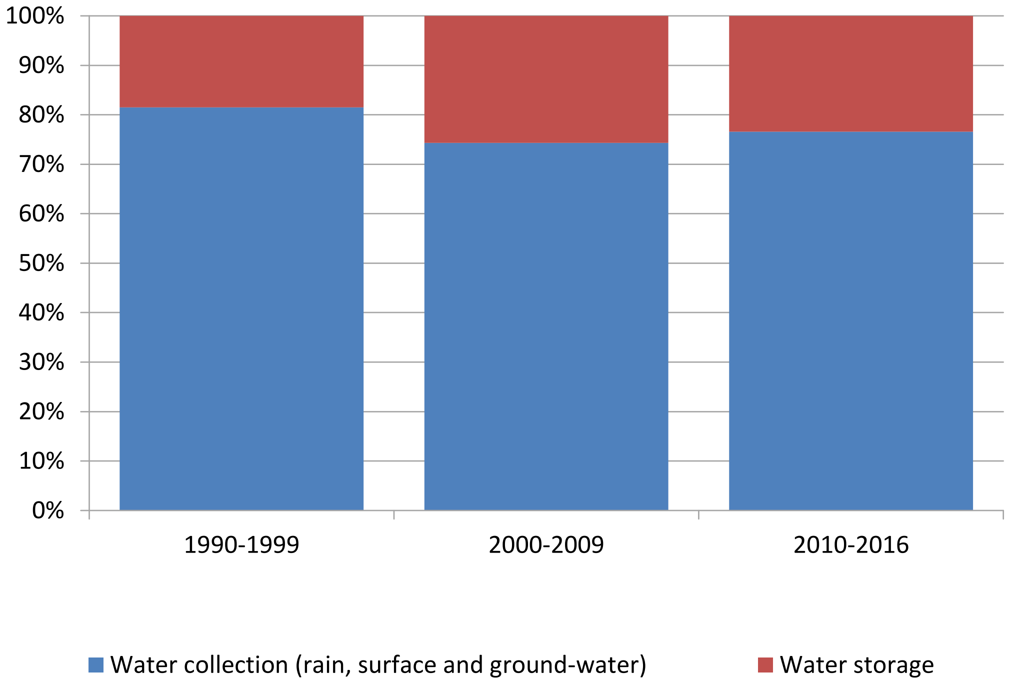
1.2.3. Supply-Side Technologies

Water collection technologies[12] represent the lion's share of supply-side technologies in the data available, averaging 77% over the period, with annual fluctuations between 66% and 90%. Water storage comprises the remaining portion. Not included in the data set, due to a lack of a search algorithm, are data on desalination technologies.[13] Desalination is an important area of research and development, which previous estimations suggest would comprise between a quarter and a third of supply-side patented inventions if added to the data (Dechezleprêtre, Haščič and Johnstone, 2015[3]).

[12] Including technologies for collecting tap or drinking water from rain, surface, or ground waters.

[13] This search strategy is currently under development (Haščič and Migotto, 2015[6]).

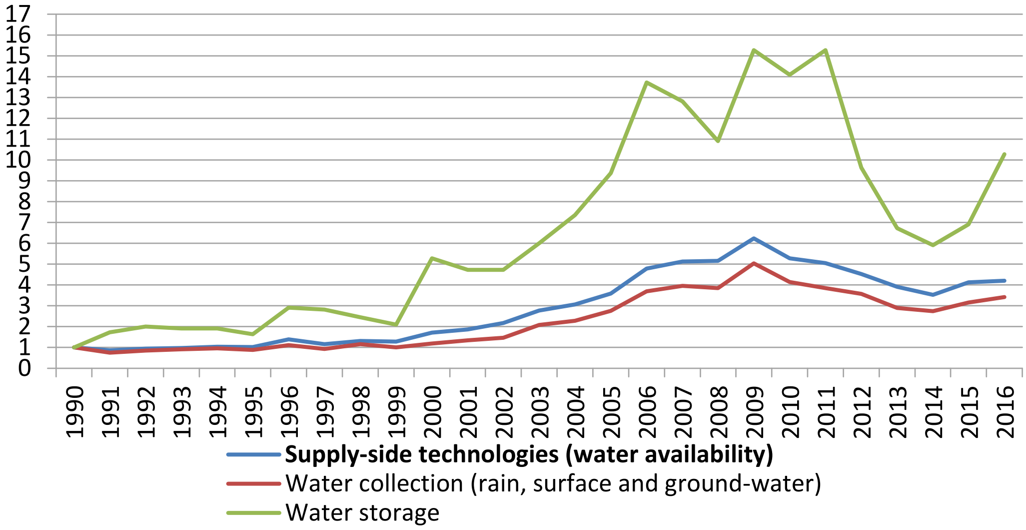
Figure 1.8. Supply-side Technologies



Source: (OECD, 2020[2]).

Despite accounting for the smallest proportion of supply-side patented inventions, storage technologies have grown at a much faster rate than collection technologies (Figure 1.10). On average during the period 2006-2011, more than 12 times as many water storage patents were registered each year than in 1990, although 2012 and 2013 saw that rate cut approximately by half.

Figure 1.9. Relative number of patented inventions in supply-side technologies by year



1990	
Technology	Number of Patents
Supply-side technologies (water availability)	164
Water collection (rain, surface and ground-water)	104
Water storage	11

Note: The annual number of patented inventions filed for each category have been normalised to one in 1990.
Source: (OECD, 2020[2]).

2. The Geography of Water-related Invention

2.1. Major Inventors

2.1.1. Overall Invention

The United States is a clear leader in overall inventive activity, accounting for at least one fifth of global technology patenting (both overall and water-related) in every year from 1990 to 2016, while Korea rose from less than 1% of water-related patents in 1990 to 20% in 2016 (Table 2.1). For Korea, this growth outpaced even its rapid increase in its share of overall patenting, which went from 2.2% to about 20% over the same period.

The People's Republic of China (hereafter "China") and Chinese Taipei collectively accounted for 3.3% of water-related patenting in 1990, growing to 22% in 2006, before falling back to below 5% since 2010 (averaging 11% over the entire period). Germany fell from a peak of around 20% in the early 1990s to sit at around 7% in the last few years.

Relative technological advantage (RTA) is a measure of a country's specialisation in a particular technological domain, in this case, patents related to water security. It is calculated as the ratio between a country's share of water security patents and its share of total patents. Korea has a RTA of 1.40, indicating it is relatively specialised in water security technologies compared to other domains (Table 2.1). Conversely, the United States is 'underweight' water security patenting relative to other areas of invention.

Table 2.1. Top Water-Related Inventor Countries, 1990-2016

Country/Economies	Share of global water-related technologies (total patents), 1990-2016	Relative Technological Advantage (RTA)
United States	23.5%	0.86
Korea	20.1%	1.40
Germany	9.9%	1.01
China (People's Republic of)	8.5%	1.15
Japan	8.1%	0.57
Russia	3.1%	1.08
United Kingdom	2.8%	1.14
France	2.7%	1.02
Canada	2.6%	1.51
Chinese Taipei	1.5%	0.42

Note: Water-related patented inventions include water pollution abatement or demand- or supply-side technologies as outlined in Annex B.
Source: (OECD, 2020[2]).

Table 2.2lists the countries with the highest shares of patents related to water security, compared to total patents in that country. Saudi Arabia and Chile top the list, both with more than five percent of inventions by resident inventors being in water-related technological domains (Table 2.2). At a global level, the average share of water-related inventions is about 1.3% over the period.

Table 2.2. Countries with Highest Shares of Water-Related Patenting, 1990-2016

Country	Share of patents in country related to water, 1990-2016	Relative Technological Advantage (RTA)
Saudi Arabia	6.35%	4.63
Chile	5.17%	3.77
Moldova	3.62%	2.64
Colombia	3.58%	2.61
Slovak Republic	3.37%	2.46
Hungary	3.29%	2.40
Mexico	3.22%	2.35
Czech Republic	3.00%	2.19
United Arab Emirates	2.94%	2.14
South Africa	2.90%	2.12

Note: Water-related patented inventions include water pollution abatement or demand- or supply-side technologies as outlined in Annex B. Table excludes countries with fewer than 100 total patents and five per water category (water pollution abatement, demand-side, and supply-side) between 1990 and 2016.
Source: (OECD, 2020[2]).

It is noteworthy that Israel is anecdotally known for its innovation in water-related technologies, yet is not as prominent in the figures presented in this paper as one might expect. Nonetheless, Israel does feature in the Top 10 countries with the highest shares of demand-side technologies. Moreover, Israel has a relatively larger share of high-value inventions, suggesting that when it does produce inventions, they are valuable enough to be patented in multiple countries (see below).

The bulk of the data shown in this paper are in relative terms, so water-related technologies might not stand out for a country with a high level of overall innovation. Further, several reasons explain why Israeli innovation in water technologies may not appear in patent data in the first place. First, desalination technologies are not included in the database, so any patents in that field are not covered. Given the large share of Israeli water supply from desalination, this may represent a significant number of patents. Second, not all innovation is patentable. Many innovations may be protected by industrial designs, copyrights, and other intellectual property rights regimes. Notably, software often falls under different IP regimes or is not patented, so is not included in the PATSTAT database, nor are innovations in organisational and management regimes. Third, not all patentable inventions are patented. However, it is unclear if this would affect Israel in a different way to other countries.

2.1.2. High Value Invention

One measure of the value of a patented invention is if it has been protected at multiple patent offices (Dechezleprêtre, Haščič and Johnstone, 2015[3]). Total patent statistics include both technologies that are only protected in one country and those patented in multiple jurisdictions. The number of different jurisdictions in which an invention has 'claimed priority' is known as the patent's 'family size'. The larger the family size, the more markets in which a technology is potentially able to be commercialised. Technologies that are only protected in one country might indicate a (perceived) lack of commercial prospects or a small market. Following Dechezleprêtre, Haščič, Johnstone, (2015), patent families of size 2 and greater are considered 'high-value'.

The United States accounts for only 22% of overall high-value inventions, but over 28% of high-value water related inventions, compared to Japan, which leads the world in overall high-value patenting at 28%, but drops to just 15% of water-related high-value patented inventions (Table 2.3). Canadian inventors are responsible for 2% of overall high-value inventions, but 3.58% of water-related high-value patenting, showing a high relative technological advantage.[14] Similarly, Australia has an RTA of 2.63, meaning its share of water-related high-value inventions is nearly 3 times larger than its share in high-value inventions overall. Chinese Taipei, 7th overall in high-value inventions with 2.7%, does not make the top 20 for water-related high-value inventions, with only a 0.8% share.

Table 2.3. Top High-Value Water-Related Inventor Countries, 1990-2016

Country	Share of global water-related technologies (total high-value patents) , 1990-2016	Relative Technological Advantage (RTA)
United States	28.02%	1.15
Japan	15.77%	0.61
Germany	12.28%	1.07
Korea	5.40%	0.79
United Kingdom	4.61%	1.31
France	4.44%	1.11
Canada	3.58%	1.95
China (People's Republic of)	3.38%	0.78
Australia	2.41%	2.63
Italy	1.83%	0.94

Note: Water-related patented inventions include water pollution abatement or demand- or supply-side technologies as outlined in Annex B.
Source: (OECD, 2020[2]).

Over one in twenty of Chile's high-value inventions are water related (Table 2.4). This could reflect a relative focus on exporting water-related inventions compared to other types of technology. In United Arab Emirates and Australia, the countries with the second and third highest shares of high-value inventing dedicated to water-related technologies, over 3% of their high-value inventions are water related.

Table 2.4. Countries with Highest Shares of High-Value Water-Related Patenting, 1990-2016

Country	Share of high-value water-related patents in country, 1990-2016	Relative Technological Advantage (RTA)
Chile	5.9%	4.8
United Arab Emirates	4.1%	3.3
Australia	3.2%	2.6
Norway	3.1%	2.5
South Africa	3.0%	2.5
Czech Republic	2.9%	2.3
Mexico	2.7%	2.2
Brazil	2.4%	2.0
Canada	2.4%	2.0
Poland	2.3%	1.9

Note: Water-related patented inventions include water pollution abatement or demand- or supply-side technologies as outlined in Annex B. Table excludes countries with fewer than 100 total patents and five per water category (water pollution abatement, demand-side, and supply-side) between 1990 and 2016.
Source: (OECD, 2020[2]).

[14] This may reflect a relatively small domestic market, with a focus on water-related technological exports.

2.2. Specialisation by Category

2.2.1. Pollution Abatement Technology

The United States is a leader in pollution abatement technology, although its share in total pollution abatement patented inventions is less than its share in overall innovation (Table 2.5). It does slightly better than its usual share when it comes to high-value inventions. Conversely, Korea and China contribute proportionally more to global pollution abatement invention than they do to overall patenting, but this is not the case for high value technologies. This suggests patented inventions registered in those countries are less likely to be registered elsewhere.

Table 2.5. Top Pollution Abatement Inventor Countries, 1990-2016

	All patented inventions		High-value patented inventions	
Country/Economy	Share of global water pollution abatement technologies, 1990-2016	Relative Technological Advantage (RTA)	Share of global high-value water pollution abatement technologies, 1990-2016	Relative Technological Advantage (RTA)
Korea	22.0%	1.54	6.2%	0.91
United States	21.1%	0.77	25.9%	1.06
China (People's Republic of)	9.7%	1.31	3.7%	0.85
Germany	9.3%	0.95	11.9%	1.03
Japan	8.5%	0.59	17.6%	0.68
Russia	3.3%	1.14	0.7%	2.08
Canada	2.6%	1.52	3.7%	2.03
United Kingdom	2.3%	0.93	4.0%	1.13
France	2.2%	0.85	4.0%	0.99
Chinese Taipei	1.6%	0.44	0.9%	0.34

Note: High value patented inventions are those with a family size greater than one. Water pollution abatement technologies are outlined in Annex B. Relative technological advantage is calculated with reference to a country's share of all patented inventions and all high-value patented inventions, respectively.
Source: (OECD, 2020[2]).

Kuwait has a larger share of its total inventions to water pollution abatement technologies than any other country (Table 2.6). This is largely water treatment, which accounts for around three quarters of water-related inventions in Kuwait. More than 5% of all inventions in Saudi Arabia and Ecuador are also categorised as water pollution abatement technologies. Of note: inventors for pollution abatement in these countries do not seek protection for foreign markets, as countries in Table 2.6 score comparatively low for high-value patented inventions.

Table 2.6. Countries with the Highest Shares of Pollution Abatement Technologies, 1990-2016

	All patented inventions		High-value patented inventions	
Country	Share of water pollution abatement-related patents in country, 1990-2016	Relative Technological Advantage (RTA)	Share of high-value water pollution abatement-related patents in country, 1990-2016	Relative Technological Advantage (RTA)
Kuwait	6.4%	6.14	0.0%	12.88
Ecuador	6.0%	5.76	0.0%	2.85
Saudi Arabia	5.1%	4.84	0.2%	4.08
Qatar	4.8%	4.62	0.0%	6.72
Chile	4.5%	4.29	0.2%	5.75
Cyprus[15]	3.8%	3.67	0.0%	2.10
Algeria	3.7%	3.56	0.0%	3.99
Moldova	3.4%	3.26	0.0%	0.57
Sri Lanka	3.2%	3.07	0.0%	4.64
Peru	3.2%	3.06	0.0%	1.76

Note: Table excludes countries with fewer than 100 total and five water pollution abatement inventions between 1990 and 2016. High value patented inventions are those with a family size greater than one. Relative technological advantage is calculated with reference to a country's share of all patented inventions and all high-value patented inventions, respectively.
Source: (OECD, 2020[2]).

2.2.2. Demand-side Technologies

Inventors residing in the US account for over a third of all demand-side technologies patented between 1990 and 2016 and have a relative technological advantage in the field. The United Kingdom and Switzerland host a smaller share of demand-side patented technologies (4.9% and 2%) but are comparatively more specialised (RTA of 2.0 and 2.20 respectively), including for high-value patents (RTA for high-value demand side technologies of 1.86 and 2.08 respectively). China, Korea, and Japan, all have RTAs below one for demand-side technologies.

[15] Note by Turkey:

The information in this document with reference to "Cyprus" relates to the southern part of the Island. There is no single authority representing both Turkish and Greek Cypriot people on the Island. Turkey recognises the Turkish Republic of Northern Cyprus (TRNC). Until a lasting and equitable solution is found within the context of the United Nations, Turkey shall preserve its position concerning the "Cyprus issue".

Note by all the European Union Member States of the OECD and the European Union:

The Republic of Cyprus is recognised by all members of the United Nations with the exception of Turkey. The information in this document relates to the area under the effective control of the Government of the Republic of Cyprus.

Table 2.7. Top Demand-side Technology Inventor Countries, 1990-2016

	All patented inventions		High-value patented inventions	
Country	Share of all demand-side technologies, 1990-2016	Relative Technological Advantage (RTA)	Share of high-value demand-side technologies, 1990-2016	Relative Technological Advantage (RTA)
United States	34.3%	1.25	34.5%	1.41
Germany	12.2%	1.25	13.2%	1.15
Korea	10.4%	0.73	2.9%	0.43
Japan	7.7%	0.53	11.5%	0.45
United Kingdom	4.9%	2.00	6.6%	1.86
France	4.5%	1.71	5.9%	1.46
China (People's Republic of)	3.9%	0.53	2.4%	0.56
Canada	2.5%	1.48	3.1%	1.68
Russia	2.4%	0.84	0.4%	1.27
Switzerland	2.0%	2.20	2.7%	2.08

Note: High value patented inventions are those with a family size greater than one. Demand-side technologies are outlined in Annex B. Relative technological advantage is calculated with reference to a country's share of all patented inventions and all high-value patented inventions, respectively.
Source: (OECD, 2020[2]).

Philippines and Saudi Arabia are the two countries with the largest shares of their total inventive activity dedicated to demand-side technologies, which account for roughly 1% of all inventions (Table 2.8). This compares to 0.23% at an overall world level, suggesting these countries have a distinct relative technological advantage in demand-side inventions.

Table 2.8. Countries with the Highest Shares of Demand-Side Technologies, 1990-2016

	All patented inventions		High-value patented inventions	
Country	Share of demand-side patents in country, 1990-2016	Relative Technological Advantage (RTA)	Share of high-value demand-side patents in country, 1990-2016	Relative Technological Advantage (RTA)
Saudi Arabia	1.0%	3.97	0.2%	4.41
Philippines	1.0%	3.71	0.1%	6.37
Pakistan	0.7%	2.76	0.0%	3.47
Egypt	0.7%	2.69	0.0%	0.61
Greece	0.6%	2.35	0.1%	2.20
United Arab Emirates	0.6%	2.25	0.0%	3.86
Switzerland	0.6%	2.20	2.7%	2.08
Tajikistan	0.6%	2.14	0.0%	n/a
Israel	0.6%	2.13	1.9%	2.34
Australia	0.5%	2.06	1.9%	2.05

Note: Table excludes countries with fewer than 100 total and five demand-side inventions between 1990 and 2016. High value patented inventions are those with a family size greater than one. Relative technological advantage is calculated with reference to a country's share of all patented inventions and all high-value patented inventions, respectively.
Source: (OECD, 2020[2]).

2.2.3. Supply-side Technology

Korea has the largest share of the world's patented inventions for supply-side water technologies. However, of global water supply-side inventions that are patented in more than one jurisdiction, Korea has a 6.6% share and an RTA of 0.98. This may be due to these inventions being tailored to the local context or possibly a lower propensity for Korea-resident inventors to seek patent protection in other jurisdictions. Australia, which accounts for 2.7% of total supply-side patenting (4.96 times its share of overall patenting), is also home to 7.6% of high-value patented inventions (8.30 times its average share), suggesting a strong relative technological advantage in water collection and storage. The ranking of the US, Germany and China reflects their overall position as inventors, with no particular specialisation in supply-side technology. Japan is significantly less prominent in this category than for other types of inventions (not water related).

Table 2.9. Top Supply-side Technology Inventor Countries, 1990-2016

	All patented inventions		High-value patented inventions	
Country	Share of all supply-side technologies, 1990-2016	Relative Technological Advantage (RTA)	Share of high-value supply-side technologies, 1990-2016	Relative Technological Advantage (RTA)
Korea	27.7%	1.93	6.6%	0.98
United States	19.5%	0.71	26.0%	1.06
Germany	10.6%	1.09	14.1%	1.23
China (People's Republic of)	7.6%	1.02	3.7%	0.85
Japan	3.6%	0.25	8.9%	0.34
United Kingdom	2.9%	1.18	3.8%	1.08
Russia	2.8%	0.97	0.5%	1.40
Australia	2.7%	4.96	7.6%	8.30
Canada	2.6%	1.54	4.3%	2.37
France	2.4%	0.90	4.2%	1.05

Note: High value patented inventions are those with a family size greater than one. Supply-side technologies are outlined in Annex B. Relative technological advantage is calculated with reference to a country's share of all patented inventions and all high-value patented inventions, respectively.
Source: (OECD, 2020[2]).

Of all technologies developed by Moroccan-resident inventors between 1990 and 2016, 0.8% were water supply-related, the largest share of all countries with at least five supply-side inventions (Table 2.10). Peru and United Arab Emirates were the countries with the second and third highest share, at 0.6% and 0.5% respectively. Given Australia's strong relative technological advantage in supply-side technologies, it is not surprising it represents a large share of overall Australian inventive activity.

Table 2.10. Countries with the Highest Shares of Supply-Side Technologies, 1990-2016

	All patented inventions		High-value patented inventions	
Country	Share of supply-side patents in country, 1990-2016	Relative Technological Advantage (RTA)	Share of high-value supply-side patents in country, 1990-2016	Relative Technological Advantage (RTA)
Morocco	0.8%	12.92	0.7%	16.07
Peru	0.6%	9.04	0.4%	8.93
United Arab Emirates	0.5%	7.97	0.6%	13.88
Australia	0.3%	4.96	0.4%	8.30
Indonesia	0.3%	4.72	0.2%	4.90
Brazil	0.3%	4.04	0.2%	4.27
Saudi Arabia	0.2%	3.84	0.1%	2.80
Colombia	0.2%	3.81	0.3%	6.31
Croatia	0.2%	3.65	0.2%	4.91
Chile	0.2%	3.52	0.2%	5.67

Note: Table excludes countries with fewer than 100 total and five supply-side inventions between 1990 and 2016. High value patented inventions are those with a family size greater than one. Relative technological advantage is calculated with reference to a country's share of all patented inventions and all high-value patented inventions, respectively.
Source: (OECD, 2020[2]).

3. Invention and Water Stress

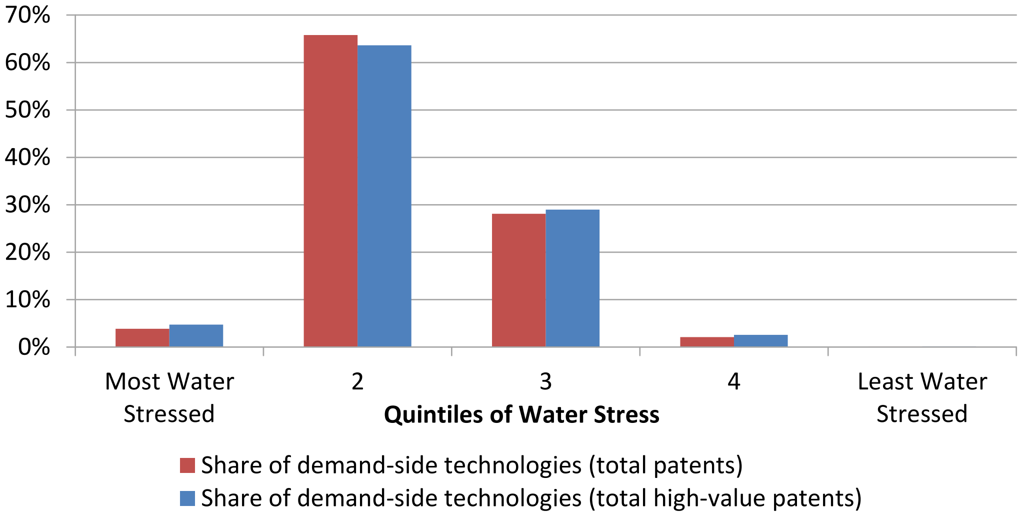
3.1. Demand-side Invention and Water Stress

Figure 3.1 shows where demand-side water conservation technologies have been invented according to the degree of water stress amongst quintiles of countries' baseline water stress (a measure of water used as a proportion of water available) using indicators from the World Resources Institute's AQUADUCT database (Gassert et al., 2013[4]).

Inventors resident in countries in the most water-stressed quintile invented just 4% of global demand-side water technologies. This small share largely reflects the composition of the group of countries, which are largely tropical and arid nations, with many small islands/territories. The second quintile has the largest share of patented inventions (66% overall and 64% of high-value patents), which follows from a number of large inventor countries featuring in this group, including the US, Korea, Japan, and China.

The middle quintile accounts for around 28% of inventions (29% of high-value ones), notably in Germany, the UK, Russia, and France. The top two least stressed quintiles account for around 10% of inventions between them.

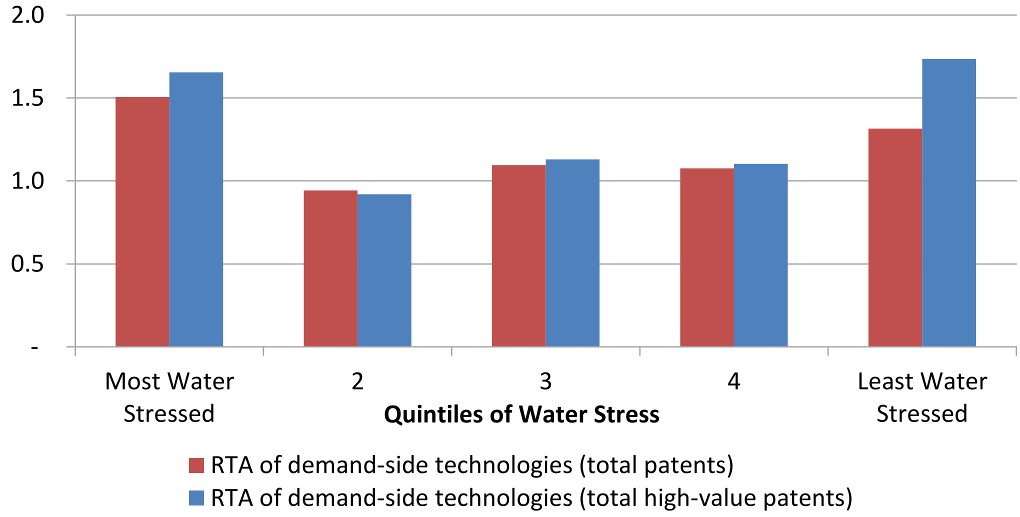
Figure 3.1. Shares of Demand-side Technologies by Degree of Water Stress, 1990-2016



Note: Quintiles 1-5 are countries' rankings on a measure of baseline water stress, 1 being most stressed.
Source: (OECD, 2020[2]); World Resources Institute AQUADUCT.

Nonetheless, the countries with the greatest water stress are relatively specialised in demand-side inventive activity, with an RTA of around 1.5 (Figure 3.2). Using this measure, results are not influenced by countries with large overall shares of invention, instead showing how specialised countries are relative to their baseline level of inventive activity.

Figure 3.2. RTA in Demand-side Technologies by Degree of Water Stress



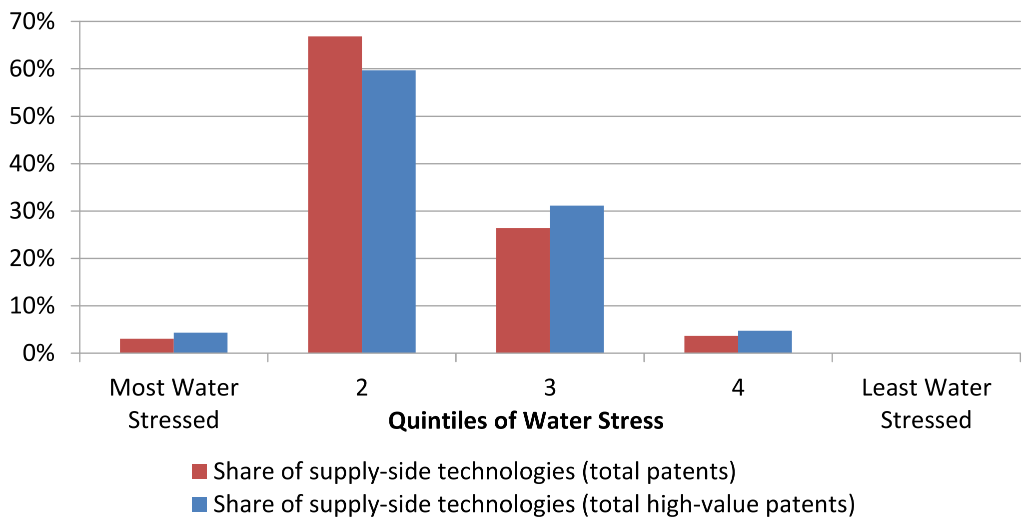
Note: Quintiles 1-5 are countries' rankings on a measure of baseline water stress, 1 being most stressed.
Source: (OECD, 2020[2]); World Resources Institute AQUADUCT.

The above results depend on the composition of the groups, but are largely robust whether countries are divided into more or fewer groups. Excluding the five largest inventor countries (the US, Japan, Korea, China, and Germany) does not greatly alter the results either.

3.2. Supply-side Invention and Water Stress

The patterns for supply-side water availability technologies according to water stress are broadly similar to those for demand-side inventions, as shown in Figure 3.3. The main difference is for countries in the second quintile, which have a larger share of overall patented inventions, but a lower share of high-value ones. The 4th quintile shows relatively more high-value supply-side inventions, due to a number of these countries having a relative technological advantage in this area, such as Switzerland, Canada, Brazil, and Norway.

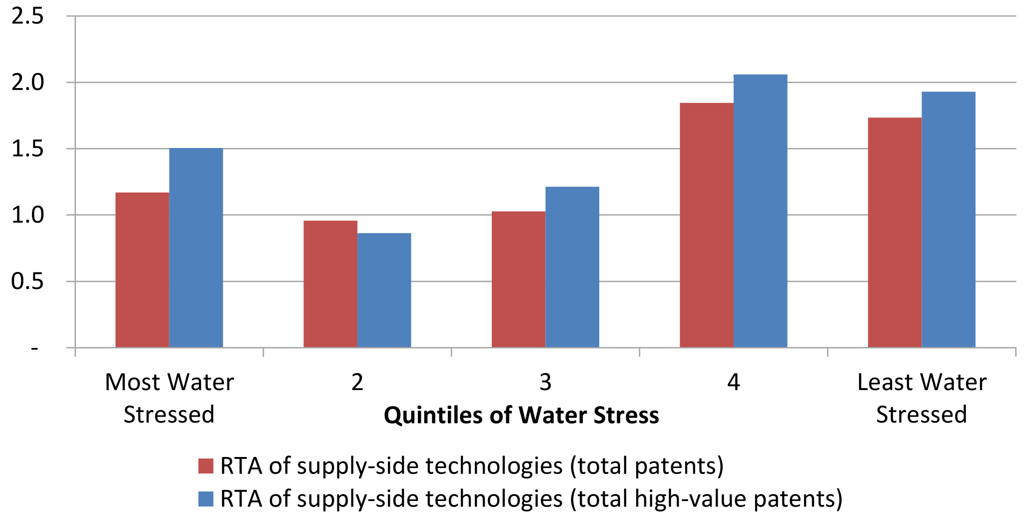
Figure 3.3. Shares of Supply-side Technologies by Degree of Water Stress, 1990-2016



Note: Quintiles 1-5 are countries' rankings on a measure of baseline water stress, 1 being most stressed.
Source: (OECD, 2020[2]); World Resources Institute AQUADUCT.

Relative technological advantage in supply-side, or water availability, patenting is highest in the 4th quintile of water stress, although 2nd quintile has significantly higher RTAs for high-value patented inventions than for all inventions. The same broad pattern emerges as for demand-side patenting, namely that the most water stressed countries have a pronounced relative technological advantage in water-related technologies, the least water stressed do not, and that in between the extremes there is a negative correlation between water stress and invention.

Figure 3.4. RTA in Supply-side Technologies by Degree of Water Stress



Note: Quintiles 1-5 are countries' rankings on a measure of baseline water stress, 1 being most stressed.
Source: (OECD, 2020[2]); World Resources Institute AQUADUCT.

These patterns show the share of global invention for water-related supply and demand-side technologies is progressively higher in more water stressed countries, with the exception of the most stressed. This is likely due to the most water stressed countries being largely small and/or lower-income countries that may not have developed research and development sectors. Using different indicators of water risks and different grouping rules (for example, deciles instead of quintiles), the broad pattern remains unchanged, suggesting invention in these technologies initially increases sharply for moderately water stressed countries but then decreases steadily after a point around the 30th percentile. Conversely, the most water-stressed countries do have a high relative technological advantage, suggesting a greater share of their own invention focuses on water demand and supply, compared to other countries.

It is not clear to what extent invention in water security technologies is driven by necessity (for example, water stress) and to what extent by the size of a country's economy and propensity to innovate/undertake R&D. Both are likely to contribute to innovation and interact in complex ways. For instance, economic growth could increase both water stress as well as research and development, which in turn might decrease water stress through innovation, but also contribute to economic growth, which in turn may adversely impact water stress again. Identifying complex causality, with this type of feedback loop, requires an approach that is beyond the scope of this paper.

4. International Diffusion of Water-related Inventions

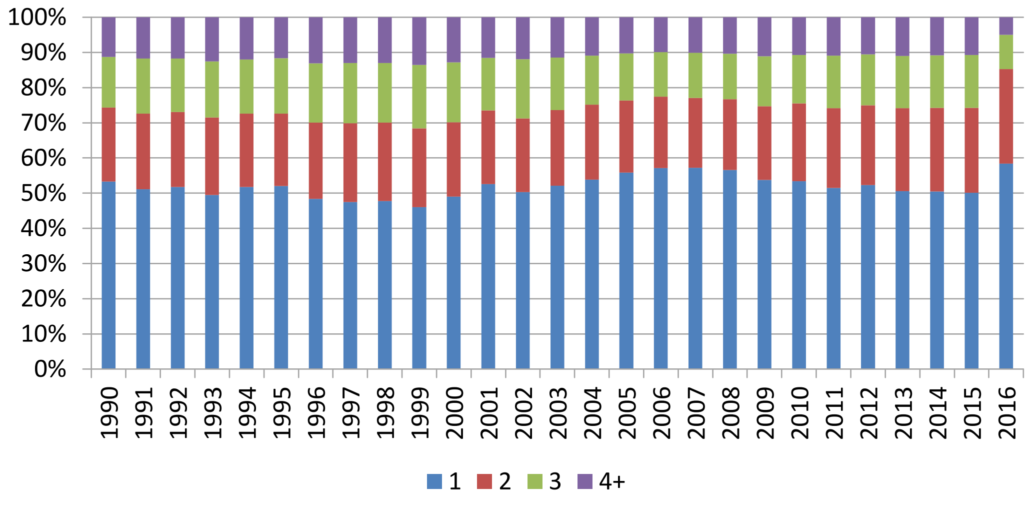
4.1. Patent Family Size Trends

As discussed in Chapter 2, one measure of a patented invention's value is the number of foreign jurisdictions in which the inventor(s) seek protection, known as that patent's "family size". More valuable inventions tend to be patented in more countries, typically the largest markets for such technologies. This international diffusion of patent protection shows which technology fields and which markets are perceived to be the most valuable.

4.1.1. Water Pollution Abatement

Around 55% of water pollution abatement patents are of family size one (also known as singletons), although towards the end of the period the proportion rose slightly (Figure 3.1). Families of size 4 or more accounted for 13% in the 1990s, but fell below 11% in the years since. This suggests proportionally more of the rise in water pollution abatement patenting activity since the end of the 1990s has been in inventions that are not protected in other jurisdictions. This might be because these inventions are adapted to country-specific contexts and because of the share of inventions in Korea, which rose from barely 1% of the world total in 1990 to nearly a third by 2009, and which is relatively less likely to protect patients overseas (see Section 2.2.1). Given the majority of pollution abatement patents identified are water and wastewater treatment technologies, the trends below are mainly driven by that category of invention.[16]

Figure 4.1. Water Pollution Abatement Patent Family Sizes



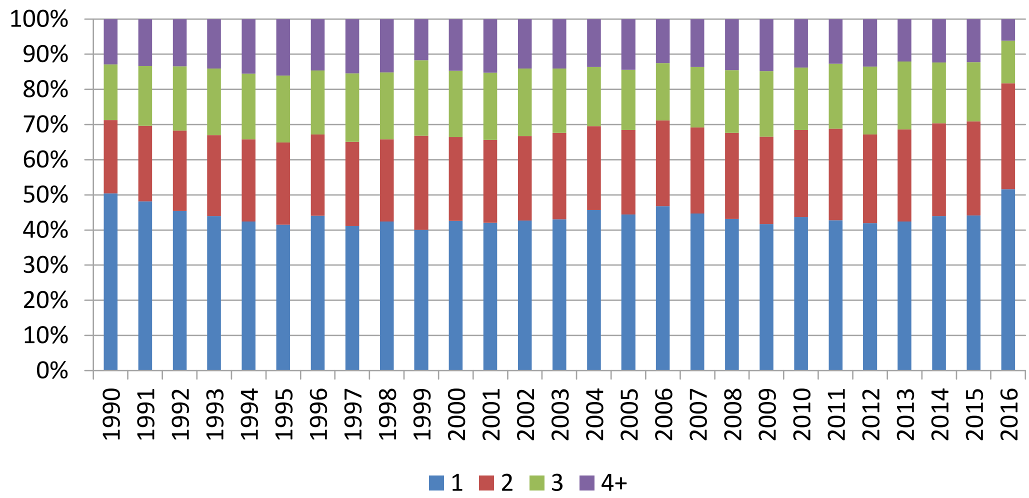
Note: Patent family size refers to the number of jurisdictions in which a patent is protected. Larger family sizes tend to indicate higher value technologies.
Source: (OECD, 2020[2]).

[16] See Annex C for a further breakdown by specific category.

4.1.2. Demand-side Technologies

Less than half of demand-side patents registered between 1990 and 2016 were singletons, with just under 15% of size 4 or more (Figure 4.2). Families of size 2 grew from 21% of the total in the 1990s, to nearly 30% in the years since, while size 3 families generally held steady at about 17% the same period. This suggests demand-side technologies are increasingly considered worth protecting in foreign jurisdictions. The category with the largest share of patents with a family size of 4 and above is water conservation in thermoelectric power production, where 40% are registered in more than 3 jurisdictions (and 30% in 2 or 3), compared to around 25% for other demand-side technologies (water distribution, as well as indoor and irrigation water collection). Annex C provides a more detailed breakdown by category.

Figure 4.2. Demand-side Patent Family Sizes

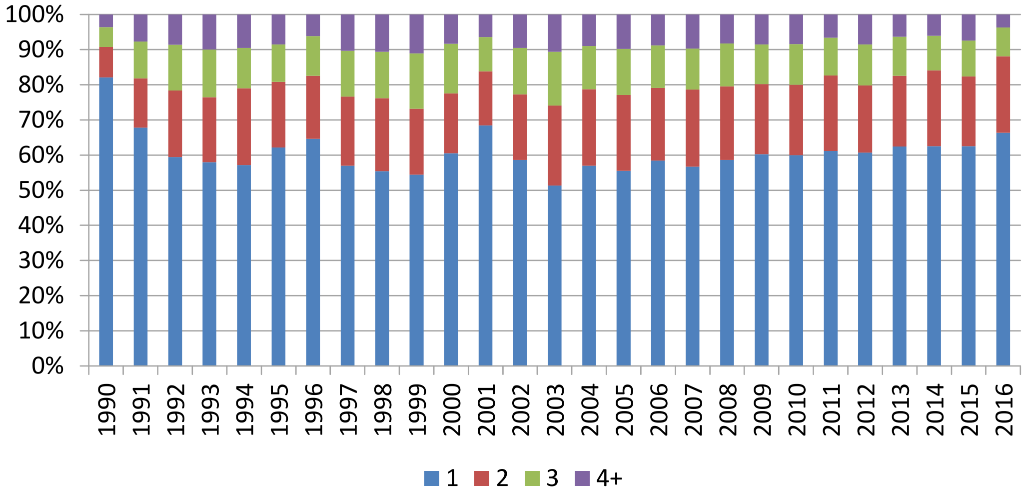


Note: Patent family size refers to the number of jurisdictions in which a patent is protected. Larger family sizes tend to indicate higher value technologies.
Source: (OECD, 2020[2]).

4.1.3. Supply-Side Technologies

Supply-side inventions (water collection and storage) are mostly only patented in their country of invention, with 65% of inventions being singletons, although the proportion of larger family sizes increased slightly during the 2000s. Patents of family size 2 accounted for just under 19% over the whole period, compared to about 12% for family size 3.

Figure 4.3. Supply-side Patent Family Sizes



Note: Patent family size refers to the number of jurisdictions in which a patent is protected. Larger family sizes tend to indicate higher value technologies.
Source: (OECD, 2020[2]).

4.2. Major Markets for Water-related Technologies

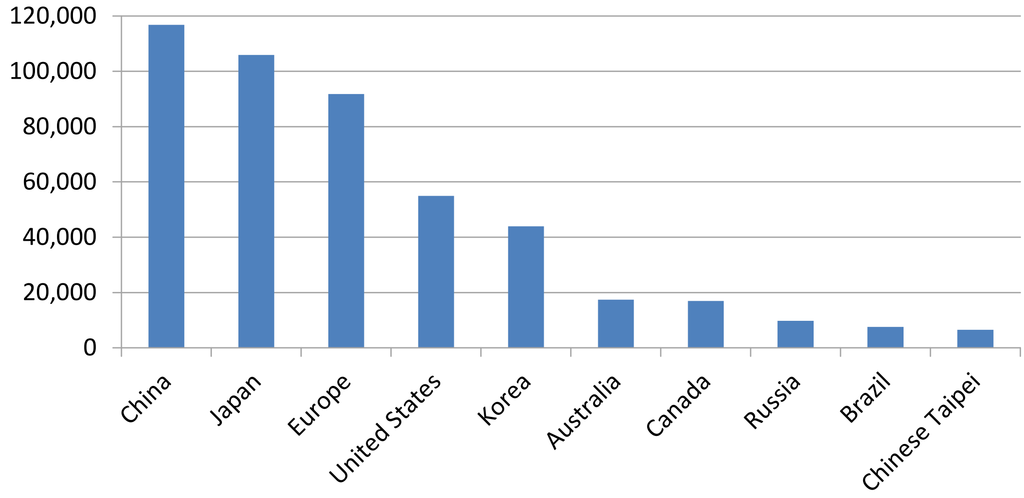
While the previous section shows which technologies are patented in more than one market, it is also instructive to explore in which jurisdictions inventors most frequently seek to protect patents. This can be considered a proxy for the actual or perceived likelihood of a market offering commercial returns to an invention.

4.2.1. Water Pollution Abatement

China is the largest potential market for pollution abatement technologies, followed by Japan, Europe[17], and the US. Within Europe, Germany is by far the largest single country in which inventors seek protection, followed by Austria and Spain. These last two are somewhat surprising given the apparent relationship between economic output and patent protection. This may suggest relatively developed markets for water and wastewater treatment and for wastewater fertilisers in these countries or possibly barriers to entry in larger markets (such as France or the UK). Perhaps unsurprisingly, Norway is the second largest market in Europe in which inventors seek to protect oil spill clean-up technologies.

[17] Because some patents are registered directly with the EPO, rather than at national IP offices, data for EPO member countries are combined, reflecting the importance of the European common market as a whole. Reporting data by country, while ignoring EPO-registered patents, would understate the importance of European countries as potential markets, which can be accessed both directly and via the EPO.

Figure 4.4. Pollution Abatement Patents Seeking Protection at IP Offices, 1990-2016



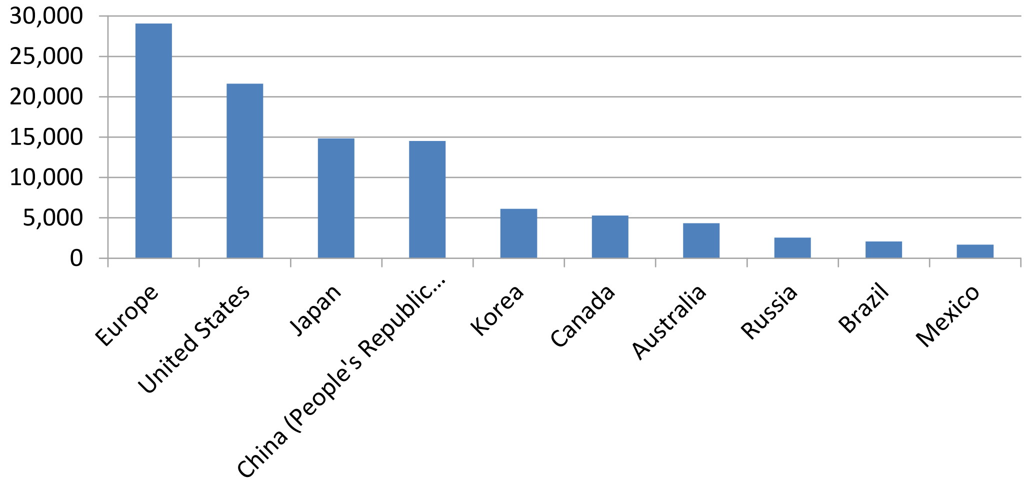
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

4.2.2. Demand-side Technologies

The largest market in which water conservation technologies are patented is Europe, followed by the US and Japan. Europe tops three categories (indoor and power production conservation and distribution), while the United States is the largest market for conservation of irrigation water. Within Europe, Germany is the largest jurisdiction for patent protection across all categories, with the UK second overall, as well as for indoor water conservation and distribution. France is third overall and second for conservation of water in thermoelectric power production.[18]

[18] This may reflect the cooling requirements of nuclear power production, in which France is a major player.

Figure 4.5. Water Conservation Patents Seeking Protection at IP Offices, 1990-2016

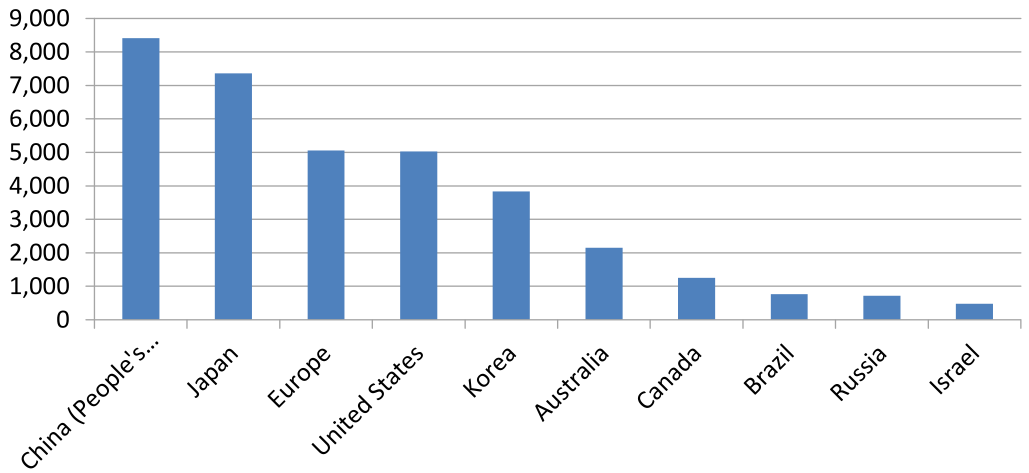


Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

4.2.3. Supply-side Technologies

The top five potential markets for supply-side technologies are the same as for water pollution abatement inventions. However, the rankings differ by category. China is the largest potential market for water collection, followed by Japan, Europe, and the US. Within Europe, Germany is once again largest, with the UK and France second and third. Japan has the highest number of protected patents sought for water storage, followed by China, Europe, and Korea.

Figure 4.6. Water Availability Patents Seeking Protection at IP Offices, 1990-2016



Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

4.3. Major Markets by Water Stress

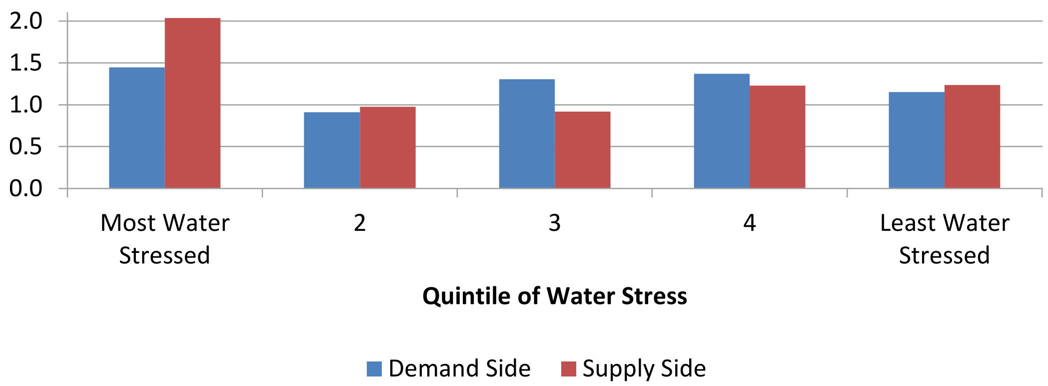
One measure of the relative importance of a market for particular group of technologies is the relative propensity to patent (RPP). In this case, an RPP greater than one indicates a country is a relatively important market for water-related technologies and accounts for countries' size in a way that a simple patent count cannot. The most water-stressed countries, as well as the 3rd and 4th quintiles, are relatively important markets for water-related technologies, while the second most and the least stressed countries are not. Much the same pattern emerges for supply-side water availability technologies as for demand-side ones. Countries in the second-most water-stressed quintile are the ones in which the most patents protections are sought overall, but at a lower rate than other technologies. Patent offices in the most water-stressed countries receive requests to protect supply-side water patents at a higher rate than other patents, while the least stressed receive them at a lower rate. Much the same pattern emerges for supply-side water availability technologies as for demand-side ones. Countries in the second-most water-stressed quintile are the ones in which the most patents protections are sought overall, but at a lower rate than other technologies. Patent offices in the most water-stressed countries receive requests to protect supply-side water patents at a higher rate than other patents, while the least stressed receive them at a lower rate.

Figure 4.7 shows the relative propensity to patent (RPP) water-related technologies, the share of water-related patents protected in countries relative to their share of total patents protected, compared to other technologies in countries grouped by quintile of water stress.

As with the analysis of relative technological advantages (countries' propensity to innovate, as opposed to the propensity for inventors to protect their inventions there), the results for the two extremes is as expected, but the correlation in the middle three quintiles runs counter to expectations. Again, this reflects largely the individual countries included in each quintile. Further analysis would be required to establish whether there is a relationship between water stress in a country and that country being an important market for inventions.

Much the same pattern emerges for supply-side water availability technologies as for demand-side ones. Countries in the second-most water-stressed quintile are the ones in which the most patents protections are sought overall, but at a lower rate than other technologies. Patent offices in the most water-stressed countries receive requests to protect supply-side water patents at a higher rate than other patents, while the least stressed receive them at a lower rate.

Figure 4.7. Relative Preponderance of Demand-side Patents Protected by Water Stress, 1990-2016



Note: Quintiles 1-5 are countries' rankings on a measure of baseline water stress, 1 being most stressed.
Source: (OECD, 2020[5]); World Resources Institute AQUADUCT.

5. Options for Future Analysis

The results presented in this paper provide a number of areas for future analysis. Some are sketched below, hoping they may inspire further research.

Analysts, governments and corporates would benefit from a better monitoring of "soft" innovation. Considering the relevance and dynamics around hydro-informatics, smart water management and supporting technologies, a more thorough econometric analysis of trends in this domain would be valuable.

Additional work could focus on innovation at the firm level, as opposed to the national level, to understand which types of companies in which sectors are active innovators, as measured by patenting activity. This would help identify which sectors and firm sizes are most involved in inventive activity, as well as how concentrated innovation is within companies in a given country.

Further work on understanding the financing of water-related inventions may be possible by joining the data presented here with other company-level databases. By matching patents registered by firms with company-level data, it would be possible to analyse the origins of funding streams backing inventions. For example, building on work undertaken at the OECD in the area of venture capital could focus on characteristics and success of start-ups in the water field.[19]

Disentangling the role of water stress from other factors affecting invention in, and the diffusion of, water-related technologies is another area of possible future research interest. In particular, work to isolate the effects of a country's economic size and growth rate, their population, and their underlying propensity to innovate would also help identify the causal role of water-related risks on invention and could help identify countries that will need to attract innovation or foreign patents to deal with increasing water risks.

Understanding the divergences between overall and high-value patenting and the underlying drivers would shed light on whether inventors actively target foreign markets or if they focus more on domestic conditions. Similarly, detailed research could examine the impact market structures have on the ability of inventions to diffuse internationally, as well as the extent to which national regulations and standards hinder or enhance technological diffusion.

Further analysis is required to support the ongoing development of policies designed to stimulate innovation. Specifically, targeted empirical work on inventions can inform the policy debate about how to promote the supply of inventions, stimulate demand for inventions, and how to make innovation attractive for investors. This would be particularly appropriate in areas where the OECD is active, including policies to address contaminants of emerging concern, a domain where new science and technology (to analyse water quality or treat wastewater) can support more effective and cost-efficient policies. Water and health, or addressing urban water scarcity are other promising options.

[19] Breschi, S., J. Lassébie and C. Menon (2018), "A portrait of innovative start-ups across countries", *OECD Science, Technology and Industry Working Papers*, No. 2018/02, OECD Publishing, Paris, https://doi.org/10.1787/f9ff02f4-en.

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OECD (2013), *Water Security for Better Lives*. [1]

World Intellectual Property Organisation (2010), *World Intellectual Property Indicators*. [11]

Annex A. Methodology and Background Information

Methodology

The OECD.Stat innovation in environment-related technologies database contains information relating to over 10 million individual patents filed worldwide between 1990 and 2016. These are drawn from the Worldwide Patent Statistical Database (PATSTAT), managed by the European Patent Office (EPO).

The PATSTAT database has worldwide coverage, containing data from over 90 patent offices, spanning a period stretching back to 1880 for some countries. This covers patent documents from all major patent offices in the world, including regional patent offices and international patent applications filed under the Patent Cooperation Treaty. The database is updated on a regular basis (usually biannually). Patent documents are categorised using the International Patent Classification (IPC) and the Cooperative Patent Classification (CPC) systems. In addition to basic bibliometric and legal data, the database also includes patent descriptions (abstracts), applicant and inventor names, as well as citation data. The PATSTAT database is thus an ideal source of information for the purposes of the production of patent-based indicators.

As part of its set of Green Growth Indicators, the OECD identifies in excess of 840 000 patents as belonging to one of around 80 selected environment-related technology fields (Haščič and Migotto, 2015[6]). These include environmental management and climate change mitigation and demand- and supply-side technologies in energy, transport, waste, water and other sectors. The full list of water-related technologies is provided in Annex B.

Key Terms

The following definitions of key terms are drawn from Haščič and Migotto (2015).

Application (or filing) date: The patent application date is the date on which the patent office received the patent application.

Application for a patent: To obtain a patent, an application must be filed with the authorised body (patent office, or application authority) with all the necessary documents and fees. The patent office will conduct an examination to decide whether to grant or reject the application.

Claimed priority: A priority application that has been duplicated at a foreign patent office at least once. An international patent family with at least two members.

International Patent Classification (IPC): The International Patent Classification, which is commonly referred to as the IPC, is based on an international multilateral treaty administered by WIPO. The IPC is an internationally recognised patent classification system, which provides a common classification for patents according to technology groups. IPC is periodically revised in order to improve the system and to take account of technical development.

Inventor country: Country of the residence of the inventor, which is frequently used to count patents in order to measure inventive performance.

Novelty: If an application for a patent is to be successful, the invention must be novel (new). The invention must never have been made public in any way, anywhere, before the date on which the application for a patent is filed (or before the priority date).

Obviousness: The concept that the claims defining an invention in a patent application must involve an inventive step if, when compared with what is already known (i.e. prior art), it would not be obvious to someone skilled in the art.

Patent family: A patent family is a set of individual patents covering different geographical regions, that is, all the equivalent patent applications deposited at various patent offices corresponding to a single invention. Patent family size is a measure of the geographical breadth for which protection of the invention is sought. Several definitions of patent family exist, including "simple" and "extended".

Patent: A patent is an intellectual property right issued by authorised bodies to inventors to make use of, and exploit their inventions for a limited period (generally 20 years). The patent holder has the legal authority to exclude others from commercially exploiting the invention (for a limited period). In return for the ownership rights, the applicant must disclose the invention for which protection is sought. The trade-off between the granting of monopoly rights for a limited period and full disclosure of information is an important aspect of the patenting system.

PATSTAT: The EPO's Worldwide Patent Statistical Database.

Priority country (office): Country (office) where the patent is first filed before being (possibly) extended to other countries.

Priority date: The priority date is the first date of filing of a patent application, anywhere in the world (often the applicant's domestic patent office), to protect an invention. The priority date is used to determine the novelty of the invention, which implies that it is an important concept in patent procedures. For statistical purposes, the priority date is the closest date to the date of invention.

Advantages and Disadvantages of Using Patent Data as a Measure of Innovation

Patent data have been used extensively as a measure of technological innovation (Griliches, 1998[7]). There are a number of attractive features of patent data[20], including:

- a strong correlation with research and development spending;
- their ability to describe the output of inventive activity;
- broad comparability across countries due to well-defined patenting criteria;
- being readily quantifiable and widely available; and
- being disaggregated into specific technological categories.

Griliches (1998) identifies the strong correlation between patenting activity and R&D spending across firms and sectors. Further, patent data measure actual outcomes of innovation, as opposed to input-based measures like R&D spending. This means they are more likely to identify economically significant technological inventions, which in most cases are patented (Dernis, Guellec and van Pottelsberghe de la Potterie, 2001[8]).

[20] Based on Haščič and Migotto (2015).

In order to be awarded a patent, inventions must be novel, non-obvious, and useful. As such, using patent data avoids trivial "innovation by construction". Nonetheless, there is some variability in the success rates of patent applications across countries, which may indicate differing levels of stringency for adherence to the criteria (Griliches, 1998[7]). This may indicate patent "quality" differs across countries.

Patent data are convienent for studying innovation within sectors, due to the large range of metadata and categorisiation that accompany an application to a IP Office. For instance, the International Patent Classification (IPC) system includes more than 70 000 technological classes, and the Cooperative Patent Classification (CPC) system, an extension of the IPC, has over 200 000 classes (Haščič and Migotto, 2015[6]). The classification codes and definitions used in this paper are included in Annex B.

The main drawbacks relating to using patent data as a measure of innovation fall into three broad categories:

- not all inventions are able to be patented;
- not all patentable inventions are patented; and
- the "quality" of patented inventions can vary.

As discussed above, inventions that do not meet certain criteria cannot be patented, but may represent a useful technological advance. Some inventions may be subject to other forms of intellectual property protection, such as copyrights and industrial designs. Managerial, organisational, and non-technological innovation cannot be patented (Haščič and Migotto, 2015[6]).

Some patentable inventions may not be patented to protect trade secrets and IP from the disclosure associated with a patent application. Amongst patented applications, usefulness will vary, although there is no direct way to measure the actual or potential value of most patents.

A further potential drawback of the strategy used to generate the data in this paper is that the algorithms used to identify technologies related to water security may omit some relevant innovation. This may be where there are advances identified as belonging to other domains that actually affect water security. For example, technologies that improve the performance of a machine, while reducing the amount of water required to operate it, will contribute to water security (by reducing demand for water), but might be classified under another IPC/CPC category. One notable category that is missing from the database is desalination, for which a search strategy is under development.

It is also possible that irrelevant technologies are included in the data, although the data used for the OECD's Green Growth Indicators (the same approach used in this paper) were subject to quality assurance to minimise this risk. For more information about the search strategies used see Haščič and Migotto (2015).

Annex B. Patent Classification Codes

Table A B.1. Descriptions and IPC Classes of Water Security Patents

Category and Description	IPC Class/Code
WATER POLLUTION ABATEMENT	
Water and wastewater treatment	
Arrangements of installations for treating waste-water or sewage	B63J4
Treatment of water, waste water, sewage or sludge	C02F
Chemistry; Materials for treating liquid pollutants, e.g. oil, gasoline, fat	C09K3/32
Plumbing installations for waste water	E03C1/12
Sewers – Cesspools	E03F
Fertilisers from wastewater	
Fertilisers from waste water, sewage sludge, sea slime, ooze or similar masses	C05F7
Oil spill clean-up	
Devices for cleaning or keeping clear the surface of open water from oil or like floating materials by separating or removing these materials	E02B15/04-10
Vessels or like floating structures adapted for special purposes - for collecting pollution from open water	B63B35/32
Materials for treating liquid pollutants, e.g. oil, gasoline or fat	C09K 3/32
DEMAND-SIDE TECHNOLOGIES (water conservation)	
Indoor water conservation	
Self-closing valves, i.e. closing automatically after operation, in which the closing movement, either retarded or not, starts immediately after opening	F16K21/06-12
Self-closing valves, i.e. closing automatically after operation, closing after a predetermined quantity of fluid has been delivered	F16K 21/16-20
Arrangement or mounting of devices, e.g. valves, for venting or aerating or draining	F16L 55/07
Jet regulators with aerating means	E03C 1/084
Flushing devices discharging variable quantities of water	E03D 3/12
Cisterns discharging variable quantities of water	E03D 1/14
Urinals without flushing	A47K 11/12
Dry closets	A47K 11/02
Waterless or low-flush urinals	E03D13/007
Special constructions of flushing devices with recirculation of bowl-cleaning fluid	E03D5/016
Greywater supply systems	E03B1/041
Optimisation of water quantity (for dishwashers)	Y02B 40/46
Optimisation of water quantity (for washing machines)	Y02B 40/56
Irrigation water conservation	
Watering arrangements located above the soil which make use of perforated pipe-lines or pipe-lines with dispensing fittings, e.g. for drip irrigation	A01G 25/02
Watering arrangements making use of perforated pipe-lines located in the soil	A01G 25/06
Control of watering	A01G 25/16
Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, e.g. plasmids, or their isolation, preparation or purification; for drought, cold, salt resistance	C12N15/8273
Water conservation in thermoelectric power production	
Combustion heat from one cycle heating the fluid in another cycle	F01K 23/08-10
Non-positive-displacement machines or engines, e.g. steam turbines / Preventing or minimizing internal leakage of working fluid, e.g. between stages	F01D 11
Water distribution	
Pipe-line systems / Protection or supervision of installations / Preventing, monitoring, or locating loss	F17D5/02 and E03
Devices for covering leaks in pipes or hoses, e.g. hose-menders	F16L55/16 and E03

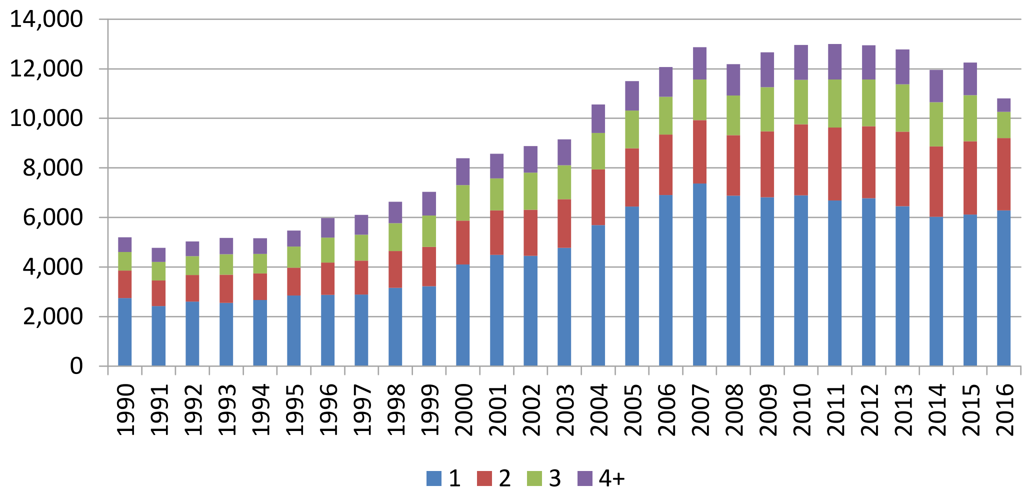
Investigating fluid tightness of structures, by detecting the presence of fluid at the leakage point	G01M 3/08 or G01M 3/14 or G01M 3/18 or G01M 3/22 or G01M 3/28 and E03
SUPPLY-SIDE TECHNOLOGIES	
Water collection (rain, surface and ground-water)	
Use of pumping plants or installations	E03B 5
Methods or installations for obtaining or collecting drinking water or tap water from underground	E03B 3/06-26
Methods or installations for drawing-off water	E03B 9
Methods or installations for obtaining or collecting drinking water or tap water from surface water	E03B 3/04; 28-38
Methods or installations for obtaining or collecting drinking water or tap water from rainwater	E03B 3/02
Special vessels for collecting or storing rain-water for use in the household, e.g. water-butts	E03B 3/03
Methods or installations for obtaining or collecting drinking water or tap water; rainwater, surface water, or groundwater	E03B 3/00 E03B 3/40
Water storage	
Arrangements or adaptations of tanks for water supply	E03B 11

Source: Haščič and Migotto (2015)

Annex C. Additional Graphs

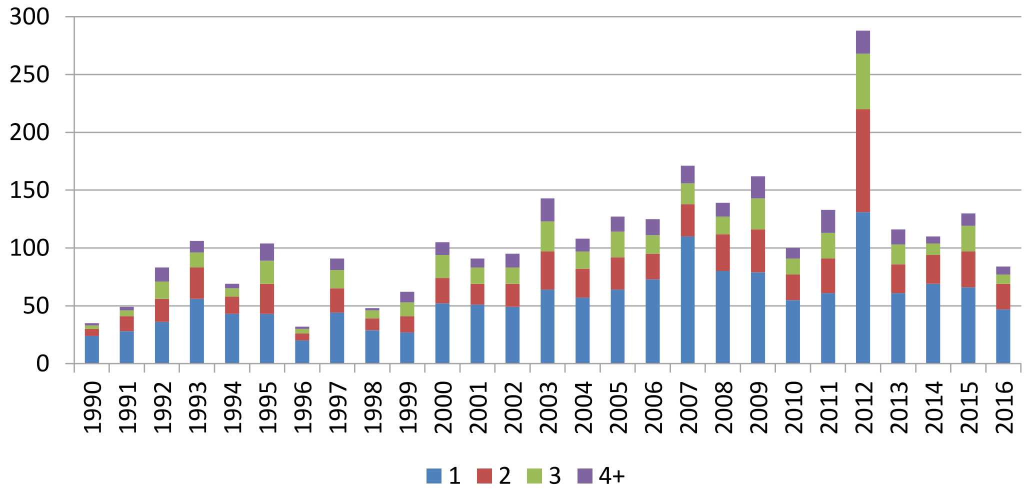
Family Size Trends by Category

Figure 8. Water and Wastewater Treatment Patent Family Sizes



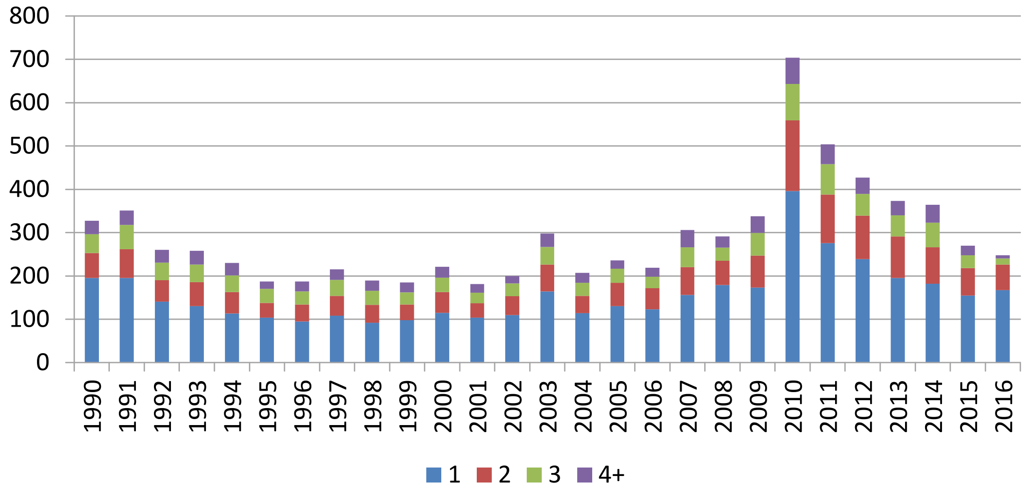
Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

Figure 9. Wastewater Fertiliser Patent Family Sizes



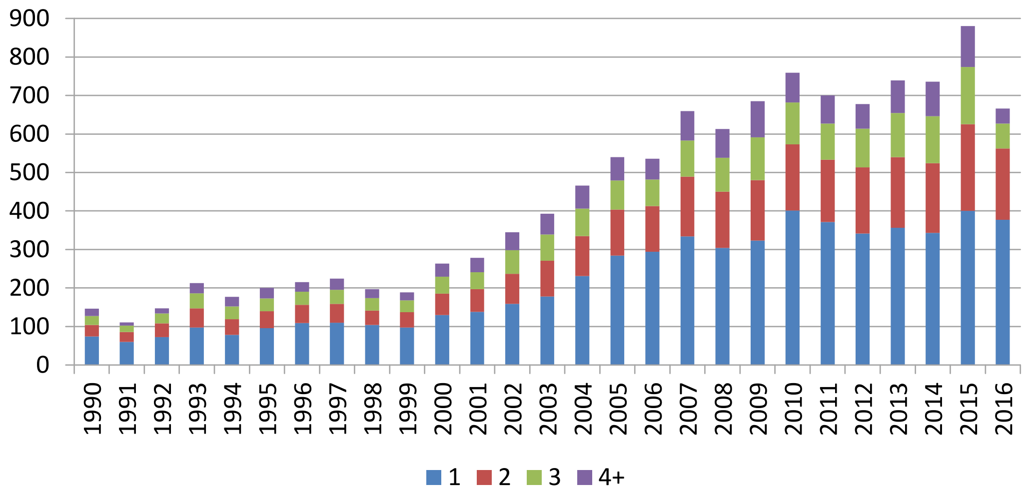
Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

Figure 10. Oil Spill Clean-up Patent Family Sizes



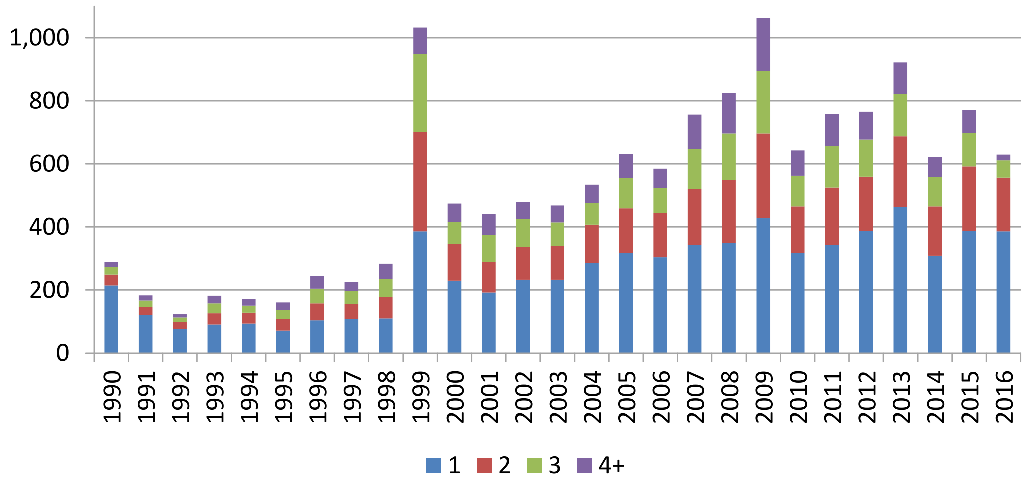
Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

Figure 11. Indoor Water Conservation Patent Family Sizes



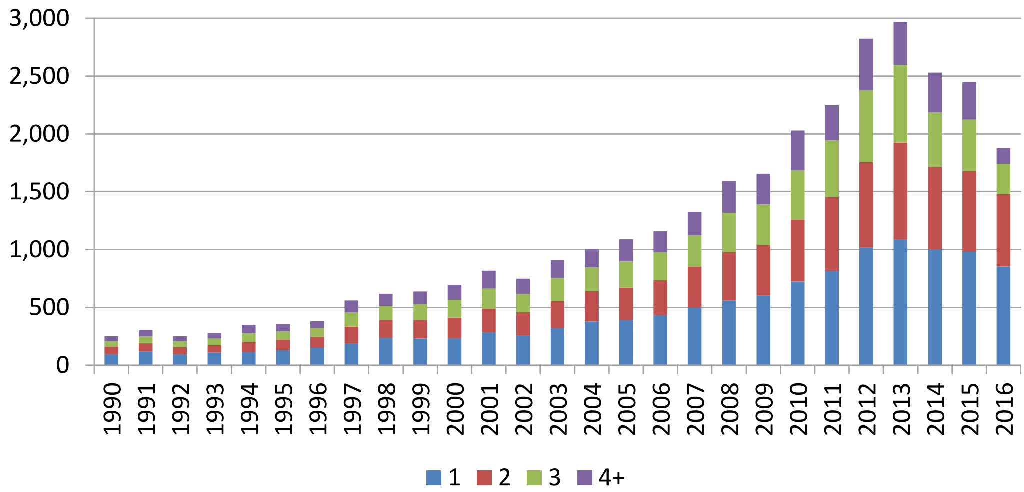
Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

Figure 12. Irrigation Water Conservation Patent Family Sizes



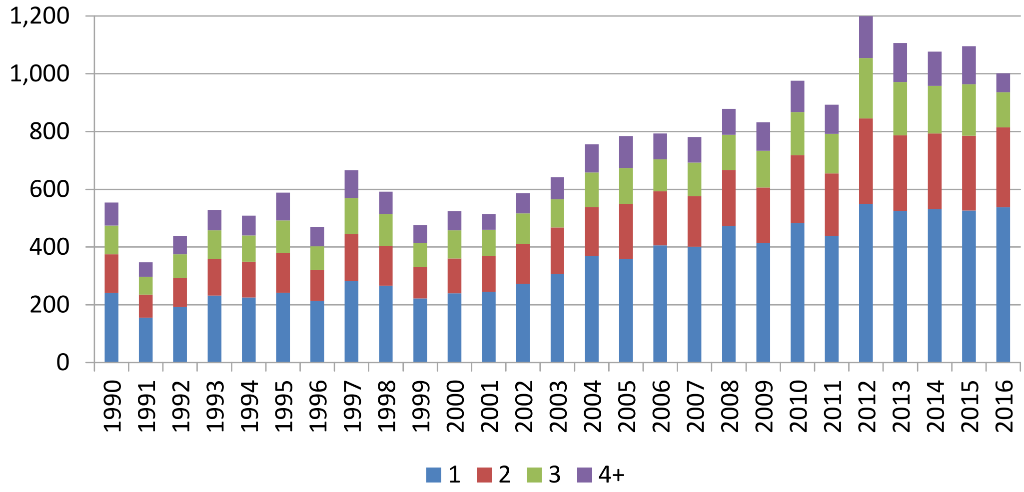
Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

Figure 13. Power Production Water Conservation Patent Family Sizes



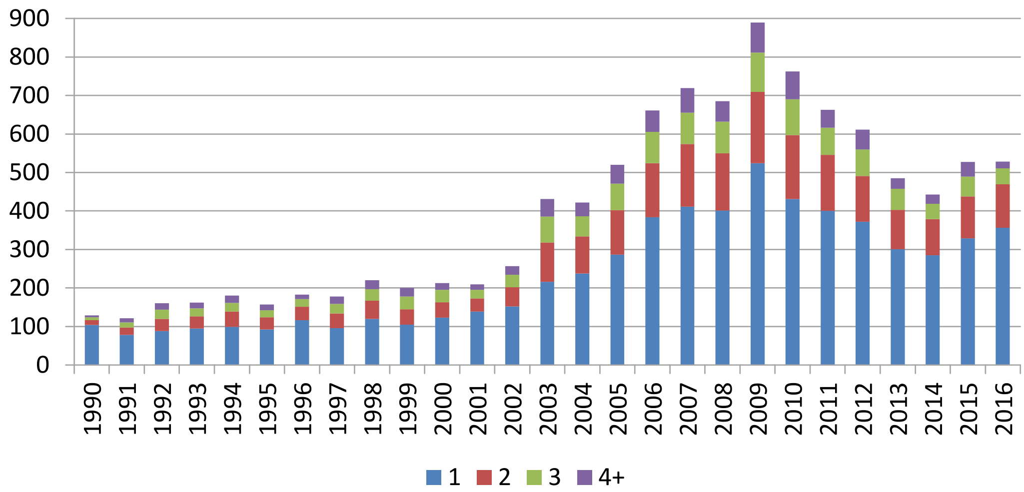
Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

Figure 14. Water Distribution Patent Family Sizes



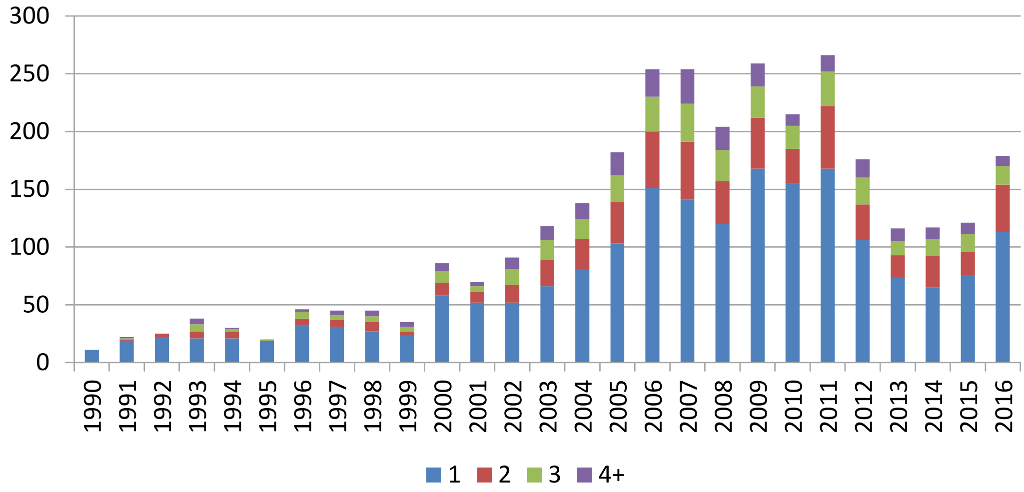
Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

Figure 15. Water Collection Patent Family Sizes



Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

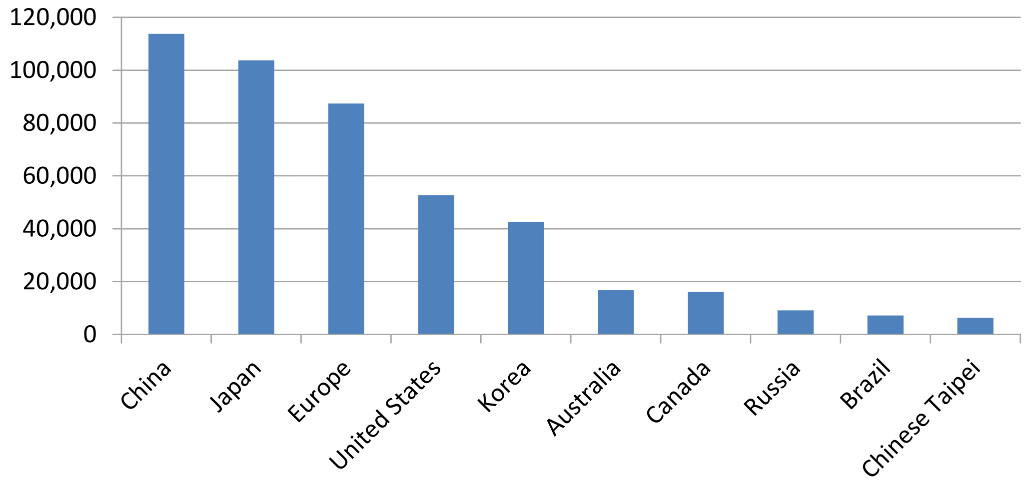
Figure 16. Water Storage Patent Family Sizes



Note: Patent family size refers to the number of jurisdictions in which a patent is protected.
Source: (OECD, 2020[2]).

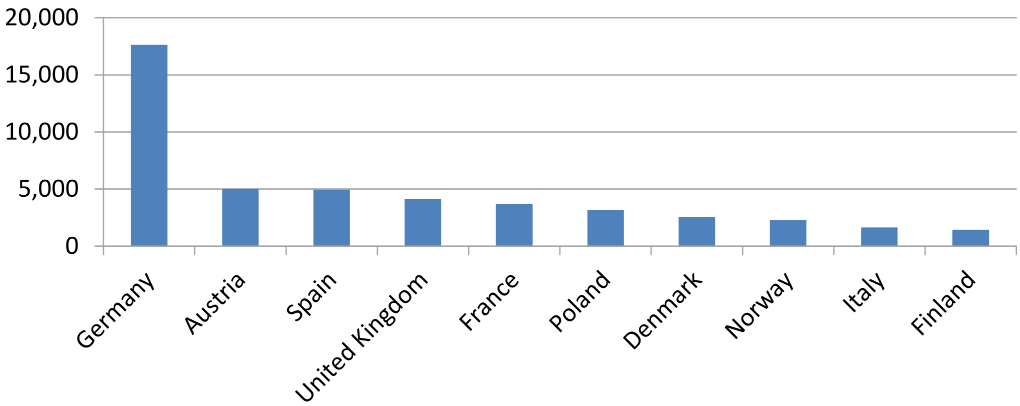
Major Markets by Category

Figure 17. Water and Wastewater Treatment Patents Seeking Protection at IP Offices



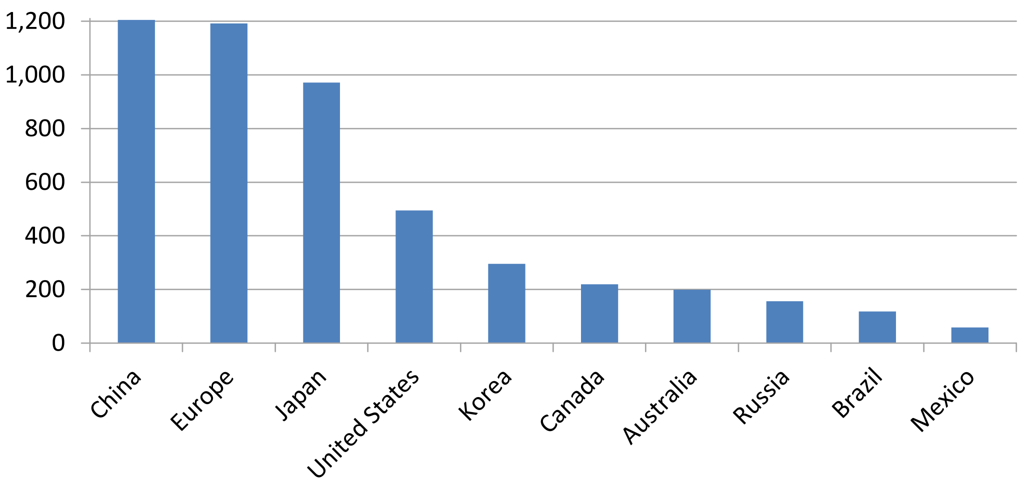
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 18. Water and Wastewater Treatment Patents Seeking Protection at European IP Offices



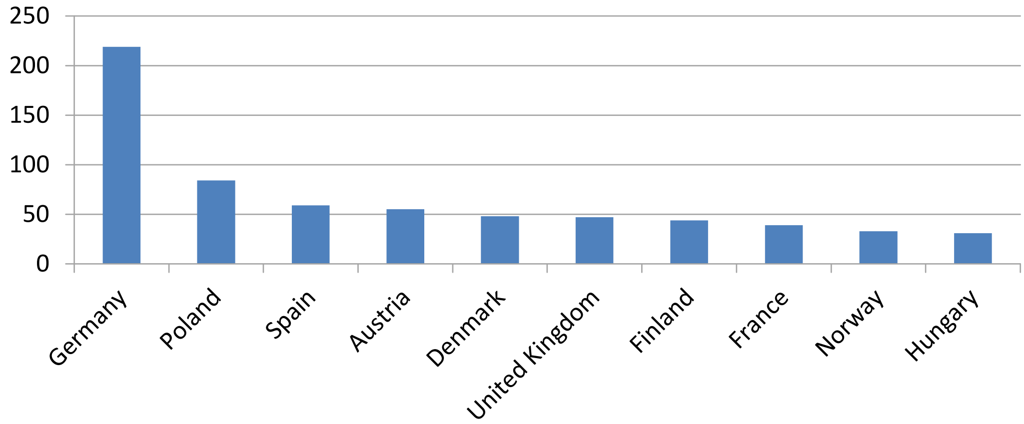
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 19. Wastewater Fertiliser Patents Seeking Protection at IP Offices



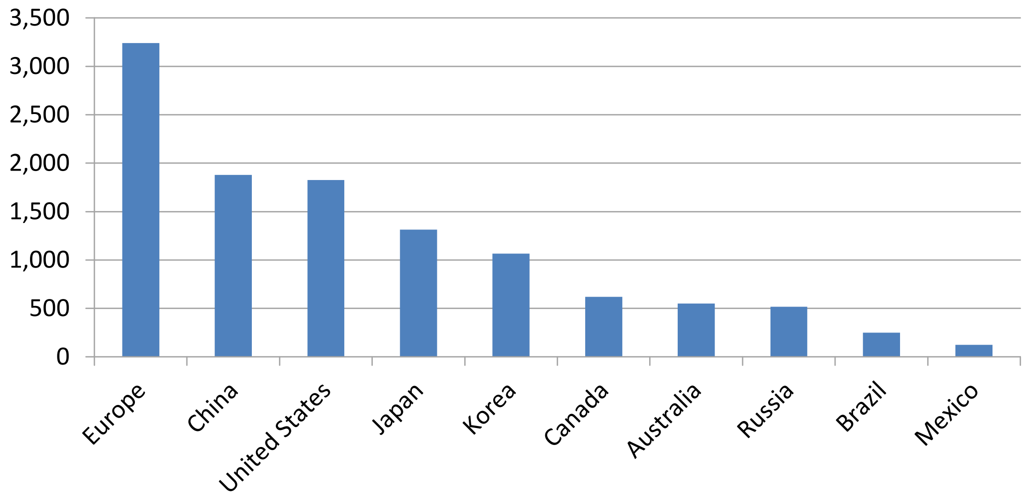
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 20. Wastewater Fertiliser Patents Seeking Protection at European IP Offices



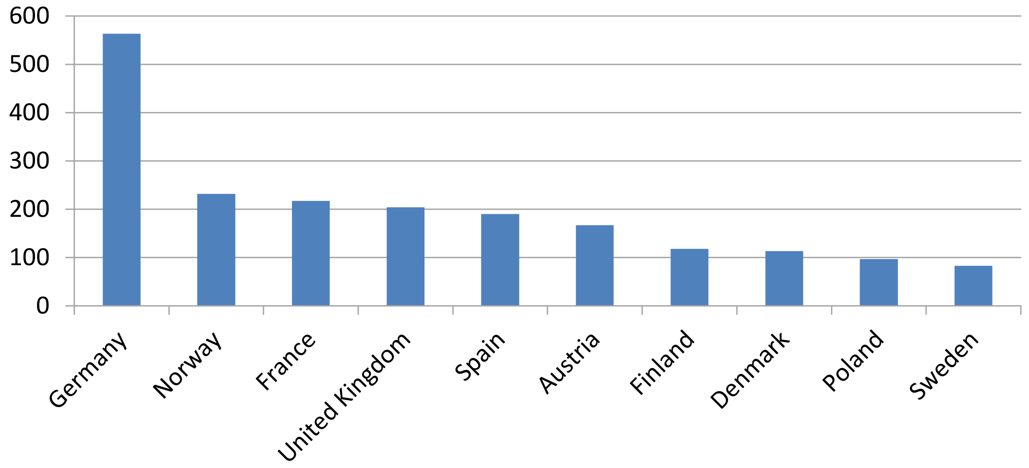
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 21. Oil Spill Clean-up Patents Seeking Protection at IP Offices



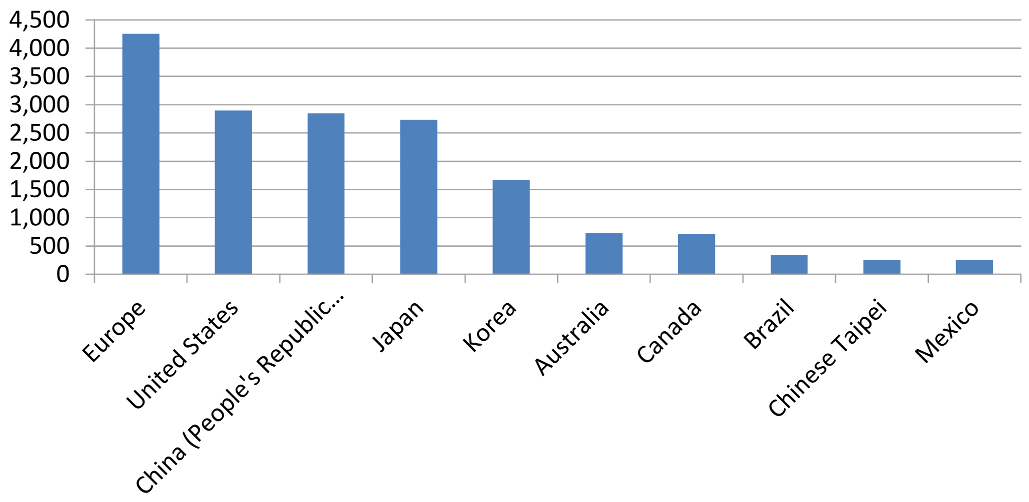
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 22. Oil Spill Clean-up Patents Seeking Protection at European IP Offices



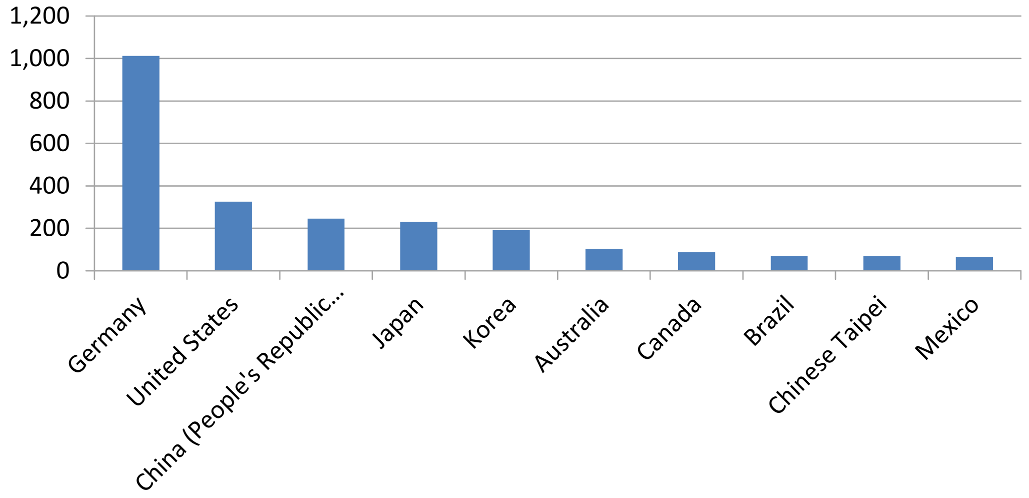
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 23. Indoor Water Conservation Patents Seeking Protection at IP Offices



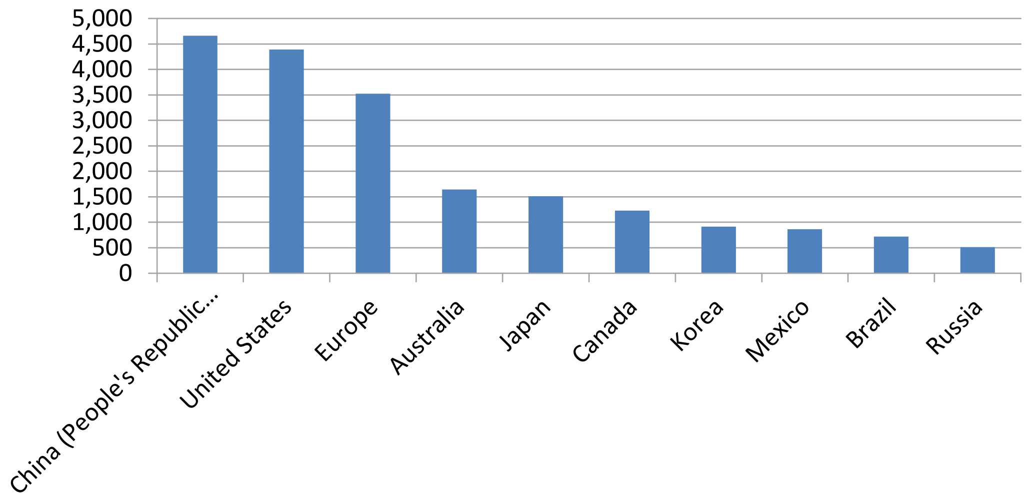
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 24. Indoor Water Conservation Patents Seeking Protection at European IP Offices



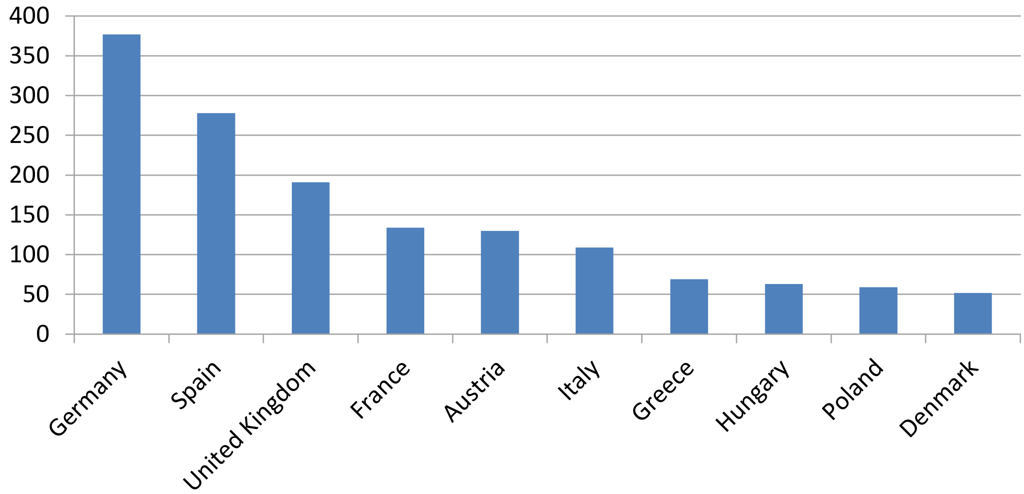
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 25. Irrigation Water Conservation Patents Seeking Protection at IP Offices



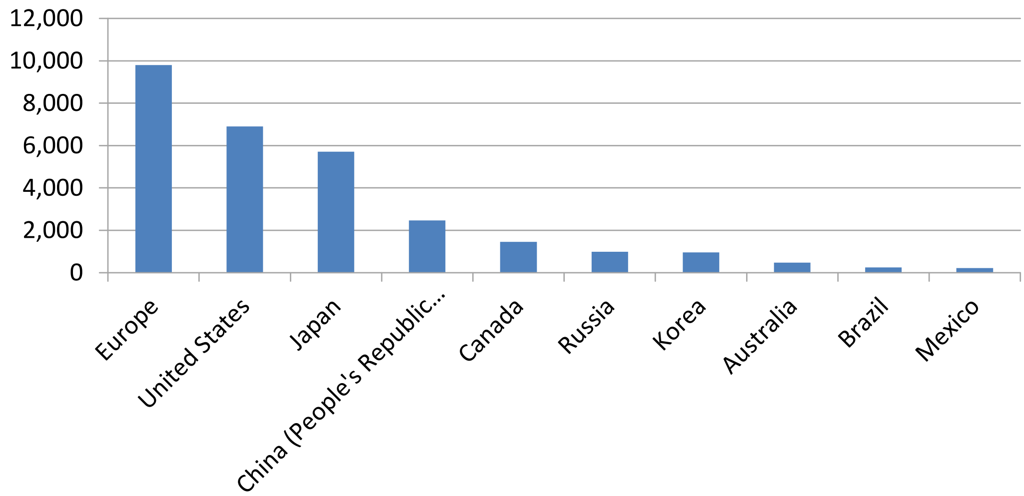
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 26. Irrigation Water Conservation Patents Seeking Protection at European IP Offices



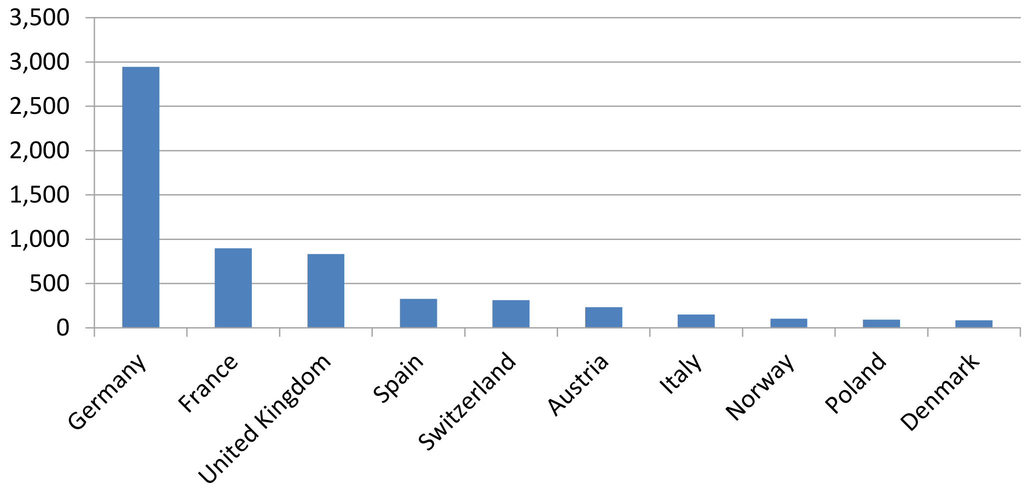
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 27. Power Production Conservation Patents Seeking Protection at IP Offices



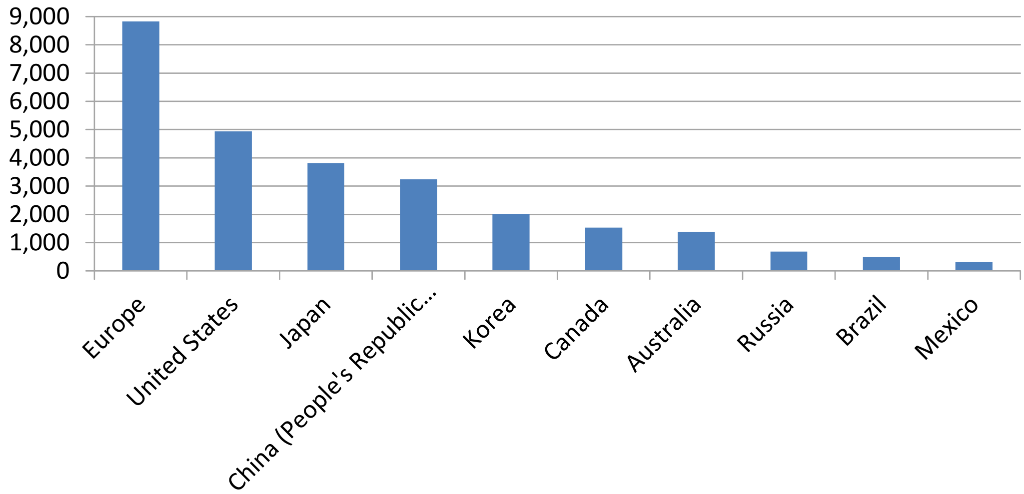
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 28. Power Production Conservation Patents Seeking Protection at European IP Offices



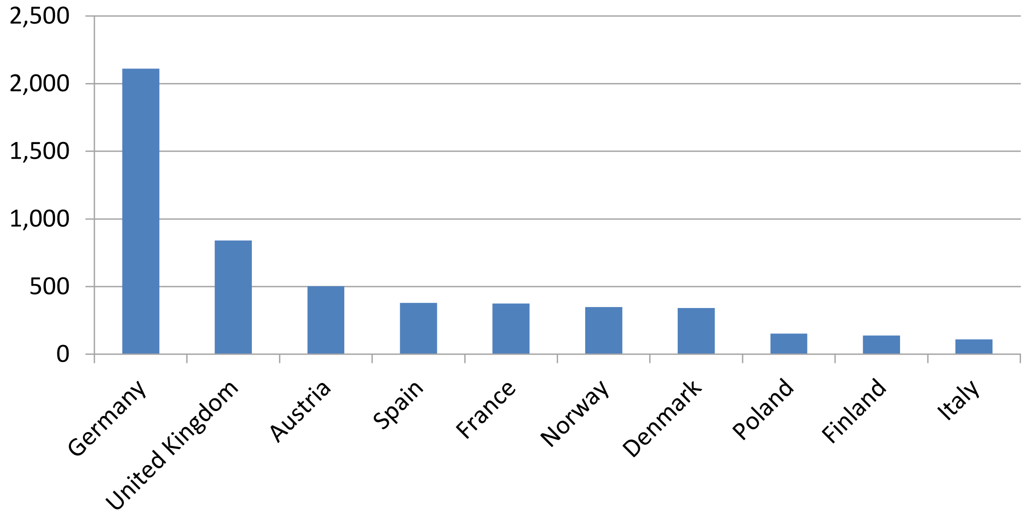
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 29. Water Distribution Patents Seeking Protection at IP Offices



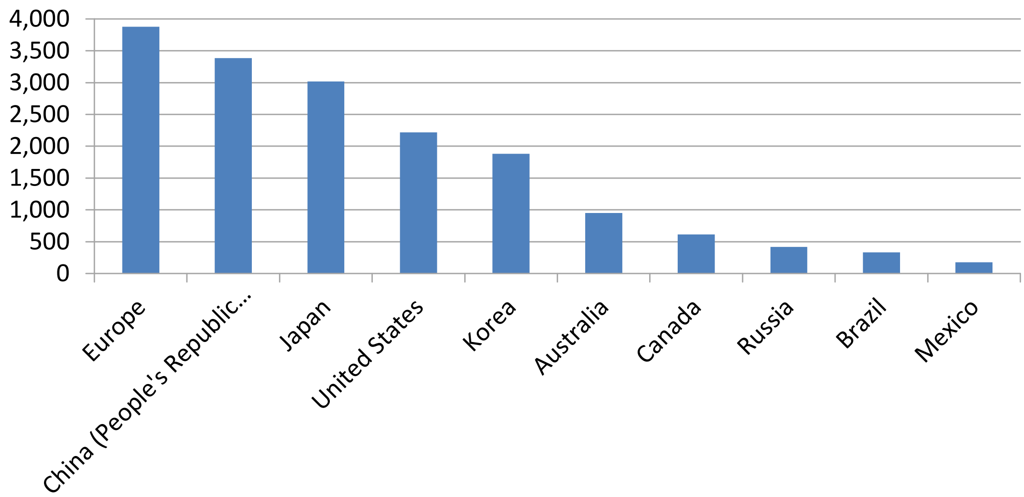
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 30. Water Distribution Patents Seeking Protection at European IP Offices



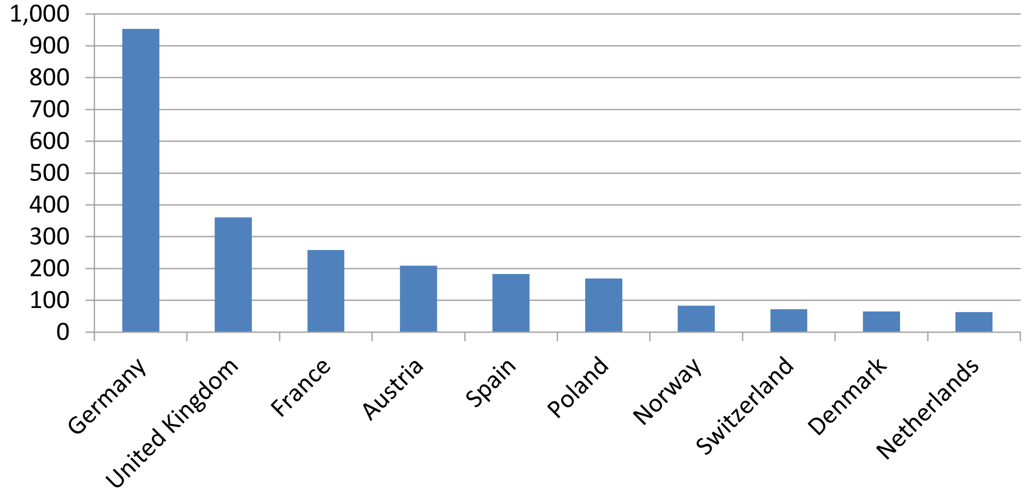
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 31. Water Collection Patents Seeking Protection at IP Offices



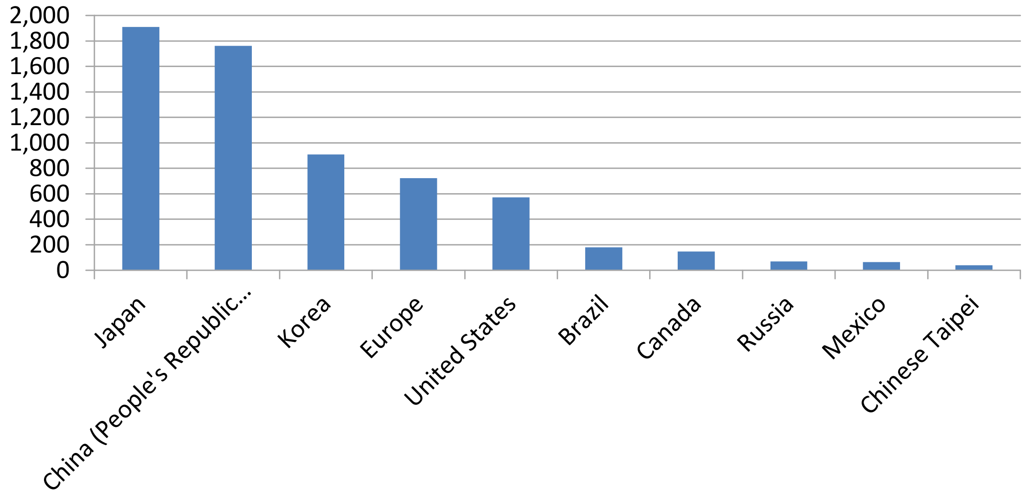
Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 32. Water Collection Patents Seeking Protection at European IP Offices



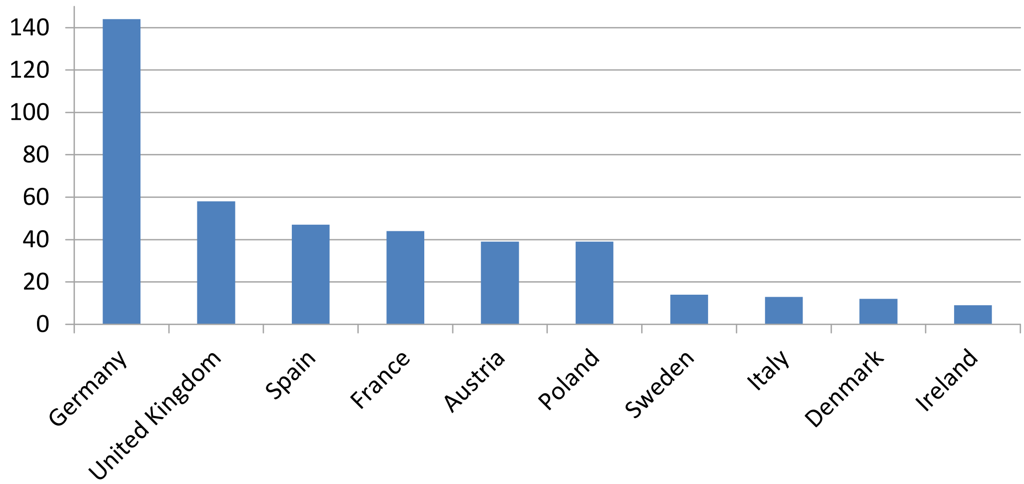
Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 33. Water Storage Patents Seeking Protection at IP Offices



Note: Europe refers to patents filed at any current member of the European Patent Office (EPO) or at the EPO itself. The period is from 1990 to 2016.
Source: (OECD, 2020[5]).

Figure 34. Water Storage Patents Seeking Protection at European IP Offices



Note: The period is from 1990 to 2016.
Source: (OECD, 2020[5]).