Technological innovation and green transition: where does Belgium stand?

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Introduction

Responses to the many challenges related to climate change are (partly) based on established technologies but will mostly rely on technological breakthroughs that can ensure, or even accelerate, the transition to a low-carbon economy. Given the growing concern about climate change across the world, the need to respond to the global challenge it presents is now pressing. So, technological development and innovation, which are considered as the source of an economy's prosperity and productivity growth, will also be an important driver of the structural changes in favour of a "greening" of production in many areas of activity and final consumption.

Substantial progress has already been made in several domains, but the technological advances needed require an acceleration both in the pace of innovation and in the application and deployment of the research and development (R&D) carried out. This is also an opportunity to develop low-energy products and components and reach new markets, modernise industries and infrastructure by making them more sustainable, while stimulating the economy to achieve the desired transition. New growth and job opportunities are likely to emerge.

This article discusses the importance of research and diffusion of green inventions in the economy to ensure sustainable economic growth. In continuity with the article in the December 2020 Economic Review on Belgian innovation capacity assessed through the prism of patent data, this article deals more specifically with innovation in "green" technologies. The context of green innovation is captured by using patent data. By its design (protection of the invention in exchange for mandatory public disclosure of the progress made), the patent system promotes innovation and the spread of new technologies. In this respect, it is a useful – although not perfect and incomplete – source of information to measure innovation capabilities and technological change. The analysis of the patent data aims to give an overall picture of the contribution of European and Belgian innovators and innovation eco-systems to the deployment of technologies that are beneficial to the environmental transition.

1. Inventive activity in climate change mitigation technologies

Achieving climate targets requires the production and consumption of more carbon-efficient goods and services for reducing greenhouse gas (GHG) emissions. This will affect all parts of the economy and society and will require green technological innovation and adoption worldwide of not only existing but also new and possibly disruptive

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technologies. Some of them will have cross-cutting applications, while others will target specific activities. A wide range of solutions involve nanotechnology, biotechnology, additive manufacturing or materials technology.

1.1 Green innovation through the lens of patent data

Patent data serve as a measure of technological innovation as they relate to the output of the inventive process. Thanks to the temporary protection and exclusive commercial rights for owners of patented inventions, the patent system provides an incentive to innovate and facilitates the dissemination of new technologies (better visibility of technological change, improved transaction processes). In terms of their use for statistical analysis, patent data include a wealth of information on the nature of the inventions, their inventors and the owners of the patents (referred to as “applicants”).

However, it is worth mentioning that patent-based indicators are subject to measurement issues that can be partially corrected or should at least be kept in mind [1]. While the propensity to patent may reflect greater inventive activity, it may also be motivated by other – regulatory or fiscal – considerations. Not all inventions are patented; there is no obligation to patent and other means of intellectual property rights protection are available. Regarding innovation, not all patented inventions necessarily lead to an industrial application or marketable product. In terms of statistical reporting, the availability of patent data is subject to a delay of at best 18 months between the priority date and their publication by the patent office that received the application. If patent families are considered (a patent filed in at least two jurisdictions), then the timeline may go up to 32 months.

Given the growing interest in analysis of green innovation efforts, the European Patent Office (EPO) has developed a dedicated tagging scheme to target patents covering “*technical achievements which directly or indirectly either help reduce the emission of greenhouse gases or actively enhance the sinks of such gasses*” (Angelucci, 2018). It identifies climate change adaptation and mitigation technologies (Y02 category) and technologies linked to smart grids (Y04S category). The related Y02/Y04S classes are exclusively used to label patent applications which are already classified or indexed in the Cooperative Patent Classification (CPC) system, but which fall within the broad definition of these green technologies. The EPO Worldwide Patent Statistical Database (PATSTAT database) and its Y02 classification make it possible to monitor technological developments and identify cross-cutting technologies that can mitigate climate change and which do not systematically correspond entirely to a section of the CPC. The identified patent documents relating to climate change mitigation technologies (CCMTs) are classified between seven sub-classes organised around the many areas within which these technological achievements apply. If deemed appropriate, a patent document can receive more than one indexing code of these sub-classes.

The analysis below is based on data relating to CCMTs, excluding climate change adaptation technologies. This latter (Y02A) classification covers adaptation technologies to preserve coastal zones, water supplies or resource conservation or efficiency, agriculture, forestry, livestock or food production, adaptation technologies in human health protection and protecting infrastructure or their operation (resilient infrastructure). The separated Y04S dedicated to smart grids has not been considered either even if it is closely connected to the Y02 as it concerns systems integrating technologies and information and communication technologies (ICT) for improving electrical power generation, transmission, distribution, management or usage. About two-thirds of the smart-grid Y04S categories relate to CCMTs and patent documents tagged under Y04S will often also be coded under Y02B (interactions with end-user applications), Y02E (electric power system management) or Y02T (interoperability of the electric and hybrid vehicles with the power network) (Angelucci *et al.*, 2018).

1 For a survey on patent measurement issues, see Cheliout S. (2020), “Belgium’s innovative capacity seen through the lens of patent data”, NBB Economic Review, December. The various counting methodologies and their impact are presented in Dernis *et al.* (2001). For international comparisons de Rassenfosse *et al.* (2013) illustrate the importance of the jurisdiction(s) considered to compute statistical series. The link between innovative efforts (R&D expenditure) and patent filings is complex, as shown by de Rassenfosse *et al.* (2013). The authors suggest – and provide evidence – that this link is imperfect, due to three factors: heterogeneous research productivity (not all research projects lead to useful inventions); heterogeneous propensity to patent (once the invention is made, do you patent it or not?); and heterogeneous strategic propensity (once you patent an invention, how many patents do you file?).

Table 1

Climate change mitigation technologies distributed across many areas

Y02B	CCMTs relating to buildings	Integration of renewables in buildings, lighting, heating, ventilation and air conditioning, home appliances, constructional or architectural elements improving the thermal performance of buildings
Y02C	Carbon capture and storage (CCS)	CO_2 and GHG emissions capture and storage
Y02D	ICT aiming at the reduction of their own energy use	Energy-efficient computing, techniques for reducing energy consumption in wireline/wireless communication networks
Y02E	CCMTs relating to energy generation, storage and distribution	Renewable energy sources (RES) production, efficient combustion, nuclear energy, biofuels, efficient transmission and distribution, energy storage (hydrogen, batteries, fuel cells)
Y02P	CCMTs in industrial processing or production activity	Metal processing, chemicals/petrochemicals industry, minerals processing (cement, lime, glass), food industry
Y02T	CCMTs relating to transport	E-mobility, hybrid cars, efficient internal combustion engines, efficient technologies in railways, air and waterways transport
Y02W	CCMTs in waste and wastewater treatment	Wastewater treatment, solid waste management, bio packaging

Source: EPO.

In combination with patent statistics tools, the tagging scheme makes it possible to map the development of sustainable technologies within the PATSTAT database which represents some 18 million records of patent data (with all CPC classes) filed and registered at the EPO over the period 2000-2016.

1.2 Inventive activity in CCMTs worldwide

To place the CCMT patent landscape in context, we first investigate the inventive activity in these fields worldwide, considering patents filed in all jurisdictions as reported in the OECD Environment database (OECD/ENV). To sketch the inventive activity across countries and years, we elaborate on patent statistics based on country of residence of the inventor(s) and priority date, which is the closest date to the research activity and invention. Patent families are considered here, which include the subsequent international patent applications associated with a priority filing. The larger the patent family, the higher the potential value of the invention, as it bears additional costs for the patent owner, and a willingness to enter foreign markets. As a unique patent may have many inventors (or applicants) located in different countries, it is divided equally amongst all of them and their corresponding country of residence (fractional count method, see Dernis *et al.*, 2001) to avoid multiple counts in establishing the geographic origin which then better reflects the effective contribution of each country to the inventive activity. Patent counts in absolute numbers are aggregated around the specific CCMTs to sketch how these technologies are developing and evolving across countries [1].

1.2.1 After a strong increase, patent filings relating to CCMTs have levelled out in recent years

There has been a rapid growth in the number of green patents filed worldwide over the past 25 years and particularly since 2005. Record numbers of green patents have been filed globally, reaching 35 200 patents at the highest point in 2012. Green inventions have grown much faster than in other areas, to the extent that CCMTs in the years 2015-2016 account for 9 % of the world's inventions, up from 4 % in the 1990-1994 period. Between 2000 and 2012, the number of new climate-change-mitigation inventions patented globally grew at an annual rate of 10 %, more than triple the rate of innovation in all technologies. Patent registrations for CCMTs started to slow in the five years following the 2008-2009 financial crisis and even declined from 2012 on in

1 See appendix on several concepts around patenting used in this article.

specific technological fields, in contrast to the findings for other flourishing sectors (health-related technologies and ICT) (IEA, 2019).

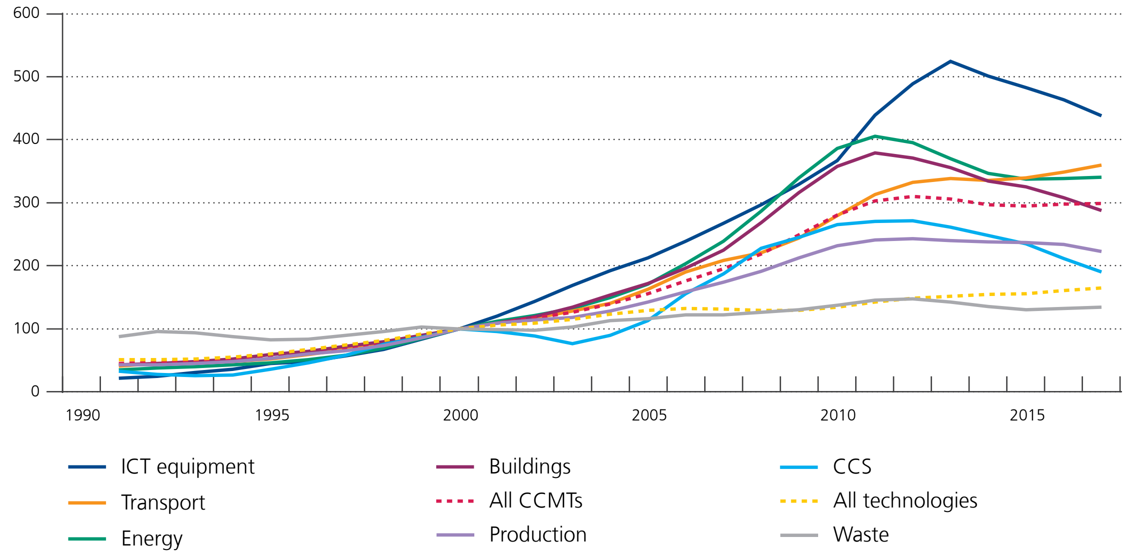
Several factors may be behind this trend. Public policies support the development of green technologies. The adoption and reinforcement of environmental regulations, whether in the form of compulsory standards on equipment (for instance, on electricity and heat production equipment to reduce sulphur dioxide (SO_2) and nitrogen oxide (NOx) emissions with pollution-abatement techniques) or because of the change in relative CO_2 prices that climate change regulations trigger (induced innovation when profit-motivated R&D and inventors expect higher benefits) drive the development of low-carbon technologies. The higher energy prices incurred by those policy measures are associated with wider green patenting. Moreover, much of this innovation response occurs within the space of five years (Dechezleprêtre *et al.*, 2016). The fall in oil prices since mid-2014 reduces the value of future energy savings and/or alternatives to fossil fuels as well as the incentive to go green. Based on patent data in car technologies, Aghion *et al.* (2016) have shown that higher fuel prices boost innovation in low-carbon technologies while curbing it in high-carbon ones. A similar rationale can be used with regard to the CO_2 price to be paid by large (EU-ETS-regulated) emitters (Calel *et al.*, 2016). Increasing technological maturity of several CCMTs may also explain the slowdown in patenting activity with further developments working with the existing (patented) innovations as in solar PV, for instance (IEA, 2019). Finally, the loosening of environment-friendly policies – not to mention the end of the United States' membership of the Paris Agreement – might also have reduced the pace of innovation in the United States. A surge in CCMT patents may well be expected in the coming years, given the drastic change in policy with ambitious green targets for the future and, on the European side, implementation of the Green Deal on which the European recovery depends to support future economic growth.

Importantly, these declining low-carbon innovation efforts are not a meaningless observation, given the time lag between innovation and market diffusion at a reasonable economic cost for large-scale deployment. This change

Chart 1

Growth of worldwide yearly patent applications for CCMTs [1]

(index 2000 = 100 [2])



Source: OECD/ENV.

1 All known patent families worldwide are considered. Refers to inventions filed in two or more jurisdictions (patent family size equal to or larger than two).

2 Index of 3-year moving average.

has been particularly striking across the energy (Y02E) and buildings (Y02B) classes. This downward trend is not visible in the maritime and air transport CCMTs (Y02T) which have moved higher up in environmental policy discussions in recent years.

1.2.2 Nevertheless, CCMT patents represent a rising share of the overall innovation effort

At the peak of patent filings around 2010-2014, those related to CCMTs accounted for some 10 % of all patents filed by European inventors, double the proportion in 2000-2004. It is true that the rate of growth of low-carbon innovation activities reflected in patents has accelerated in Europe from 2005 onwards, which coincides with the implementation of the EU ETS mechanism. However, even if it appears that the introduction of the mechanism has led to a 10 % increase in the patenting of CCMT-related inventions among EU-ETS-regulated firms, the EU ETS accounts for only about 2 % of the post-2005 surge in low-carbon patenting in Europe (as it has not affected patenting of non-EU-ETS-regulated companies) (Calel *et al.*, 2016). Denmark's notable performance and specialisation in CCMT patenting (nearly 20 % of patent applications with inventors located in Denmark are in the field of CCMTs) are linked to its very active research and innovation-oriented low-carbon industries which have an average of 9 out of 100 employees working in the field of research and innovation compared to on average 5 out of 100 employees in traditional Danish companies (Danish NECP, 2020).

Table 2

Share of CCMT patents in the total patent portfolio [1]

(in % of the patent portfolio of each country/zone, average over periods)

	2000-2004	2005-2009	2010-2014	2015-2016
World	5.3	7.6	10.3	9.3
Japan	6.7	7.9	11.1	10.1
United States	4.6	7.5	10.0	9.3
EU28	5.0	7.9	10.9	9.8
Germany	5.8	8.5	11.6	10.4
France	4.8	7.9	11.4	10.3
The Netherlands	3.9	6.5	8.6	7.2
Belgium	4.1	5.6	7.9	7.7
Denmark	5.5	14.7	20.1	18.3
South Korea	4.9	7.8	12.8	12.1
China	4.5	6.4	7.6	6.9

Source: OECD/ENV.

1 All known patent families worldwide are considered. Refers to inventions filed in two or more jurisdictions (patent family size equal to or larger than two). Fractional patent counts are based on the priority date and the inventor's country of residence.

1.2.3 Innovation in digitalisation supports CCMTs development

Table 3 shows that the changes triggered by rising digital technology and innovation in CCMTs are noticeable in the energy system, i.e. in the way stakeholders produce and consume energy as digital technologies enable a multi-directional and highly-integrated energy system. The energy sector has been a traditional user of digital technologies for grid management. It further develops smart electricity grids to mainstream decentralised production from renewable energy sources (RES) in the electricity system on an efficient and reliable way. These innovations also have applications for buildings enabling demand-side response thanks to intelligent home systems connecting devices to reduce peak loads or store energy in batteries. Digitalisation is key for

Table 3

Rate of penetration of digital technologies in CCMTs

(in % of patent families[1] which include both the technology field considered and at least one class related to ICT)

	1990	2000	2005	2010	2015	2018
All technologies	23.0	34.9	40.3	39.8	39.8	40.0
Health technologies	3.8	5.6	8.2	9.3	10.5	8.8
CCMTs	9.3	18.0	24.1	29.8	25.2	23.5
Buildings	14.1	21.2	27.8	34.0	24.8	37.4
Energy	18.8	26.1	26.6	36.7	29.3	37.1
Production	10.0	20.7	24.5	29.2	22.7	17.8
Transport	1.6	2.9	8.4	10.6	4.4	4.4

Sources: OECD/ENV and IEA (2019).
1 Patent family size equal to or larger than two.

autonomous driving, connected and electrified vehicles (EVs), and shared mobility which will eventually shape all road transport modes. It leads to the development of new services such as those made possible by smart mobility applications for real-time passenger and freight transport dispatching. One-quarter to one-third of CCMT patents are tagged as related to ICT and this share reaches almost 40 % in energy and buildings CCMTs. As energy technologies develop, advances in design, conception and operation increasingly rely on innovation in ICT. Hence, climate change mitigation will also benefit from the research effort on digitalisation in general, making the energy systems more connected, smart, efficient and reliable.

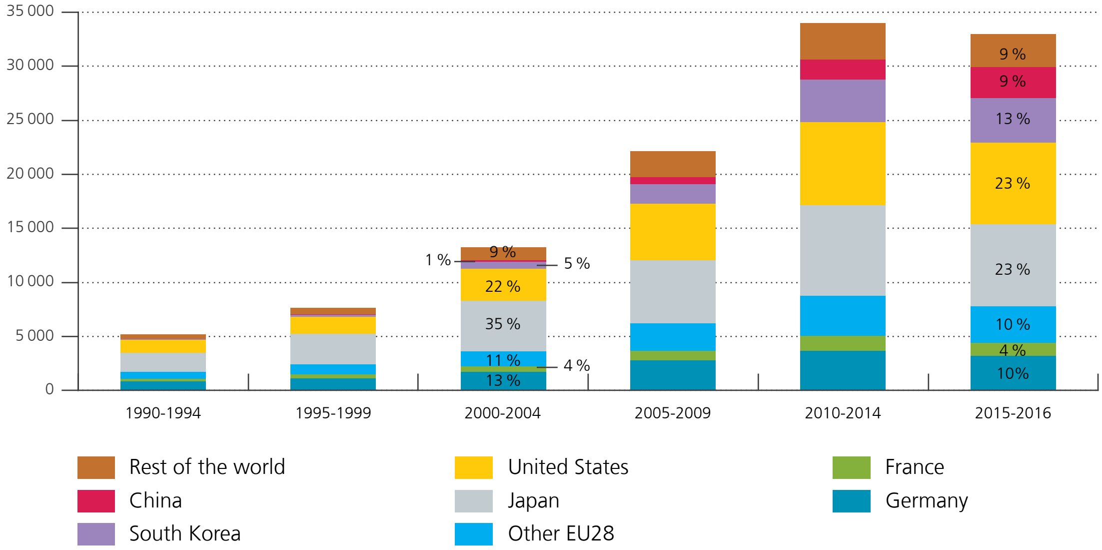
1.3 CCMT inventions are mostly developed by inventors from major economies …

In terms of the geographical origin of patent applications, 70 % of CCMT patents worldwide are brought by American, Japanese and European inventors. With the consequent development of inventive activities in green technologies in China and Korea, Japanese and European inventors are losing ground. Chinese inventors have been particularly active in patenting, with annual green patents filings almost twenty times higher in 2015-2016 compared to 2000-2004. This exponential growth is due to the strong growth of patent applications in China and is a consequence of the broader context of innovation policy: in the late 1990s, policies to boost innovation among Chinese inventors were put in place with the ambition of the authorities to move China up the value chains by producing more goods of higher value. In 2006, the authorities implemented so-called

Chart 2

Number of patents by inventor's country of residence

(yearly number of CCMT patents and share by origin in % [1])



Source: OECD/ENV.

1 All known patent families worldwide are considered. Refers to inventions filed in two or more jurisdictions (patent family size equal to or larger than two). Fractional patent counts are based on the priority date and the inventor's country of residence.

indigenous innovation policies aimed at promoting domestic innovation by boosting R&D capabilities of domestic high-technology manufacturing industries. There is strong support from public funding programmes through the national key R&D projects,15 out of 64 of which are currently dedicated (fully or partially) to R&D in clean energy (IEA, 2020a and Development Solutions Europe Ltd, 2019).

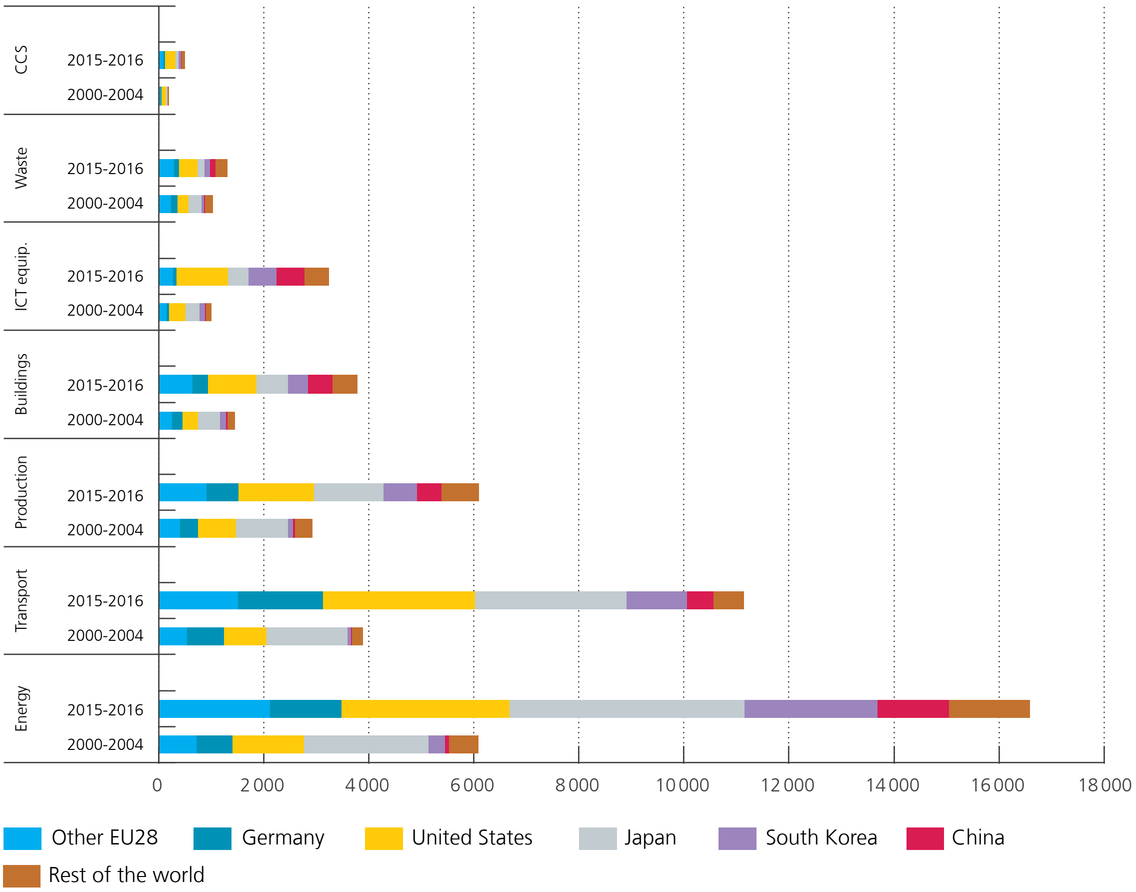
1.4 … with specialisation in some fields

On a global scale, most patented inventions are in green energy production and transmission, transport and production processes. Patented inventions in waste and wastewater management and in production processes have seen more moderate growth and seem to be more mature. Future technology improvements in waste management are in line with the relative decoupling of primary materials use and stimulate the transition to a more circular economy. The European Commission's March 2020 "Circular Economy Action Plan" aims to reduce the EU's materials consumption footprint and double its circular material use rate (ratio of the circular use of materials to overall material use). The need to drive innovation in how material resources are used and re-used has been acknowledged in this Action Plan. More generally, patenting activity in the respective technology fields also reflects the efforts made upstream in terms of R&D investment. The provision of policy incentives for the development of specific technologies such as the feed-in tariffs on solar and wind energy production – requiring utilities to buy the power produced at a rate above the wholesale price of electricity – in Germany (1991), Denmark (1993) or Spain (1994) has introduced conditions to make these technologies more attractive to develop for industries and markets. It is also consistent with the EU's renewable energy target introduced in 1997. In all fields, the relative share of inventions from the EU28 is declining, as it is for Japan. Chinese and Korean inventors are taking an ever more visible position in the fields related to energy and ICT equipment (energy-efficient wireline and wireless communication networks with low power mode, for instance).

Chart 3

Number of patents by CCMT field and by inventor's country of residence

(yearly number of CCMT patents [1])



Source: OECD/ENV.

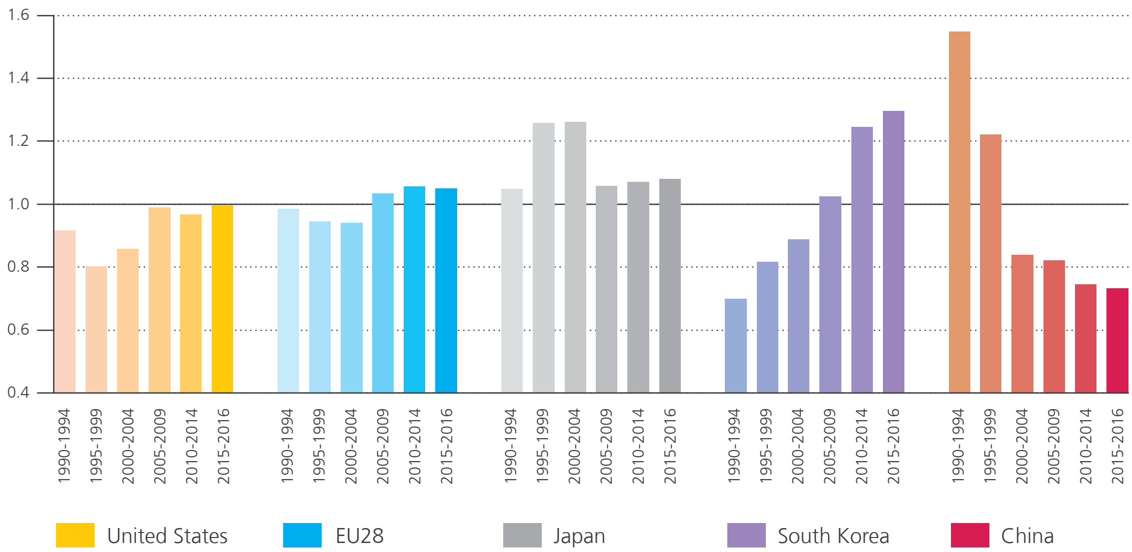
1 All known patent families worldwide are considered. Refers to inventions filed in two or more jurisdictions (patent family size equal to or larger than two). Fractional patent counts are based on the priority date and the inventor's country of residence.

There is a growing specialisation in the EU28 from 2004-2005 onwards: its revealed technological advantage (RTA) index is above one, which means that the percentage of green patents among a country's total patents is higher than the percentage of green patents worldwide, reflecting a relative better performance in CCMTs than the overall innovation record. The United States and China do not appear to be highly specialised, unlike South Korea, which quickly specialised and Japan which has always devoted a larger share of its overall innovation effort to CCMTs.

Chart 4

Revealed technological advantage index

(index > 1 means relative specialisation i.e. % green patents among total patents for country j > % green patents worldwide [1]; index world = 1)



Source: OECD/ENV.

1 All known patent families worldwide are considered. Refers to inventions filed in two or more jurisdictions (patent family size equal to or larger than two). Fractional patent counts are based on the priority date and the inventor's country of residence.

2. Focus on Europe's inventive capabilities in CCMTs

In the current and subsequent sections, the focus will be on the applicants of CCMT patents, as opposed to their inventors, or their country of residence, analysed in the previous sections. Figures on applicants – or patent owners – by geographical origin of CCMT patents provide an indication of their interest to protect their inventions on the European markets and how far they see a potential to develop and to sell them, that is, their market reach. Patenting activity in the European market – and Belgian market in section 3 – is assessed on the basis of one reference office, the EPO, in order to avoid bias due to differences in patent regulations and changes in laws over time. Direct applications filed with the EPO and international Patent Cooperation Treaty (PCT) applications for which the EPO is the designated International Search Authority – the so-called Euro-PCT applications – are considered too, still displayed by priority date. This also reflects some value given to these technologies by the applicants who have taken the step of patenting them at the European market level, which means wider – and more costly – protection than solely applying for a patent at national level. Fractional count is used to avoid multiple counts when applicants from different countries are concerned. Fractional count is also used at total CCMTs level when a patent document has received more than one indexing Y02i code (the patent is related to several CCMT fields); otherwise it would generate double counts and potentially bias the analysis.

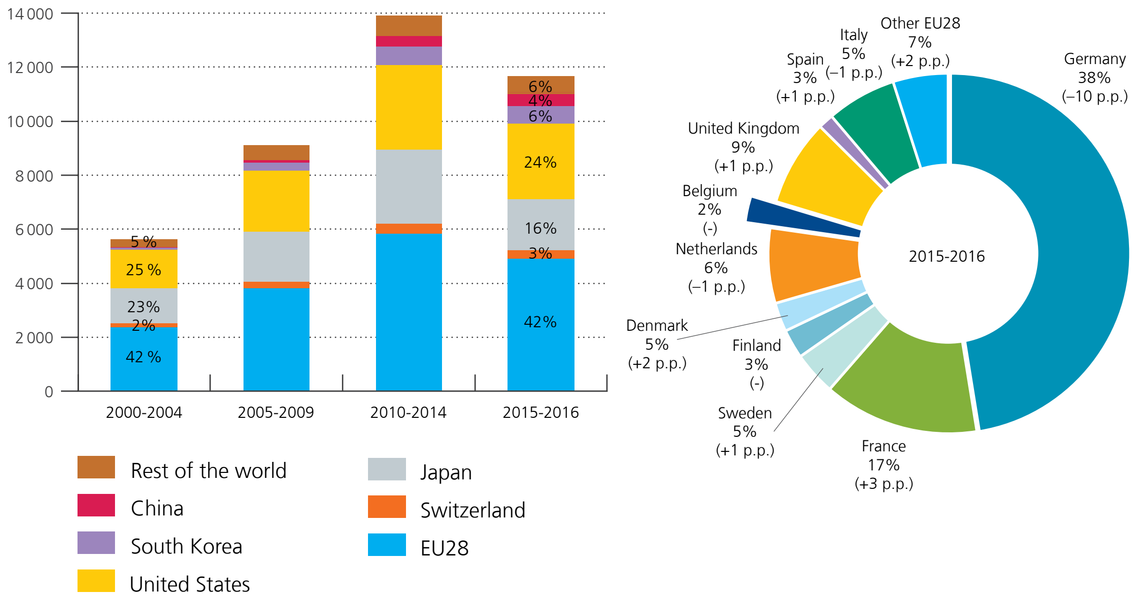
2.1 In Europe, most patenting activity is carried out in a few countries

Yearly CCMT patent filings with the EPO by EU28-based applicants increased by 5.3 % a year on average between 2000 and 2016 and accounted for some 42 % of patents. A geographical bias in favour of European applicants may influence this result with domestic applicants tending to file more patents in their home

Chart 5

Number of patents filed at the EPO by applicant's country of residence

(left: yearly number of CCMT patents at the EPO from all world economies[1];
right: share within the EU28 in 2015-2016 in % and difference to 2000-2004 in percentage points)



Source: EPO (PATSTAT).
1 Aggregate data at total CCMTs level corrected for multiple counts as patents may be classified in more than one Y02i technology class.

country/zone than non-resident applicants[1]. As already mentioned, European patent applicants have maintained the pace of new patents across all CCMT fields, similarly to the United States. This is less the case for Japan, which at the turn of the century was the first to file CCMT patents but is now being challenged by the United States, the EU28 and South Korea.

Patent filings by non-European applicants are an indicator of the willingness of multinational and/or non-EU firms to protect their innovations on the European market and to what extent it is an attractive and strategic place for CCMT development. Put another way, Europe's market commercial attractiveness for climate-driven technologies can easily be gauged. Behind the size and the potential of the market, the propensity to patent may be further motivated by the quality of intellectual property regulations and the reputation of the patent office (regarding rules or cost of patenting). American and Japanese green patent applications have gradually lost ground to the benefit of other non-European players (patents filed for Chinese and Korean inventions).

The patenting activity of European applicants in CCMTs is highly concentrated in a few European countries. Patent applicants from only five countries – Germany, France, United Kingdom, the Netherlands and Sweden – are accountable for 75 % of the applications filed by EU players. Among these European applicants, Germany emerges largely ahead of France, but its relative position has deteriorated: the number of green patents filed in 2016 has fallen by 33 % compared to the maximum level reached in 2011 (mainly in renewable energy in absolute numbers).

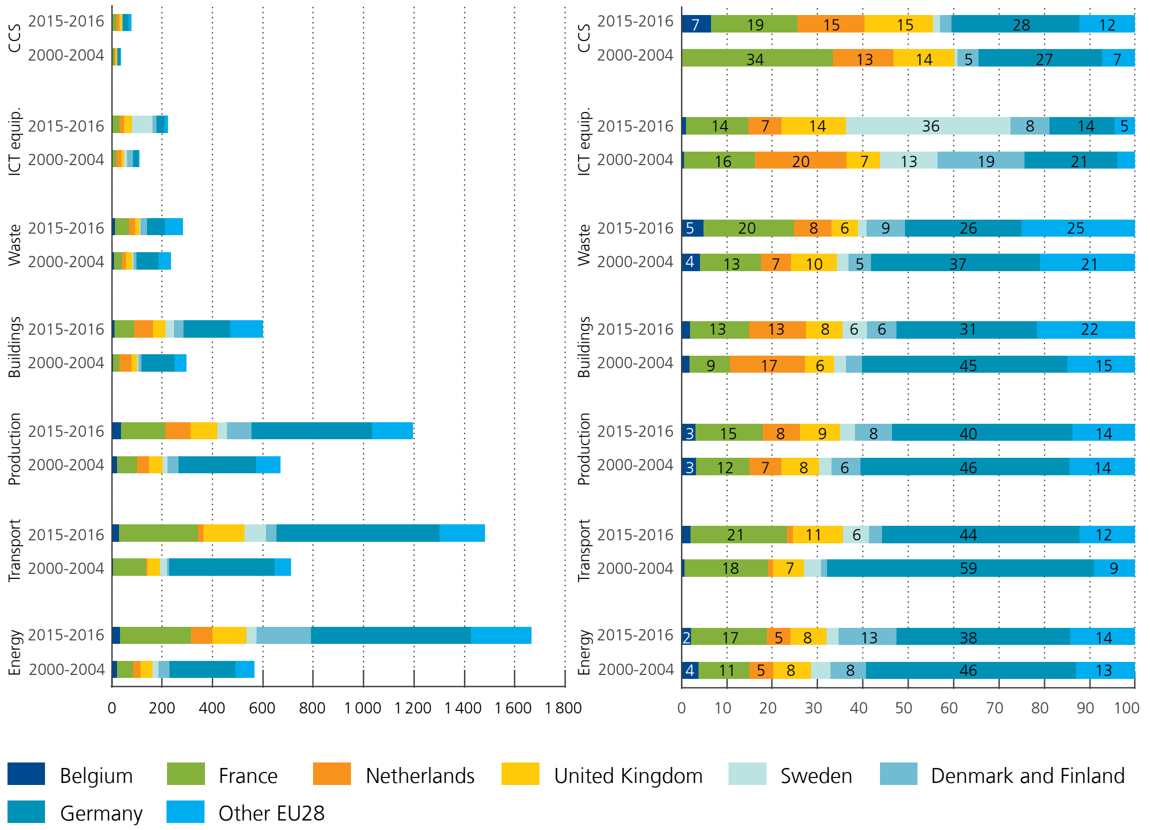
The increase in the number of CCMT patents is seen across all technology classes; it is less marked in technologies relating to waste management and manufacturing processes linked to metallurgy, food processing, chemicals, non-metallic minerals (glass, cement). For the latter, the search for innovation was already well

1 This is even more the case here as it concerns patent applications filed with the EPO which cover 38 countries including all EU27 Member States, UK, Norway, Switzerland, Turley, Iceland, Albania, Liechtenstein, Monaco, North Macedonia, Serbia and San Marino.

Chart 6

Number of patents field at the EPO by applicants from European origin by CCMT field

(left: average of yearly number of CCMT patents filed at the EPO;
right: country share within the EU28 in %)



Source: EPO (PATSTAT).

under way (energy-intensive industries seeking to reduce the cost of energy inputs, heavy industries with high GHG emissions, mostly subject to the EU ETS). There was no such strong increase in patenting activities as for technologies related to transport and particularly clean energy production, sectors in which environmental regulations play an important driving role.

Looking further into energy-related CCMTs, patenting from EU28 countries have been strong compared to the rest of the world in wind rotors, in advanced biofuels and in solar thermal energy. Germany is by far the leader in patenting for geothermal technology and industrial heat recovery. In wind energy, the largest share of patent applications is in the onshore wind turbine segment and patents by EU-based entities are filed in multiple patent offices worldwide. Historically, more patent applications for batteries have been filed outside Europe and even though France and Germany stepped up patenting and R&D public spending, the EU is still catching up. Most building-related CCMT patents are in micro-generation and thermal energy storage but patenting activity in district heating is extremely low (due to the maturity of core technologies and the small number of companies involved); the share of heat pump patents has been steadily rising, however. Germany dominates activity in CO_2 capture technologies, followed by France and the Netherlands. These countries were also among the four countries with interest in CO_2 storage, together with Austria. CO_2 storage and transport projects are typically driven by global gas and oil companies including outside of Europe. The market for CCS technologies may be relatively small today, but there are high expectations of potential growth with higher CO_2 prices and as a technology to offset GHG emissions (EC, 2020b).

2.2 How do European countries position themselves in patenting green technologies?

Unsurprisingly, the ranking of countries according to the number of green patents filed annually is overwhelmingly influenced by the major economies, including of non-European origin. In the recent period, both Korea and China have climbed into the top 10. Korea was already 11th in the ranking in 2000-2004 and is now in 5th place. China has moved 12 places upwards. Since 2000 the number of Belgian CCMT patents has doubled (between 2000 and 2016: 62 to 124) and Belgium could keep its position being just overtaken in this ranking by Spain. The 120 annual CCMT patents filed represent 8% of all Belgian patents filed at the EPO in 2015-2016.

Besides reflecting the innovative capacity of a country, legal aspects may also influence this ranking based on patent counts. German law on employee inventions promotes the propensity of German companies to patent because any invention made by an employee must be immediately reported to their employer who has a right of first refusal for four months. If the employer decides not to file a patent, the invention and all rights and obligations associated with it revert to the employee. The structure of the business fabric, more specifically companies' size distribution may interfere too, because larger companies tend to have a higher patent propensity.

Table 4

Top 20 countries ranked according to their number of patents filed at the EPO in CCMT fields [1]

(in absolute numbers [2] and divided by the population in millions of inhabitants, unless otherwise stated)

Country	Fractional count					Country	Fractional count per million of inhabitants				
	2000-2004	Rank 2000-2004	2015-2016	Rank 2015-2016	Rank change		2000-2004	Rank 2000-2004	2015-2016	Rank 2015-2016	Rank change
US	1 418	1	2 787	1	0	DK	11.5	4	39.4	1	3
JP	1 310	2	1 901	2	0	CH	18.1	1	37.3	2	–1
DE	1 131	3	1 850	3	0	SE	10.4	5	26.8	3	2
FR	333	4	852	4	0	FI	12.0	3	26.1	4	–1
KR	80	11	659	5	6	DE	13.7	2	22.6	5	–3
GB	184	5	449	6	–1	AT	8.7	8	19.2	6	2
CN	16	19	439	7	12	NL	10.0	7	17.1	7	0
CH	132	8	310	8	0	JP	10.3	6	15.0	8	–2
NL	161	6	291	9	–3	KR	1.7	17	12.9	9	8
SE	93	10	264	10	0	FR	5.4	10	12.8	10	0
IT	150	7	255	11	–4	**BE**	**5.5**	**9**	**10.6**	**11**	**–2**
DK	62	14	225	12	2	US	4.9	11	8.7	12	–1
AT	70	12	166	13	–1	GB	3.1	13	6.9	13	0
FI	63	13	143	14	–1	IL	2.7	15	6.0	14	1
CA	96	9	135	15	–6	IT	2.6	16	4.2	15	1
ES	32	17	122	16	1	TW	0.7	19	3.8	16	3
BE	**57**	**16**	**120**	**17**	**–1**	CA	3.1	14	3.8	17	–3
TW	16	20	89	18	2	ES	0.8	18	2.6	18	0
AU	61	15	61	19	–4	AU	3.1	12	2.5	19	–7
IL	18	18	51	20	–2	CN	0.01	20	0.3	20	0

Source: EPO (PATSTAT).

1 The country of residence is determined by the first applicant listed (first-named applicant principle).

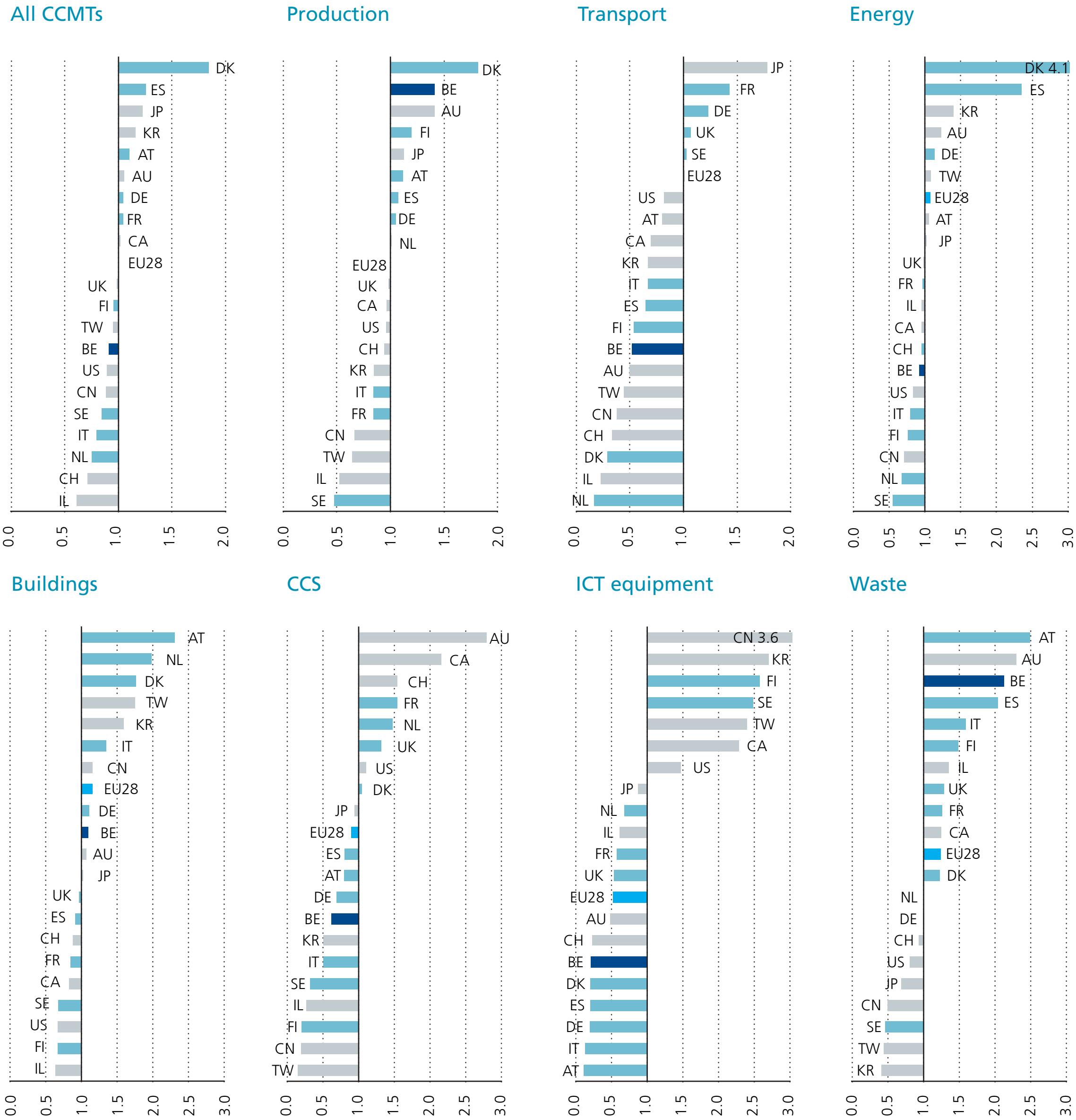
2 Aggregate data at total CCMTs level corrected for multiple counts as patents may be classified in more than one Y02i technology class.

The tax environment is also relevant to the location of companies' headquarters and research centres, as patenting tends to be carried out in countries that offer an advantageous tax system for patent activity. So, many innovative multinationals have set up their business operations in Switzerland because of the quality of its researchers and because of its competitive tax system too. With 48 CCMT patents per million inhabitants, Luxembourg is at the top within the EU28 ranking; its attractiveness is influenced by a policy of exempting patent and software income through an intellectual property box regime. By calibrating the number of patent

Chart 7

Revealed technological advantage in CCMT fields of the top 20 origins (including EU28) for patent applications filed at the EPO over the 2000-2016 period

(percentage green patents among the total patents of a country divided by the percentage green patents in total patents filed at the EPO from all countries)



Source: EPO (PATSTAT).

applications by size of the applicant country (its population), the ranking shifts in favour of these countries with special schemes and in favour of Denmark, Sweden and Finland, all three flagged up as innovation leaders within the latest European Innovation Scoreboard 2020. Austria, the Netherlands and France continue to outperform Belgium which has noticeably improved its ranking when calibrating with its population, just outside the top 10.

When considering the relative specialisation of these countries in chart 7, Denmark and Spain (albeit on a lower level) have the highest specialisation index in CCMTs. This position is strongly influenced by their specialisation in energy-related CCMTs, the technological field in which more than 50 % of their climate-related patents originate. The specialisation of non-EU28 players is the strongest in greening ICT equipment with a noticeable presence from the Asian and North American applicants. European countries with their own national car brands have a relative technological advantage in the transport field but the highest specialisation goes to Japan (as many as 40 % of Japanese green patents to the EPO are linked to transport). Belgium-based applicants have a technological advantage in CCMTs linked to (solid) waste management (only one major player with 20 % patents hold by Solvay), production processes (mainly for CCMTs relating to chemical industry – see section 3) and buildings (in technologies improving the efficiency of home appliances and heating, ventilation or air conditioning).

Moving to the individual company level, not surprisingly, the ranking is dominated by large industrial groups. Five of the top six applicants to the EPO (by number of CCMT patents) over the 2000-2016 period have filed applications linked to transport technologies. Given the contribution of transport to total GHG emissions and the emphasis that regulations put on controlling the environmental impact of transport in general, firms in the sector devote a significant part of their efforts to the development of transport-related CCMTs. The most green-patenting European companies are German firms.

CCMTs have cross-cutting applications in a wide range of industries. However, at EU level, it appears that the majority of patents are filed by companies in a limited number of branches of activity, and that these patents

Table 5

Top 6 worldwide and European applicants to the EPO – 2000-2016

(patent count in absolute numbers)

	Origin	Number of CCMT patents	Main CCMT fields [2]
Applicants from all countries [1]			
1. Siemens AG	DE	4 500	Energy – Transport – Production
2. Toyota Jidosha Co	JP	4 345	Transport [3]
3. General Electric Co	US	3 863	Energy – Transport
4. Mitsubishi Group	JP	2 851	Energy – Transport – Buildings
5. Robert Bosch GmbH	DE	2 132	Transport [3]
6. Samsung Electronics Co Ltd	KR	2 032	ICT equipment – Energy
EU28 applicants			
1. Siemens AG	DE	4 500	Energy – Transport – Production
2. Robert Bosch GmbH	DE	2 132	Transport [3]
3. Airbus – EADS	DE FR ES	1 463	Transport [3]
4. BASF AG	DE	1 132	Production – Energy
5. Vestas A/S	DK	946	Energy [3]
6. Telefon AB LM Ericsson	SE	904	ICT equipment [3]

Source: EPO (PATSTAT).
1 Entities with the same corporate name.
2 Share of patents in main CCMT fields in the company's green patent applications is larger than 20 %.
3 Share of patents in main CCMT fields in the company's green patent applications is larger than 70 %.

represent a significant part of the patent portfolio of an industry in a small number of NACE sectors. The EPO has identified 25 NACE sectors (out of 615 considered) which hold 57 % of the patents. These are mostly manufacturing industries except for crude oil extraction and power generation. This illustrates the innovation undertaken by European companies in these industries to reduce the negative impact of their economic activity on the climate (EPO and EUIPO, 2019).

3. Green innovation in Belgium

3.1 Technological fields concerned

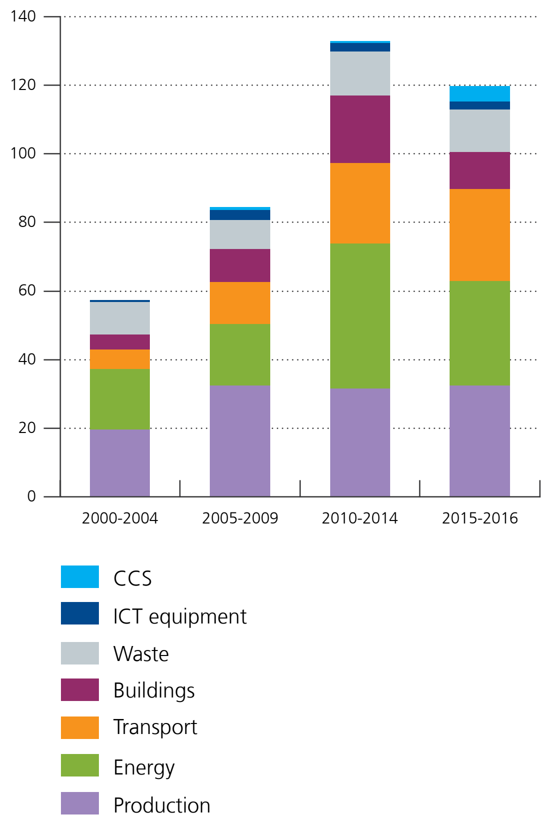
Yearly green patent filings from Belgian applicants accounted for some 120 patents in 2015-2016 and mirrored the global trend in filings rising until 2010-2012 then falling off. The largest share of patent applications is in production processes technologies and has remained stable since 2005-2009. It reflects, more generally, the specialisation of Belgian innovation in the field of specialised machinery (mechanical engineering) for the preparation of chemicals, minerals, glass and plastic products [1].

1 See Cheliout S. (2020), "Belgium's innovative capacity seen through the lens of patent data", NBB, Economic Review, December.

Chart 8

Number of patents in CCMT fields filed by Belgium-based applicants

(average yearly number of patents filed at the EPO [1])



Source : EPO (PATSTAT).

1 Aggregate data at total CCMTs level corrected for multiple counts as patents may be classified in more than one Y02i technology class.

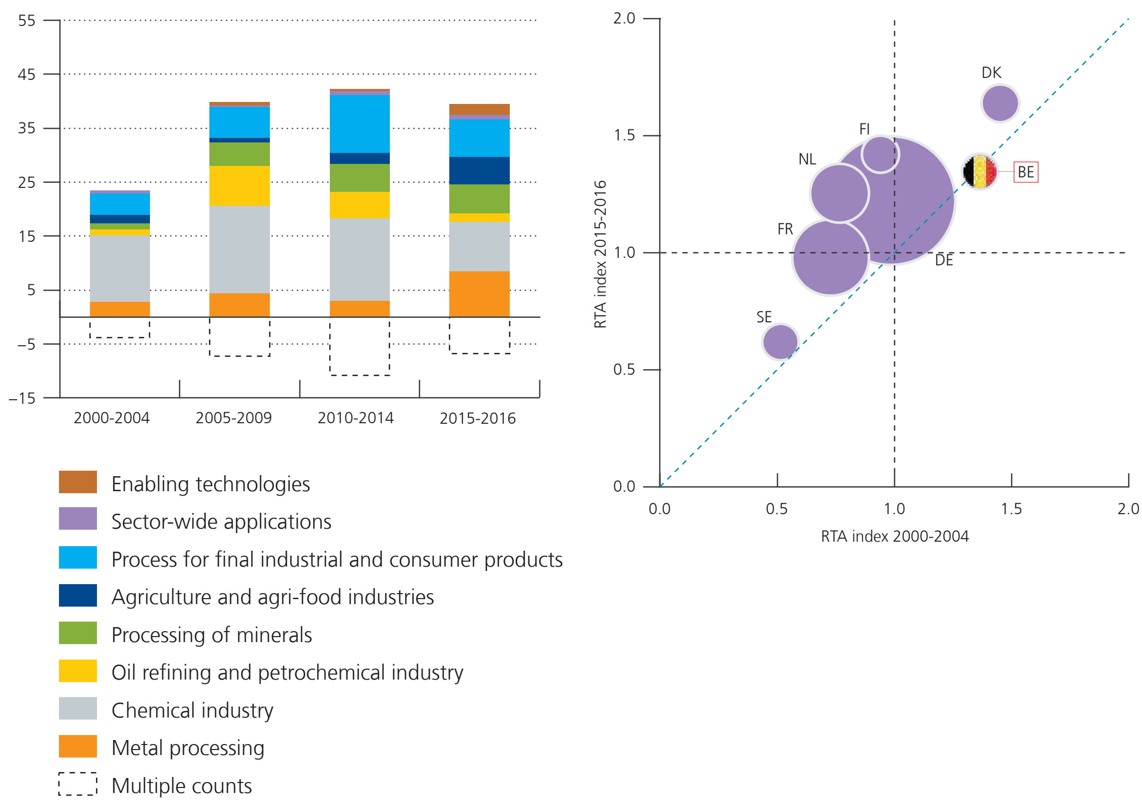
The number of applications for patents increased significantly from 2005-2009 onwards in the CCMTs relating to production processes. The patents regarding technologies of the chemicals and petrochemicals industries are predominant (some 50 % of production-related CCMT patents) and have marked this trend which may be linked to the presence in Belgium of several chemical hubs. These are mainly patent applications from companies active in the chemicals and petrochemicals sectors (Solvay and Total / Atofina research). The same applies to technologies related to the processing of mineral products with the active implication of AGC Glass Europe. Many applicants have filed rather individual patents regarding patents for processes related to agriculture and (agri-)food industries. The inter-university centre IMEC (microelectronics) is at the origin of many patents in technological fields related to the production processes of industrial or consumer products (e.g. improvement of machine tools in terms of energy efficiency, heat recovery or GHG emissions reduction) which accounts for almost 20 % of patents related to production processes.

In comparison to the three neighbouring countries and the most innovative Nordic countries in the EU28, Belgium' patenting activity is rather well specialised in greening production process equipment and it has stuck to this specialisation. Over the years, the technological advantage in chemicals and petrochemicals-related technologies has diminished (but still remains higher than one), while specialisation in green technologies related to the processing of mineral products and to the (agri-)food industries has strengthened. Belgium has almost lost its specialisation in technologies related to metal processing. Progress is also visible in comparison

Chart 9

Patents in CCMTs in the production or processing of goods

(average yearly number of patents filed at the EPO [1] and RTA index [2])



Source : EPO (PATSTAT).

1 Data regarding subdivisions (6-digit level) within one main Y02i technological class are not corrected for multiple counts (multiple counts given with a negative value for information).

2 Revealed technological advantage index : percentage green patents among the total patents of a country divided by the percentage green patents in all patents filed at the EPO. Size of the bubble proportional to the absolute number of patents on average 2015-2016 from the country in the technology field considered. RTA index above 1 signals a specialisation in the field, the higher the more specialised. Countries above (below) the 45-degree line have reinforced (reduced) their specialisation between 2000-2004 and 2015-2016.

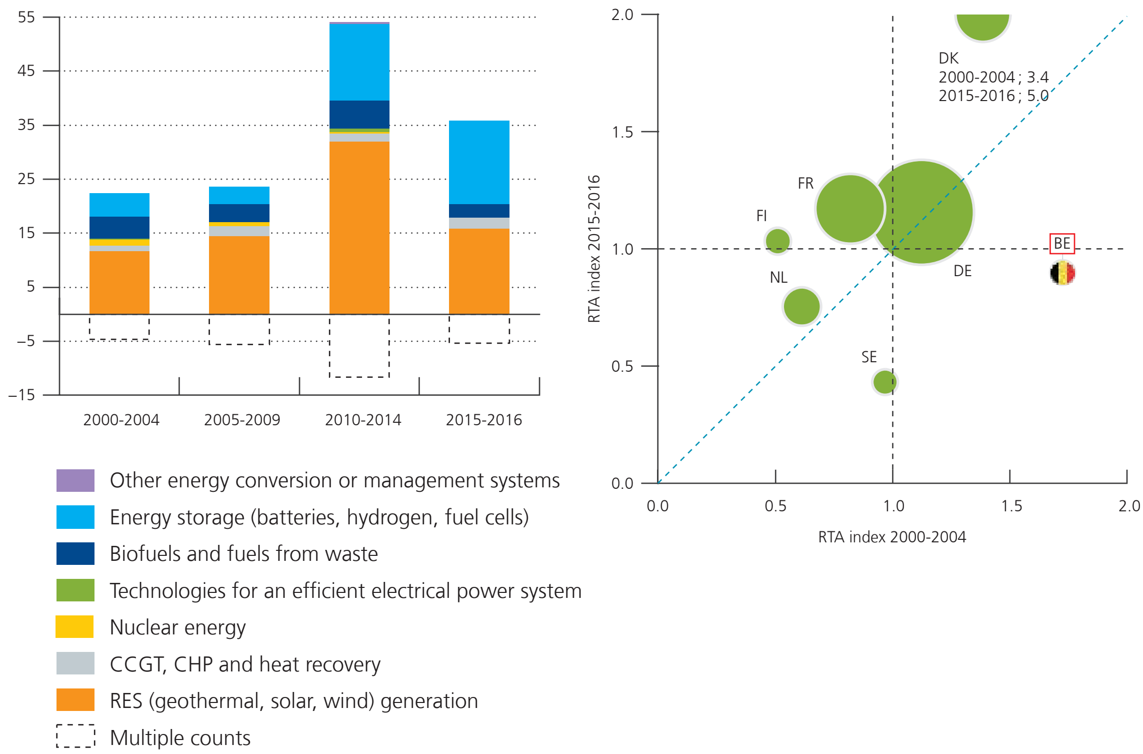
to countries where the RTA specialisation index has increased with most applications also being filed in the chemicals/petrochemicals industries technologies. Subsequently, the number of patents has risen the most in metal processing equipment (Germany, France, Finland) and in relation to production processes for final industrial or consumer products (Germany, France, Denmark).

The sustained development of patent applications in the energy-related technologies since 2005-2007 is no exception in Belgium, with filings increasing fourfold to a peak in 2011-2012, mainly for technologies related to energy production through RES which account for some 55 % of patents in the energy domain: patents in solar PV and solar thermal energy saw the strongest growth, followed by wind power. The upward trend slowed significantly after 2012. Patent applications for enabling technologies in the energy sector, which include electricity storage solutions, developed later and have not dropped off in the recent period as it has been the case for clean energy production. From 2010 on, patenting activity on battery and hydrogen technologies increased and, together with patent filings in fuel cells technologies, represented some 25 % of patent applications within the 2000-2016 period; it reached a level similar to patents filed in solar and wind technologies. Research into non-fossil fuels (biofuels and fuels from waste) has also led to regular patent applications since 2000 and it accounts for 12 % of patent applications in this field. All these developments are largely driven by the activity of a few players in the wind (ZF Wind Power Antwerpen) and solar sector (IMEC). For technologies related to biofuels and waste products, there are no key players, but rather a series of diverse smaller players.

Chart 10

Patents in CCMTs related to energy generation, transmission or distribution

(average yearly number of patents filed at the EPO [1] and RTA index [2])



Source: EPO (PATSTAT).

1 Data regarding subdivisions (6-digit level) within one main Y02i technological class are not corrected for multiple counts (multiple counts given with a negative value for information).

2 Revealed technological advantage index: percentage green patents among the total patents of a country divided by the percentage green patents in all patents filed at the EPO. Size of the bubble proportional to the absolute number of patents on average 2015-2016 from the country in the technology field considered. RTA index above 1 signals a specialisation in the field, the higher the more specialised. Countries above (below) the 45-degree line have reinforced (reduced) their specialisation between 2000-2004 and 2015-2016.

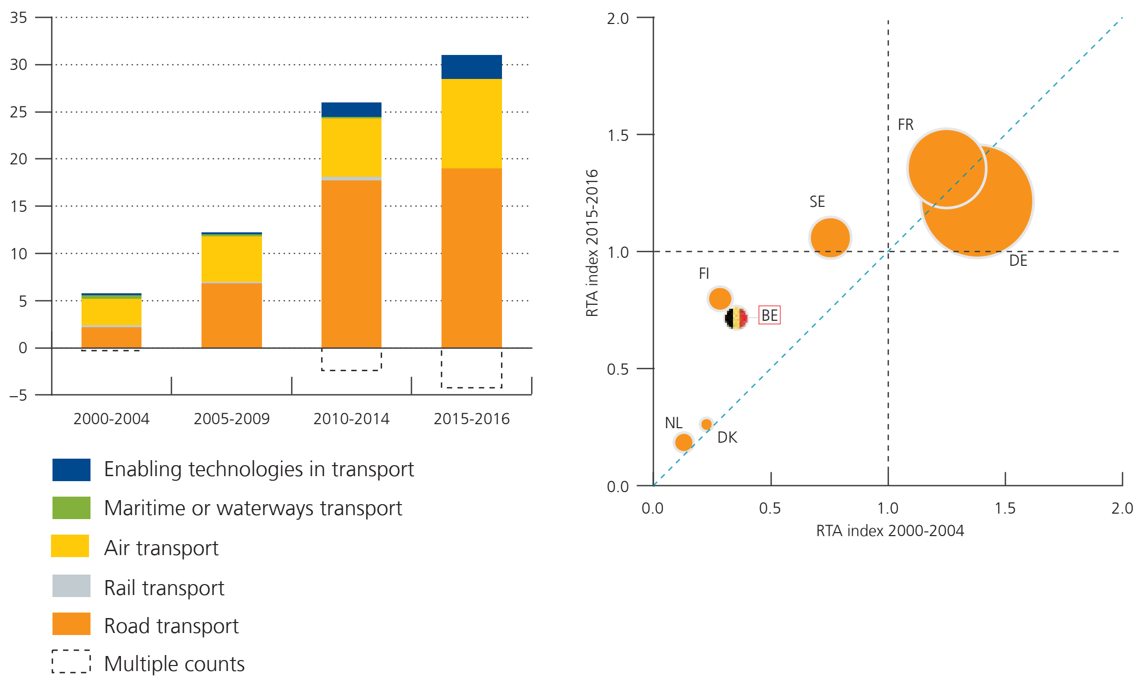
Belgium's patenting specialisation in the low-carbon energy technology fields has lost ground, while all other countries except Sweden have reinforced their specialisation with the strongest patenting activity seen in energy generation through RES. Proportionally, patenting activity in energy storage solutions is also visible in Germany, France and Finland. Like Sweden and the Netherlands, Finland holds a stronger position in patents for technologies for the production of fuel of non-fossil origin as it pursues a strong policy for developing bioenergy (mainly from forest industry by-products).

Patent filings in CCMTs relating to transport have seen continuous progress in road and air transport, with the strong involvement of one major applicant in each of the two fields: Plastic Omnium Advanced Innovation and Research (which is specialised in plastic components for the automotive industry and in fuel systems), while Safran Aero Boosters (former Techspace Aero) specialises in aeronautical and space equipment and in test cells. Some 30 % of Belgian transport-related CCMT patents filed at the EPO are for air transport applications; these include innovations on weight reduction, profiling, efficiency-enhancing electrical systems or propulsion technologies. Regarding road transport the main technologies by patent count are related to the improvement of the energy and emissions efficiency of conventional internal combustion engines which represent some 43 % of transport-related patents filed between 2000 and 2016. Patents on technologies related to hybrid and EVs have mainly been filed since 2009-2010 and are four times lower than for conventional vehicles. This observation that most of the efforts and investment made are still (and mainly) dedicated to the development of technologies improving the efficiency of internal combustion engines is shared at European level. Further innovative progress

Chart 11

Patents in CCMTs related to transport

(average yearly number of patents filed at the EPO [1] and RTA index [2])



Source: EPO (PATSTAT).

1 Data regarding subdivisions (6-digit level) within one main Y02i technological class are not corrected for multiple counts (multiple counts given with a negative value for information).

2 Revealed technological advantage index: percentage green patents among the total patents of a country divided by the percentage green patents in all patents filed at the EPO. Size of the bubble proportional to the absolute number of patents on average 2015-2016 from the country in the technology field considered. RTA index above 1 signals a specialisation in the field, the higher the more specialised. Countries above (below) the 45-degree line have reinforced (reduced) their specialisation between 2000-2004 and 2015-2016.

is needed to lower the environmental footprint of transport in the short- to medium term and develop novel technologies for electric energy production and storage in transport equipment (Hernández, 2020).

Patent filings in CCMTs in transport are a German and French specialisation through the research activity of their respective car and aircraft manufacturers – but not exclusively as Robert Bosch and Siemens also feature among the large patenters in Germany as does Valeo in France. In other countries, patent activity is more concentrated among equipment manufacturers for the automotive and aviation sectors. Since 2009-2010, a more significant activity has been emerging around enabling technologies in transport like equipment needed for EVs or transport applications of fuel cell and hydrogen technologies.

3.2 Who is involved in green patenting in Belgium?

From the ranking of Belgium-based applicants according to their annual number of green patents, it appears that the leading ten patent applicants over the period 2000-2016 together account for 47 % of CCMT patent applications. The rich information found in patent documents helps to get a more detailed picture of whether the patent's owners are companies, individuals or universities and research organisations. So, behind the Belgian leader Solvay, international companies with research centres in Belgium, public research organisations and universities complete the ranking. This rather concentrated nature of patenting in CCMTs is also identified at the global – Belgian – level and coincides with similar findings regarding the Belgian innovation fabric and R&D expenditure[1]. When considering patent activity in a narrow framework like here, one has to remember that there are other means for protecting inventions. Some companies prefer to keep industrial secrecy rather than file for patents, something which is clearly not captured in the patent statistics.

When considering the main CCMT fields to which their patents relate, it appears that companies intensify the green nature of their inventions in technologies linked to their main business or flagship products: seven out of ten companies in this ranking have filed patent applications in a technological field directly related to their core business (i.e. more than 75 % of their CCMT patents fall in the same technological field). Solvay, AGC Glass Europe and Umicore have a slightly more diversified patent portfolio although still linked to their main product line: chemical applications to energy storage (fuel cells) and PV cells, glass (materials) technologies for solar PV or battery technologies. The involvement of innovative companies active in different domains provides key channels for the diffusion and further valorisation of inventions across the board.

Research organisations and universities within the top ranking together hold 184 patents, slightly more than first-ranked applicant Solvay. Behind providing qualified human capital, universities and research organisations are at the root of basic research and scientific knowledge and patenting is a major tool for the valorisation of their discoveries: their developed patents can be licensed or used to help create or finance spin-off companies. Those applicants can therefore derive value from the patent even if they are unable to directly manufacture the products and results of their research. In addition, patenting by universities allows technology transfers from research to industries; it gives a framework to collaborative research with industries and ensures the required protection for investors to bring inventions to the markets.

All Belgian universities and research organisations filed some 13 % of CCMT patents registered within the 2000-2016 period. This share is slightly higher in comparison to the total patent portfolio where Belgian universities (patents owned or co-owned by university applicants) hold 11.2 % of patents filed at the EPO in the same period which is already a high share compared to other European countries[2].

1 See Vennix S. (2019).

2 It should be noted that statistics on the relative importance of universities in patenting activity in Belgium and in other European countries are influenced by the respective intellectual property regimes. Typically, inventions by researchers and academics may not all be patented under the university's name but rather fall under the category of individual inventor. But even when limiting to the 2006-2016 period, Belgian universities exhibit a higher share of ownership of patent applications at the EPO (see Cheliout S. (2020)).

Table 6

Top Belgian applicants of CCMT patents at the EPO over the period 2000-2016[1]

(CCMT patent portfolio in absolute number[2] and in % of total CCMT patents)

Company – institution[3]	Number of patents 2000-2016	In % of total CCMT patents	Main CCMT fields[4]
1. Solvay	176	10.9	Production – Energy
2. Total Petrochemicals Research – Atofina Research	114	7.1	Production[5]
3. Plastic Omnium Advanced Innovation & Research – Inergy Automotive Systems	113	7.0	Transport[5]
4. IMEC	73	4.5	Energy
5. Safran Aero Boosters SA – Techspace Aero	72	4.5	Transport[5]
6. Electrolux Home Products Corporation	56	3.5	Buildings[5]
7. AGC Glass Europe	44	2.7	Production – Energy
8. VITO	40	2.5	Energy
9. Umicore – Union minière	39	2.4	Production – Energy
10. ZF Wind Power Antwerpen	38	2.3	Energy[5]
First 10 applicants	769	47.4	
11. Agfa Gevaert NV	35	2.2	Energy[5]
12. Katholieke Universiteit Leuven	32	1.8	Energy – Production
13. Universiteit Gent	24	1.5	Production – Energy
14. Cockerill Maintenance & Ingénierie	16	1.0	Energy[5]
15. Université de Liège	15	0.9	Energy – Production
Belgian applicants at the EPO	1 613	100.0	Total CCMT

Source: EPO (PATSTAT).

1 Ranking of the main consolidated applicants at the EPO (first-named applicant principle). It is based on direct and Euro-PCT applications filed with the EPO during the reporting period.

2 Aggregate data at total CCMTs level corrected for multiple counts as patents may be classified in more than one Y02i technology class.

3 Entities with the same corporate name unless otherwise stated. Institution refer to universities and research organisations (with grey background). IMEC: *Interuniversity Microelectronics Centre*, VITO: *Vlaamse Instelling voor Technologisch Onderzoek*.

4 Share of patents in the main CCMT fields in a company's or institution's green patent applications is larger than 30%.

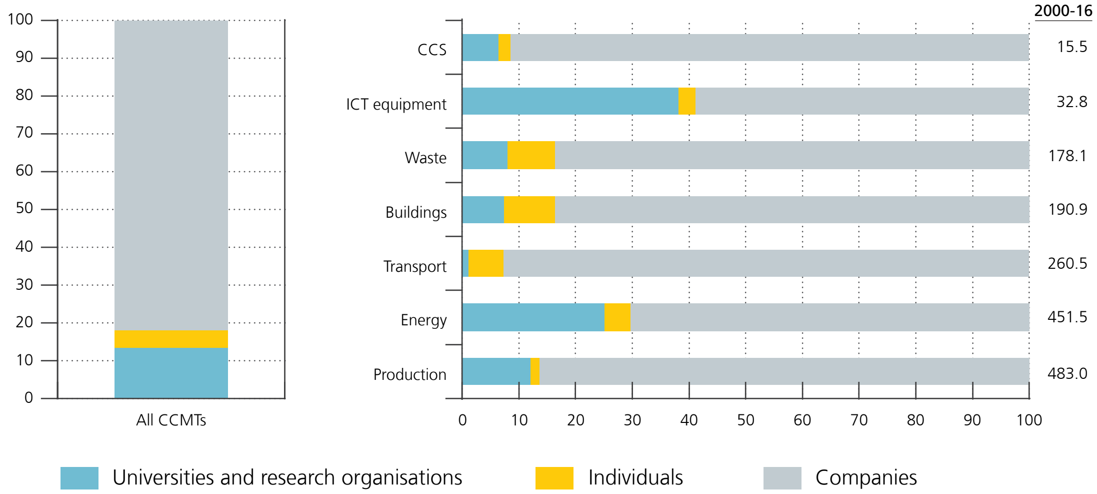
5 Share of patents in the main CCMT fields in a company's or institution's green patent applications is larger than 75%.

Within the various CCMT fields, universities and research organisations hold almost 40% of patents in CCMTs related to ICT equipment (but for a rather small number of patents, almost one-third of which have been filed by IMEC). The higher patenting activity in energy-related CCMTs by universities (25% of total applications in the field) is dedicated to solar PV (60% and this by two-thirds by IMEC) and to energy storage solutions (with strong involvement from VITO). Patented inventions in production processes are more distributed among (Flemish) universities and research organisations: first in the process for final industrial or consumer products (improving processes or mechanical equipment, where IMEC is particularly active) and second in CCMTs for the preparation of chemicals (Ghent university). VITO is the main applicant in CCMTs in buildings (efficient end-user-side electric power management and consumption, including domotics) and in waste management (in particular for wastewater treatment) but with less than six patents in each domain. The patents in transport developed by research institutions (already marginal in number) are filed for three inventions relating to EVs (which contrasts with the main patenting in the field relating to improvements to conventional internal combustion engines). Patent applications in transport are largely driven by (two) companies as is the case for CCS.

Chart 12

Structure of Belgian CCMT patent ownership

(patent applications[1] by type of filing entity in % and by number, 2000-2016)



Source: EPO (PATSTAT).

1 Aggregate data at total CCMTs level corrected for multiple counts as patents may be classified in more than one Y02i technology class.

4. Beyond environmental innovation

4.1 Technological innovation is key to achieving carbon neutrality but not enough in itself

A recent IEA survey (IEA, 2020) on the level of technical development of some 400 clean energy technologies reveals that 75 % of the cumulative CO_2 emission reductions needed to move to a sustainable path are based on technologies that are not sufficiently developed: about 35 % come from technologies that are currently at the prototype (18 %) or demonstration (18 %) stage and another 40 % of the reductions are based on technologies that are not yet widely commercialised. Efforts to accelerate innovation are therefore urgently needed even in mature technology fields where follow-up innovations are still highly relevant.

Beyond that, innovation must be disseminated through technology acquisition – an essential but time-consuming process. Economic history shows how slow the wide-scale diffusion of disruptive production processes like steam power or electrification has been. Broad adoption of new clean energy technologies may take decades to go from prototype to market introduction (even in the most active areas) and from market introduction to global diffusion: it took almost three decades to develop li-ion battery-powered EVs and solar PV, almost two decades for wind and nuclear power and even ten years to develop LED lights. Six more years were needed to reach a 1 % share of nuclear electricity supply or EVs in the light duty vehicle stock. For a 1 % share of wind electricity in total generation or of LEDs in the lighting equipment stock, it took an extra decade and a further 25 years for solar PV to achieve a 1 % share in electricity generation (IEA, 2020b). Just as climate change knows no borders, the dissemination and uptake of low-carbon solutions must also extend to all countries, which further amplifies the need to improve the diffusion of innovation on a worldwide scale. A global approach and joint commitment to international research and innovation can further accelerate the development of innovative technologies. As the global warming clock is ticking, strong action will be needed to achieve their diffusion at unprecedented speed.

This is already an issue for today's investors as the level of future emissions will be driven by the next investment cycles which tend to be in the 20-25-years range for some energy technologies. This means that some large infrastructure that is installed today often has a life span up to and beyond 2050. Decisions on investment today therefore affect the ability to meet climate targets not only in 2030 but also 2050 and beyond. It is important not to get locked in infrastructure whose use is carbon-intensive and at least to have the technical feasibility of adapting the equipment.

4.2 Innovation has to materialise

Environmental innovation must materialise in new low-carbon products and infrastructure, turning the results of the innovation effort into sustainable solutions made quickly available on a large scale to all stakeholders.

Public authorities have a role to play in this process. The entire production fabric benefits from spillover effects of different types of research networks (collaborative research, thematic knowledge clusters, public-private partnerships) linking together university expertise, basic research and applied research. Hence, there is a strong rationale for government policy support to R&D and innovation activity in order to address the market failure associated with knowledge innovation that may spill over to other firms without having to bear the full R&D costs. Dechezleprêtre *et al.* (2017) found evidence that the knowledge spillovers from patents for low-carbon technologies are among the highest: in the electricity and transport sectors, clean patented inventions are cited 43 % more than inventions in (dirty) conventional technologies and the magnitude of knowledge spillovers is comparable to IT. Such large spillovers can provide motivation for public funding of R&D as private stakeholders may be cautious about investing in these fields due to knowledge externalities that might be particularly high for some CCMTs. Focusing on low-carbon innovation would further enhance economic growth.

Public policy measures go beyond providing education and supporting knowledge and scientific research. Many and varied instruments are available to set up a favourable environment for innovation behind the (structural) funding of research centres (as is the case with IMEC and VITO) or implementing clusters and business networks around technological solutions for the energy and climate transition, fostering science and industry interactions. On the business side, new market designs and operational practices are needed to facilitate the deployment of all options like the marketing of decentralised electricity production or shared mobility. New forms of financing and investment are being developed, like crowdfunding, private-public partnerships and third-party investment formulas, all of which require at least an open mindset from the authorities and an effective regulatory framework. The implementation of a low-regulation framework (regulatory sandbox) which temporarily restricts regulations (like the Flemish green innovation space – *groene innovatie ruimte* – which is targeted at businesses and research institutions) facilitates further upscaling of small-scale demonstration projects in a real-life environment.

Besides technological innovation in itself, sufficient attention has to be paid to social innovations that will support changes in habits and (energy) consumption modes like shared mobility solutions or grouped housing. The dissemination of knowledge through education, advice and awareness campaigns will help to gain the support of citizens and communities to apply the research and innovation results so that new sustainable solutions are deployed and really matter to people.

Finally, the marketing of products developed on the basis of CCMTs is likewise a driver of sustainable economic growth. Some information on the economic importance of activities linked to environmental protection and less fossil energy use in Belgium can be found in the environmental economic accounts drawn up by the Federal Planning Bureau. These satellite accounts of the national accounts cover the activities of the environmental goods and services sector which consists of producers of goods and services relevant to environmental protection and natural resource management. It concerns such things as waste and wastewater management, the production of renewable energy, more efficient use of energy and heat savings (insulation work), and activities aimed at reducing the use of fossil energy sources as raw materials. Some 10 500 companies are identified as being suppliers of environmental goods and services in Belgium and 97 % of them employ less than 20 workers. Firms involved in waste and wastewater management and in the management of energy sources have generated around 0.8 % of the gross value added created by market activities. Their market output corresponds to roughly 1.3 % of Belgian production. Their exports also brought in almost € 2.7 billion on average between 2014 and 2018, representing 0.8 % of Belgian exports. This gives only a very partial idea of the importance of these activities: the (possibly innovative) products to which they relate are the result of global and not exclusively domestic research and not all CCMTs are included in this overview.

In order to capture the benefits of R&D, innovation needs to be diffused within the economic fabric across national borders. In a global market, the cost of technological deployment can come down quickly through economies of scale. To harness the potential of the global market, cross-border trade and investment in low-carbon goods, services and technologies need to be encouraged and scaled up. Stimulating low-carbon trade will create virtuous cycles, providing further investment opportunities and expanding the market for key technologies.

Conclusion

Building on patent data as a measure for green innovation, we provide an analysis on its origin and field of application over the period from 2000 to 2016. The CCMTs relate to seven domains into which they are categorised, such as energy, transport or building-related technologies. The worldwide inventive activity around these technologies has steadily increased since 2005 to a peak in 2012 and has since stabilised or even declined. Several technologies of growing importance for the environmental transition (like batteries) have maintained or even raised their patent numbers. Patents on CCMTs now account for 9 % of the world's inventions, up from 4 % in 1990-1994. This activity is mainly carried out by inventors from the United States, the EU28 and Japan up to 23 % each of the patents filed. There is also a noticeable emerging inventive activity from Chinese and Korean inventors, who now account for 22 % of all CCMT patents worldwide.

At the level of the European market, the majority of green patents filed with the EPO are held by European players. However, the commercial attractiveness of this market can also be gauged in the patent applications filed by non-European players wishing to protect their inventions. As far as EU patent applicants are concerned, 75 % of these come from five European countries, of which Germany largely dominates, followed by France. In fact, four of the six European companies with the most patents are of German origin. Over the period 2000-2016, Belgium has maintained its position in the ranking of countries by CCMT patent number.

A detailed analysis of the portfolio of CCMT patents filed by Belgium-based players by technological field – which represents some 1 600 patents for the 2000-2016 period – shows that where patent applications are generally more important in the green technologies linked to energy and transport, the positioning of Belgium differs: patenting activity in Belgium primarily concerns technologies linked to production processes, which coincides with an observation already made elsewhere that Belgian innovation activity as a whole is geared towards specialised machinery. The relative specialisation reflected in the relative technological advantage index (the percentage of green patents in the total Belgian patent portfolio compared with this same proportion in all patents submitted to the EPO) in this field persists. In the energy-related technological fields, patent applications pertain mostly to technologies related to RES and, more recently, to energy storage solutions. Despite these new developments, Belgium's patenting specialisation in the energy technology fields has lost ground. In the transport-related fields, most patent applications concern road and air transport equipment, almost exclusively by a single company in each sector. Low-carbon patent applications of Belgian origin are most visible in technologies related to the chemicals industry, solar power, solid waste management, energy storage and conventional internal combustion vehicle.

When considering the individual Belgian patent owners, research efforts are found to be in the hands of a small number of players (as is the case at global level): the top ten Belgian patent holders have 47 % of CCMT patents in their portfolio. Innovative Belgian and international companies with research centres in Belgium dominate this ranking. The noticeable presence of universities and research centres already observed at the level of the Belgian innovation ecosystem as a whole is even more visible at the level of CCMTs: 13 % of CCMT patents applied for the 2000-2016 period were at their initiative, compared with 11.2 % for all Belgian patent applications filed by these research establishments.

Further technological advances are still needed to achieve carbon neutrality. Moreover, successful innovation outcomes have to materialise, turning the results of the innovation effort into sustainable solutions made quickly available on a large scale across national borders too. The opportunity is given to couple environmental transition with economic stimulus by expanding markets for low-energy products and components and implementing green production processes. This time-consuming process makes it all the more necessary to push technological uptake at the fastest possible rate.

Appendix

Some concepts around patenting used in this article

Patenting can take different routes:

- an inventor first has to file an application with a **national** patent office which is generally the national office of the applicant's (the future owner) country. After examination, the patent may be granted and enforced only in this country in accordance with its national law and national patent office rules. The application can be filed with several national offices;
- the patent application may be filed at a **regional** office (like the European Patent Office) which than provides protection in the member states of the regional office (as a bundle of patents at national level or a regional patent that provides protection in the entire region);
- the applicant may file a single **international** application with national or some regional patent offices of the Patent Cooperation Treaty (PCT) contracting states or directly at the international office of the World Intellectual Property Organisation. It will have the same effect as direct application at national or regional offices of PCT contracting member states. The bulk of the patent application procedure is carried out at international level, but the patent itself is granted by each designated state within the subsequent national phase.

In this article, we consider single patent applications directly filed at the EPO (as a bundle of national patents to be validated by the respective national offices) and Euro-PCT applications, i.e. international applications for which the EPO is a designated office: the patent has been accorded international filing date with the effect of a regular European application and validation by the national patent offices.

Reference dates for a typical patent:

- priority filing date: when the applicant first files the application – generally in the country of residence. It is the closest date to the research activity and invention;
- application date: within a 12 months legal delay the applicant may eventually apply for protection in other countries;
- publication date: the application is published at least 18 months after the 'priority date'.

Reference country:

- inventor's country to evaluate a country's inventive performance;
- applicant's country to evaluate a country's innovative performance.

Measure based on patent counts: simple versus fractional count of patents. A unique patent may have many different applicants/inventors located in different countries and may be relevant for different technological fields. If there is more than one applicant/inventor, the number of patents is divided equally amongst all of them and their corresponding country of residence (fractional count) to avoid multiple counts in establishing the geographic origin. The same rule applies if a patent is relevant for different technological fields.

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