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The geography of EU green and digital inventions and their knowledge sources

Bello, M.
Castellani, D.
Damioli, G.
Marin, G.
Montresor, S.

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Joint Research Centre

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Contact information
Name: Michela Bello
Address: Via E. Fermi 2749, TP 361, Ispra (VA), I-21027, Italy
Email: Michela.BELLO@ec.europa.eu
Tel.: 0039 033278 3976

EU Science Hub
https://joint-research-centre.ec.europa.eu

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Contents

Abstract

Using a dataset of patent information for the period 2000-2017, this study provides evidence on the development of green and digital technologies in the EU, at both national and regional levels. In particular, it explores how the distributions of digital and green patent applications vary over time, as well as across countries and regions. It also provides evidence on the location of the knowledge sources relevant for the development of these technologies, which is captured using the backward citations of EU green and digital patents.

Findings of this document indicate that, while green technologies appear on average more diffused than digital ones, these technologies share similar geographical patterns. Their development concentrates in France and, even more markedly, in Germany, although there are signs of recent catching up of other EU countries, especially in digital technologies. At the subnational level, digital and green inventions in the EU appear to be driven by a few regions. Quite interestingly, the citation analysis shows that the knowledge base for the development of both green and digital technologies is mainly located outside of the EU, and especially in the United States and Japan, revealing the EU weakness in these domains.

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This report benefitted from suggestions and feedback from Athina Karvounaraki, Alessio Mitra and Tiago Pereira (DG Research and Innovation). The authors are also grateful from the comments received from participants at the 48th AIB UK & Ireland Chapter Conference (April 2022) and at the INNOVA MEASURE V intermediate and final workshops (October 2022 and April 2023). The report is a deliverable of the INNOVA MEASURE V project (Horizon Europe 101052304).

Authors

Michela Bello, European Commission, Joint Research Centre, Italy

Davide Castellani, Henley Business School, University of Reading, UK

Giacomo Damioli, Faculty of Business Studies and Economics, University of Bremen, Germany and CAPP – Centre for the Analysis of Public Policies, University of Modena and Reggio Emilia, Italy

Giovanni Marin, University of Urbino Carlo Bo, Italy and SEEDS (Sustainability Environmental Economics and Dynamics Studies), Italy

Sandro Montresor, Gran Sasso Science Institute (GSSI), Italy

1 Introduction

Over the past years, several countries have been developing a twin green and digital transition agenda to make their economies evolve along smart, sustainable and inclusive patterns of growth. On the one hand, greenhouse gas emissions and the entailed raise of global temperatures make the green transition necessary to "act forward". On the other hand, the digital transition towards more powerful and empowering digital technologies creates new opportunities - from improving green efficiency to facilitating the development of new green technologies for that to happen. The interlinking of the green and the digital transitions has been accordingly receiving increasing attention (European Commission, 2021b; Muench et al., 2022; OECD 2023).

In Europe, this policy target was already at the core of the 2020 Industrial Strategy for a green and digital Europe, aimed at strengthening the competitiveness of European companies in global markets and to improve their innovative performance, especially in the green and digital technological fields (European Commission, 2020). Such a strategy, which is strongly integrated with other major European initiatives, like the European Green Deal and the European Digital Strategy, has been recently updated in the National Recovery and Resilience Plans of the NextGenerationEU. Indeed, several of its missions refer to the combined unfolding of the green and the digital transitions (Pilati, 2021). Also outside Europe, an increasing number of countries are approaching an integrated green and digital transformation. In the US, for example, a US$2.3 trillion plan has been approved also to accelerate the green transition through infrastructural, innovation and skill investments, which are digital too. Similar initiatives have been taken in Asia. The recovery plan of South Korea, for example, included US$63 billion in green funding for smart grids and infrastructure for electric vehicles, and supporting new green digital solutions is also a key part of Singapore's Green Plan 2030.

While the term "transition" is broad, encompassing different spheres including the economic, social, cultural, and political ones, here we focus on its technological dimension. Using the European Patent Office (EPO)'s PATSTAT dataset for the period 2000-2017, this study provides evidence on the development of green and digital technologies in the EU, at both national and regional levels. In particular, we show how the distributions of the two technologies vary over time, as well as across countries and regions. Furthermore, we provide evidence on the location of the knowledge sources relevant for the development of these technologies, which we capture using the patent citations of EU green and digital patent applications.

The results of the analysis indicate that, while green technologies appear on average more diffused than digital ones, a flattening pattern of patenting activity occurred in green technologies over the last decade in contrast with an exponential growth of digital patents in the same period. Moreover, both technologies share similar geographical patterns. The development of EU green and digital technologies concentrates in France and, even more markedly, in Germany, although there are signs of recent catching up of other EU countries, especially in digital technologies. At the subnational level, digital and green inventions in the EU appear to be driven by a few regions. More specifically, München (Germany), Paris (France) and Eindhoven (The Netherlands) are leading the way for digital inventions in the EU, while Paris (France), Stuttgart (Germany), and München (Germany) do so for green inventions. Quite interestingly, the citation analysis shows that the knowledge base for the development of both green and digital technologies is mainly located outside of the EU. In particular, the United States and Japan, account alone for about 45% of citations of both EU digital patent applications and of EU green ones. Within the EU, Germany is the most important source of knowledge for green and digital technologies. In the EU, the vast majority of digital patents in the years 2009-2017 refer to inventions in the fields of additive manufacturing and robotics, while EU green inventions are mainly in the areas of energy-related climate change mitigation and environmental management.

The remainder of the paper is structured as follows. The data and the definition of our key indicators are described in Section 2. The development of digital and green technologies in EU countries and regions is discussed in Section 3. Section 4 illustrates the location of the knowledge sources used for these inventions. Section 5 concludes.

2 Data and methods

Following the empirical academic literature on innovation, the analysis we have carried out is based on patent data. These are sourced from PATSTAT (Autumn 2021), a database held by the European Patent Office (EPO) containing information on patent applications worldwide. From this database, we extract details on patent applications to the EPO and their citations. The EPO is a regional office which provides protection in 41 European countries, including all current 27 member states within the European Union, and three non-European countries. We focus on the EPO route, rather than using data on patent applications filed at national offices or via the Patent Co-operation Treaty (the PCT) procedure with the World Intellectual Property Organization (WIPO) for the following reasons. Firstly, we refrain from using information from national patent offices because legal and administrative procedures tend to differ across the latter and statistics are not always comparable across countries (OECD, 2009). Furthermore, it has been claimed that there is a home bias in the behaviour of applicants, i.e. domestic applicants tend to file more patents in their home country than non-resident applicants (OECD, 2009). Thirdly, because patents applications filed to the EPO are more prone to a broader geographical coverage, they may be assigned a greater economic value by the applicant than may be patent applications to national offices. Finally, the geographical focus of the study has led us prefer the EPO regional route to the international one (e.g., PCT). European countries are indeed more likely to file their application with the EPO than via the international procedures, such as the PCT (OECD, 2019).

We measure green technologies by identifying green patent applications to the EPO through the "OECD Envtech" classification of environment-related technologies, in turn based on the Cooperative Patent Classification (CPC) and the International Patent Classification (IPC). As an established classification of digital technological fields does not yet exist, digital patents are selected through a search query on patents' titles and abstracts based on a list of keywords. This list coincides with that developed by Bianchini et al. (2022b), which builds on the taxonomy and dimensions of the digital technology ecosystem identified by the OECD (2019a), as well as on recent contributions on the patent mapping of AI (Baruffaldi et al., 2020) and Industry 4.0 technologies (Martinelli et al., 2021). Accordingly, the keywords were selected to map the following categories of technologies: artificial intelligence, blockchain, big data, Internet of Things, computing infrastructures, robotics, and additive manufacturing (see Annex 1 for a more comprehensive description of these categories and the overall methodology).

Patent data are used to map both the development of digital and green technologies in the EU as well as their knowledge sources. More precisely, we use the backward patent citations of a green or digital patent as a measure of the knowledge base on which the respective green or digital invention draws. In order to do that, we allocate both citing and cited patents to the NUTS3 region and country of residence of the inventor. NUTS3 regions are converted into metropolitan regions using the Eurostat definition[1]. The address of the inventors is used in place of that of the assignees because the former is considered to be a better proxy of the location where the focal technology was developed. Patents developed in a specific location could in fact be assigned, for internal strategies, to the headquarter of the company or to the ultimate owner, which might not coincide with the place of the invention. Figures on green and digital patents and their citations are based on fractional counts. Annex 2 provides some basic descriptive statistics on the final dataset[2].

[1] https://ec.europa.eu/eurostat/web/metropolitan-regions/background

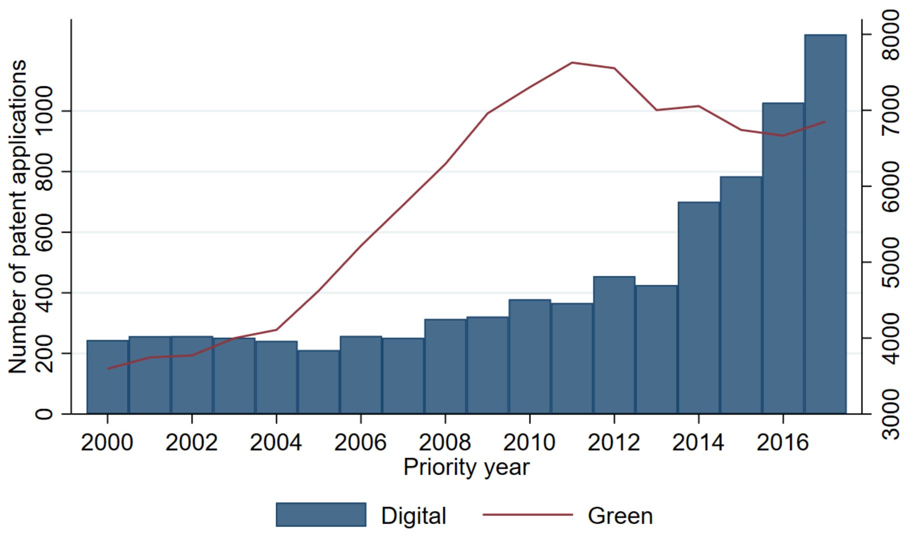
[2] Our final database combines records on green and digital patent applications to the EPO with their backward patent citations. Citations of non-patent literature are not considered because details on the location of the authors of these outputs are not available in the EPO dataset.

3 The geography of digital and green inventions in the EU

While the urgency of the digital transformation and of the green transition recurs frequently in EU policy documents, the pace at which their underlying technologies are developed is different. As Figure 1 shows, the number of EU applications in digital technologies has increased over the whole 2000-2017 period, though with an irregular but exponential trend. This pattern of marked increases in the development of digital technologies in the last decade is consistent with what has been detected worldwide in other studies (Van Roy et al. 2020; WIPO, 2019). This is compatible with the idea that the ecosystem of advanced digital technologies became mature enough in mid-2010s to allow its unprecedented widespread application to a growing number of industries and business functions (Clark 2015, McKinsey 2018). This is a consequence, among other things, of the diffusion of complementary innovations under development since the early 2000s including advancements in algorithms (e.g. machine learning, neural networks) and digital infrastructures (e.g. computing power, cloud computing) coupled with access to big data.

The development of green technologies in the EU over the same period has increased more sharply until the European debt crisis (2011), following which it has experienced a decline, up to 2016, followed by a scattered increase. A similar pattern has been documented by other recent work (Dechezleprêtre and Kruse, 2022; OECD, 2020). As evoked by these studies, over this period, private incentives to develop new clean technologies might have decreased. (Kruse et al., 2022).

Figure 1. Development of green and digital technologies in the EU, 2000-2017.



Source: Authors' calculation based on PatStat. Note: Green patents on the right axis.

The general European trend in the development of digital and green technologies is the result of an interesting heterogeneity of patent application patterns across the EU countries (Table 1). Germany accounts for half of green and digital patents in period 2000-2008, but its share declines significantly in the more recent period (2009-2017). This is particularly marked in digital technologies where the share of German patents drops from 50.1% to 36.3%. This trend reveals a process of catching-up in other EU countries[3]. Particularly strong increases in the share of digital patent applications are observed in France, which moved from a digital patent share of 12% to 16.5%. In 2009-2017, Germany contributes relatively more (by 7.4 percentage points) to green than digital patenting. Conversely, Sweden's shares are larger in digital than green patent applications (by 4.2 percentage points in 2009-2017), making the Nordic country the third most important EU innovator in digital technologies.

[3] The number of digital and green patent applications has increased in Germany in the period considered. The pace, however, is slower as compared to that reported in other countries, such as Sweden.

Country specialisation in digital and green technologies, measured by the index of revealed technological advantage (RTA)[4], also varies considerably among EU countries (Table 2), with small countries generally reporting a higher degree of specialisation given their lower patenting activity. Among the countries that account for most of EU digital and green patents (see Table 1), in 2009-2017 Sweden reported the highest level of specialisation in digital patenting (1.82), followed by Spain, Finland and the Netherlands. As compared to the previous period (2000-2008), the degree of digital specialisation increased in most countries, with Finland turning from not specialised to being highly specialised. Unlike in the digital case, international differences in the degree of green-tech specialisation are narrower. In the group of countries considered, the RTAs range much close to 1, with Denmark standing out as highly specialised in green patents throughout the 2000-2017 period. This is consistent with recent evidence showing Denmark's technological leadership in the clean energy sector (European Commission, 2022a).

Table 1. Green and digital EPO patent applications by EU country, 2000-2017

Country	Digital		Green		All	
	2000-2008	2009-2017	2000-2008	2009-2017	2000-2008	2009-2017
	Number of applications					
EU	2,286	5,713	41,107	63,766	498,645	423,755
	% over total EU					
DE	50.1	36.3	49.7	43.7	46.6	42.6
FR	12.0	16.5	15.9	17.5	16.4	17.1
IT	7.4	7.0	8.0	7.1	9.1	8.6
NL	10.5	9.2	5.3	5.4	7.2	6.7
SE	8.1	9.8	4.2	5.6	4.9	5.8
AT	3.1	2.5	3.1	3.5	3.0	3.7
BE	1.6	2.9	3.2	2.8	2.9	3.0
ES	2.4	5.0	2.5	3.4	2.4	3.0
DK	1.7	2.0	3.3	4.8	2.3	2.7
FI	2.1	3.5	2.4	3.0	2.7	2.7
Other EU	1.0	5.3	2.3	3.2	2.4	4.0

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding. The table reports countries with the highest number of patent applications (more than 2% of the total).

[4] The RTA of country (or region) c in technology t is equal to (Patents $_{c,t}$ / Patents $_{c}$) / (Patents $_{EU,t}$ / Patents $_{EU}$). A country is specialised when the index is above 1 and it is not specialised when the index is below 1.

Table 2. Degree of specialisation in green and digital technologies. Selected EU countries, 2000-2017

	Digital		Green	
	2000-2009	2010-2017	2000-2009	2010-2017
AT	0.95	0.59	1.05	0.96
BE	0.44	1.00	1.07	0.92
DE	1.18	0.87	1.06	1.01
DK	0.45	0.74	1.49	1.83
ES	1.01	1.77	1.09	1.13
FI	0.34	1.22	0.89	1.11
FR	0.80	1.03	0.97	1.03
IT	0.86	0.87	0.87	0.83
NL	1.23	1.20	0.76	0.79
SE	1.34	1.82	0.87	0.98

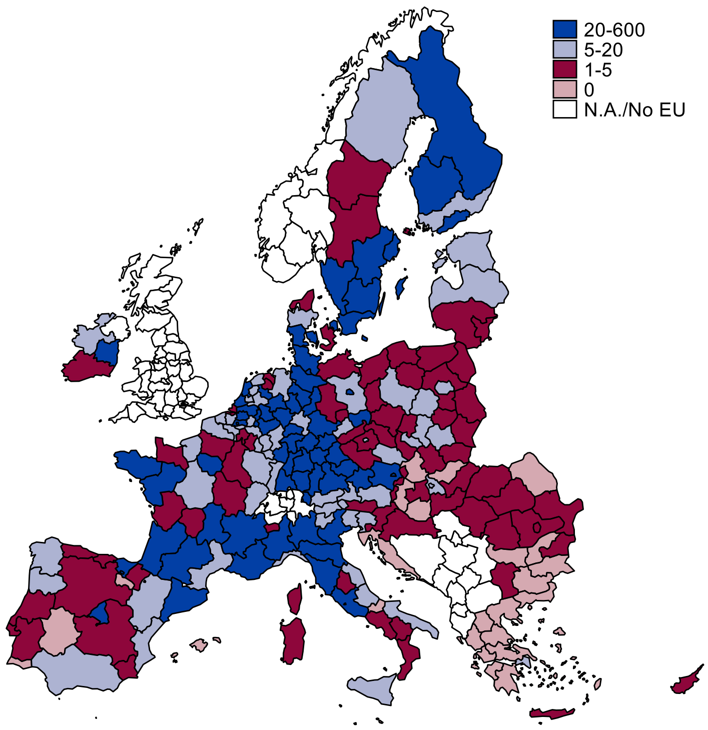
Source: Authors' calculation based on PatStat. Note: The table reports the countries with the highest number of digital and green patent applications. A country's specialisation degree in digital (green) technologies is measured as the ratio of the country's share of digital (green) patents to the total share of digital (green) patents in the EU (RTA index). A country is specialised when the index is above 1 and it is not specialised when the index is below 1.

The development of digital and green inventions in the EU is not only concentrated in a few countries, but it is also driven by a relatively small number of regions. As depicted in Figure 2, both digital and green patents are concentrated in the core regions of Continental Europe and in Sweden as confirmed in previous studies (European Commission, 2018), with the development of green inventions being slightly more dispersed than in the digital case. Around 50 percent of digital patents in the EU comes from only twenty regions belonging to seven countries (Table 3). Paris (France), München (Germany), and Eindhoven (The Netherlands) are leading the way for digital inventions in the more recent period (2009-2017). Paris (France) took over the leading position held by Stuttgart (Germany) in the previous years (2000-2008).

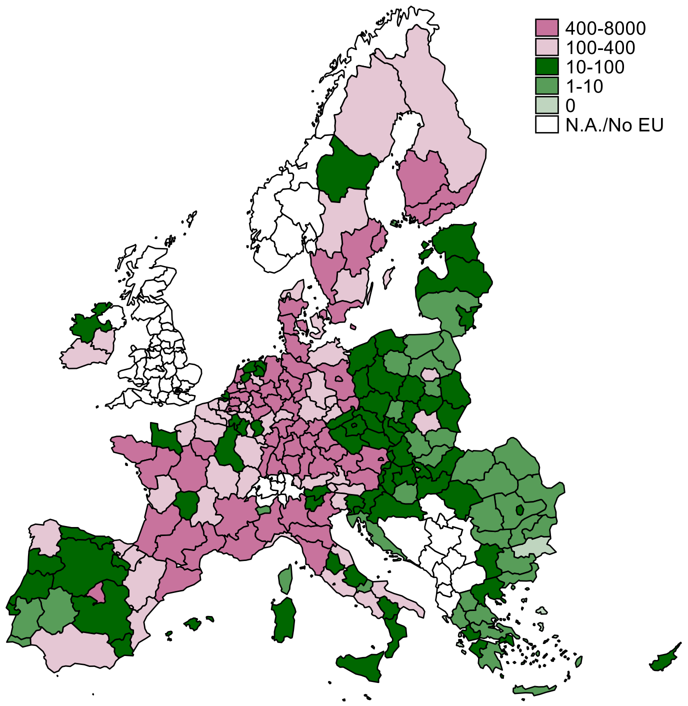
As compared to country-level figures for digital technologies, differences in the technological specialisation across regions appear even larger. The degree of specialisation in digital technologies ranged from 49.3 in Berlin (Germany) to 0.4 in Grenoble (France) in the years 2009-2017. Interestingly, while Eindhoven (The Netherlands) is among the top regions in terms of green patents, its level of specialisation in this domain is among the lowest, revealing a more heterogeneous patenting activity in this region. By contrast, Berlin (Germany), Augsburg (Germany), München (Germany), Jönköpings län (Sweden) and Paris (France) are the most specialised regions in this technological field.

As in the digital case, the development of green technologies is concentrated in a few regions within the EU. Paris (France), Stuttgart (Germany), and München (Germany), alone, concentrated 20% of total EU green patents in 2000-2008 and nearly 16% in 2009-2017 (Table 4). While this decrease is due to a drop in the share of Stuttgart from 9.1% to 5.1%, most regions did not record a large variation in their shares of green patents, suggesting that leading hubs in green innovation are well established in the EU. By contrast, the degree of specialisation in green technologies has increased in mostregions. The regions that are more specialised in this domain are German and include Berlin, Ruhrgebiet and Mannheim-Ludwigshafen. This confirms that, compared to other EU countries, Germany is a leader in the field of green innovation also at the regional level.

Figure 2. Regional distribution of EPO digital and green patent applications, 2000-2017



Digital patents



Green patents

Source: Authors' calculation based on PatStat.

Table 3: EPO digital patent applications and degree of specialisation, selected EU regions, 2000-2017

		Patent applications (as % of total EU)		Degree of specialisation	
Country	Region name	2000-2008	2009-2017	2000-2008	2009-2017
FR	Paris	5.0	8.6	1.6	10.7
DE	München	5.4	6.7	6.7	17.5
NL	Eindhoven	4.7	6.2	0.5	1.8
DE	Augsburg	4.5	4.1	53.3	31.0
SE	Stockholm	1.7	3.2	0.5	1.3
ES	Barcelona	0.7	2.3	1.3	2.6
DE	Stuttgart	6.8	2.3	8.1	3.1
DE	Berlin	1.7	2.1	38.8	49.3
FI	Helsinki	0.8	1.9	0.0	1.4
SE	Göteborg	0.5	1.8	0.1	2.0
DE	Nürnberg	2.8	1.7	14.6	6.3
FR	Rennes	0.3	1.6	0.4	0.3
SE	Västmanlands län	4.1	1.5	31.1	7.6
SE	Malmö	1.1	1.5	1.2	1.4
SE	Jönköpings län	0.1	1.4	0.0	11.1
IT	Torino	2.3	1.3	4.0	1.5
FR	Grenoble	0.9	1.2	0.4	0.4
DE	Frankfurt am Main	2.1	1.2	3.8	4.3
FI	Tampere	0.6	1.2	0.8	1.0
DE	Heidelberg	1.2	1.1	1.8	1.0
Other	Other	52.8	47.1		

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding. The table reports the top 20 regions in terms of number of digital patent applications. A region's specialisation degree in digital technologies is measured as the ratio of the region's share of digital patents to the total share of digital patents in the EU (RTA index).

Table 4: EPO green patent applications and degree of specialisation, selected EU regions, 2000-2017

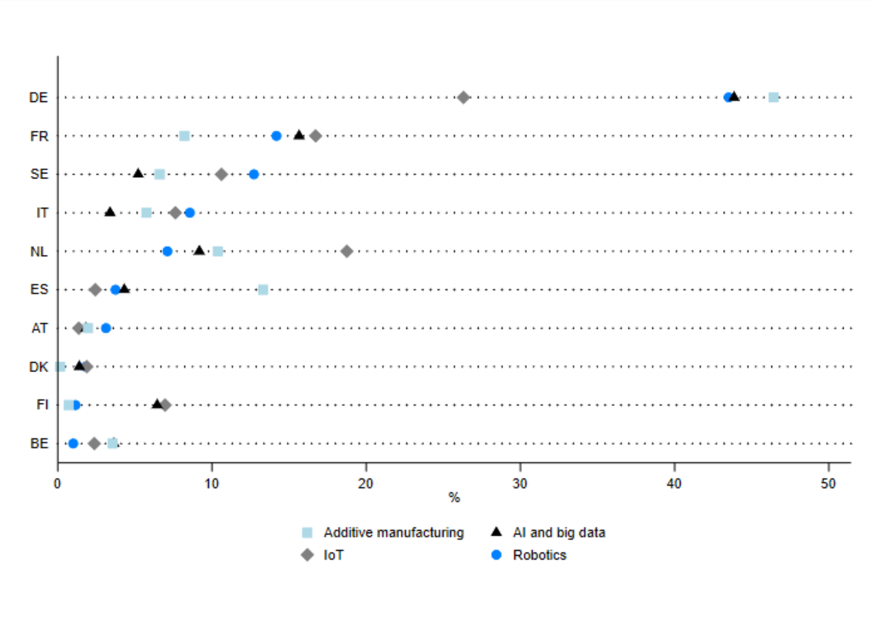
		Patent applications (As % of total EU)		Degree of specialisation	
Country	Region name	2000-2008	2009-2017	2000-2008	2009-2017
FR	Paris	7.3	6.6	5.5	7.2
DE	Stuttgart	9.1	5.1	8.4	6.8
DE	München	3.5	3.7	4.0	5.8
FR	Grenoble	1.0	2.0	0.6	1.0
DE	Nürnberg	1.9	2.0	7.5	6.8
DE	Ruhrgebiet	2.1	2.0	12.4	25.4
SE	Stockholm	1.0	1.8	0.5	0.6
DE	Berlin	1.7	1.7	31.9	27.6
NL	Eindhoven	1.5	1.6	0.3	0.4
DE	Hamburg	1.5	1.6	5.7	3.5
DE	Frankfurt am Main	1.8	1.5	5.1	7.1
FI	Helsinki	1.0	1.5	0.5	0.8
DE	Mannheim-Ludwigshafen	1.6	1.4	4.6	11.0
DK	Århus	0.6	1.4	1.4	2.1
DK	København	1.4	1.2	3.1	2.5
FR	Lyon	1.0	1.1	0.9	0.9
BE	Bruxelles / Brussel	1.4	1.1	5.0	2.9
SE	Göteborg	1.2	1.1	0.8	0.8
DE	Köln	1.2	0.9	3.1	3.4
IT	Milano	1.0	0.8	1.1	1.5
Other	Other	57.1	59.9	na	na

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding. The table reports the top 20 regions in terms of t number of green patent applications. A region's specialisation degree in green inventions is measured as the ratio of the region's share of green patents to the total share of green patents in the EU (RTA index).

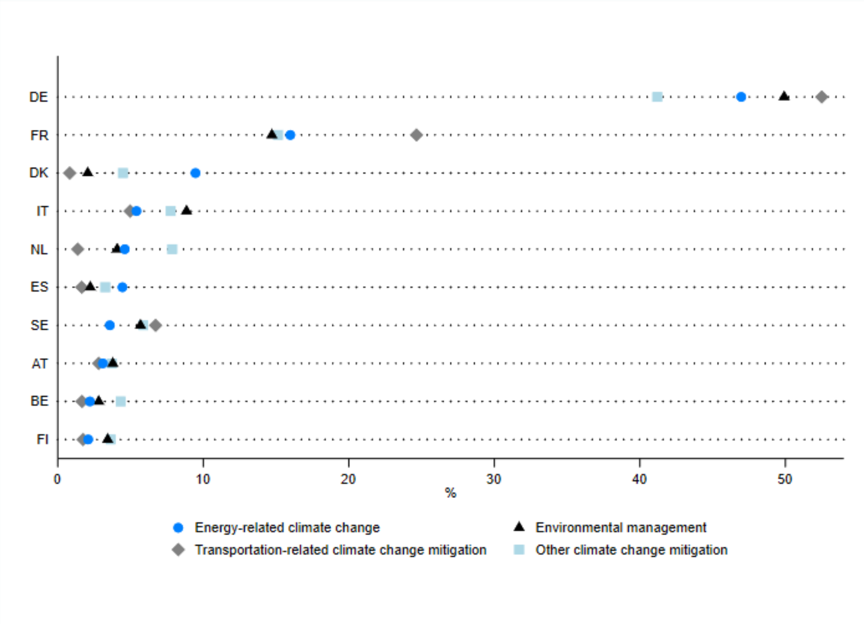
Both digital and green technologies are exposed to different domains of application, with respect to which the analysis of EU patents reveals some interesting patterns. Germany's leading role in the development of green and digital inventions also emerges when countries' shares are studied by technological area (Figure 3 and Table B.3 in Annex 2). Germany is the leading country in all green and digital areas. France follows Germany in robotics, and AI and big data, whereas the Netherlands does so in additive manufacturing and Internet of Things (Table B.3 in Annex 2). France, which is the second top country in terms of green patent applications, follows Germany in all green areas.

German patenting activity in the areas of robotics and AI and big data is mainly located in Augsburg and München, respectively (Figure 4 and Table B.4 in Annex 2). Eindhoven (NL) leads in the development of Internet of Things-related inventions in the EU, while Barcelona (ES) does so in additive manufacturing. In the green domain, Stuttgart (DE) and Paris (FR) are leading the way in all green areas. The former is the most specialised region in environmental management, while the French region reports the highest degree of specialisation in transportation-related climate change technologies. Grenoble (FR) and Århus (DK) are the EU most specialised regions in the development of energy-related climate change technologies.

Figure 3. Shares of EPO digital and green patent applications by technological category and EU country, 2000-2017



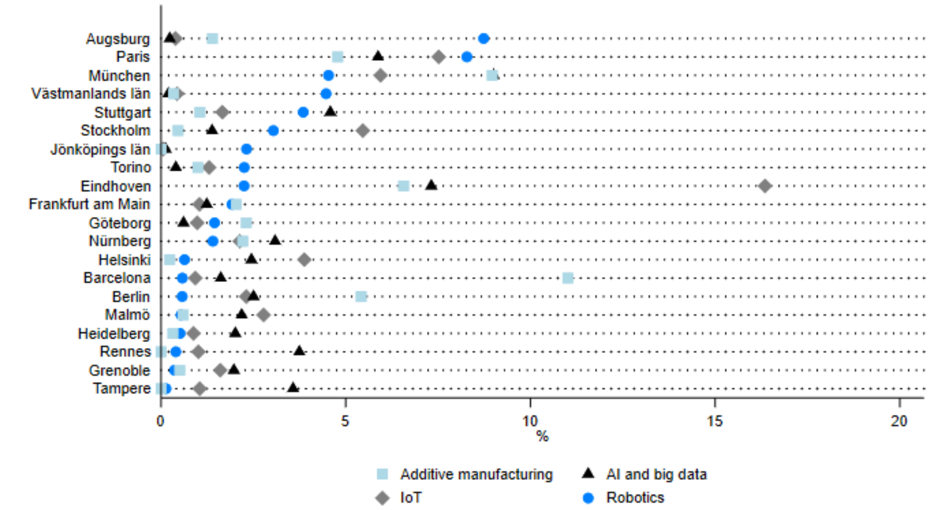
Digital patents



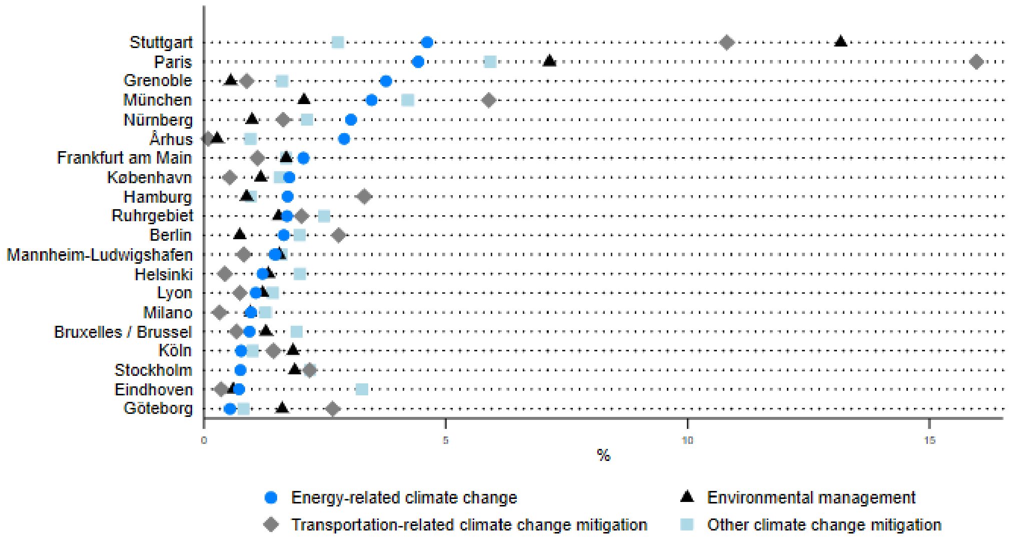
Green patents

Source: Authors' calculation based on PatStat. Note: A patent can be assigned to more than one technological area. The charts report the countries with the highest number of digital or green patent applications. Shares refer to the total number of patent applications, as a percentage of total EU.

Figure 4. Shares of EPO digital and green patent applications by technological category and EU region, 2000-2017



Digital patents



Green patents

Source: Authors' calculation based on PatStat. Note: A patent can be assigned to more than one technological area. The charts report the regions with the highest number of digital or green patent applications. Shares refer to the total number of patent applications, as a percentage of total EU. See Annex 1 for the description of digital technological classes. Green technological classes are based on the OECD Env-tech classification.

An examination of the sectors to which digital patents relate the most, shows that, as expected, the largest share of digital patents is associated to the manufacturing of computer, electronic and optical products and information and communication services (38% and 6%, respectively, in 2009-2017) (Table 5). However, digital inventions are not confined to the ICT sector. In the more recent period (2009-2017), nearly half of them occurred in other sectors, marked by heterogeneous degrees of technological intensity, including specialised supplier and scale-intensive sectors like manufacturing of machinery and equipment (20%) – which include producers of robots –, manufacture of motor vehicles, trailers and semi-trailers and other transport equipment (4%) – which include producers of electrical vehicles –, rubber, plastics and other non-metallic products (5%), metal products (5%), and science-based ones, like electrical equipment (2%), chemical products (3%), as well as services like human health activities (2%) and utilities like water collection, treatment and supply (2%). These figures as well demonstrate the pervasiveness of digitalisation and the increased reliance on the use digital tools across different sectors (OECD, 2019b).

The sectoral distribution of green patents is, as expected, different from that of digital ones. In the years 2009-2017, the largest share is represented by the manufacturing of machinery and equipment (18%), followed by the manufacturing of electrical equipment (nearly 18%), and the utilities sector (nearly 17.5% of total EU green inventions), which includes technological applications to the distribution of water, electricity, and natural gas.

Table 5: EPO digital and green patent applications by industry, 2000-2017

Industry - NACE code	Industry description	Digital		Green	
		2000-2008	2009-2017	2000-2008	2009-2017
10 - 12	Manufacture of food, beverages and tobacco products	3.0	1.1	3.0	2.5
13 - 15	Manufacture of textiles, wearing apparel and leather products	1.0	1.0	0.8	0.7
16 - 17, 31	Manufacture of wood and paper products and furniture	1.2	0.8	1.6	1.6
19 - 20	Manufacture of coke, refined petroleum and chemical products	2.6	2.8	9.6	9.1
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	1.1	0.7	6.9	3.4
22 - 23	Manufacture of rubber, plastics, and other non-metallic products	5.0	5.7	5.0	5.6
24 - 25	Manufacture of basic metals and fabricated metal products,	5.2	4.2	4.5	4.6
26	Manufacture of computer, electronic and optical products	37.9	32.6	5.1	5.4
27	Manufacture of electrical equipment	2.1	3.3	13.9	17.8
28	Manufacture of machinery and equipment n.e.c.	19.7	17.0	20.8	18.3
29	Manufacture of motor vehicles, trailers and semi-trailers	2.1	1.4	1.8	2.0
30	Manufacture of other transport equipment	1.8	4.9	2.7	3.2
18,32, 33	Other manufacturing	1.8	2.2	0.6	0.6
35	Electricity, gas, steam and air conditioning supply	0.3	0.4	4.4	4.7
36	Water collection, treatment and supply	2.4	1.9	12.6	12.1
37 - 38	Sewerage, waste collection, treatment and remediation activities	0.0	0.0	0.9	0.7
41 - 43	Construction	0.6	0.2	1.9	2.1
45 - 47	Wholesale and retail trade	0.4	1.0	0.1	0.3
49 - 53	Transportation and storage	0.2	0.0	0.0	0.1
55 - 56	Accommodation and food service activities	0.1	0.0	0.1	0.2
58-63	Information and communication	5.6	10.7	2.7	4.0
64 - 68	Financial, insurance and real estate activities	0.2	0.5	0.1	0.1
69 - 75	Professional, scientific and technical activities	1.2	1.6	0.4	0.4
77 - 82	Administrative and support service activities	0.7	0.6	0.2	0.3
84	Public administration and defence; compulsory social security, education	0.4	0.7	0.1	0.1
85	Education	0.2	0.7	0.0	0.0
86	Human health activities	1.8	3.8	0.1	0.1
87 - 98	Other services	0.0	0.0	0.1	0.1

Source: Authors' calculation based on PatStat. Note: Patents are assigned to industries (NACE rev 2) using the concordances between IPC and NACE built through an algorithmic approach developed by Lybbert and Zolas (2014). A patent can be assigned to more than one sector.

4 The knowledge sources of European green and digital inventions

Both digital and green technologies are developed through the interaction of actors (like firms, universities, and research organizations) that are embedded in places marked by specific socio-economic and institutional features. A pivotal one is their constitutive knowledge-base, which geography of innovation studies have shown to vary across countries and, within them, across regional systems of innovation. In turn, both national and regional innovation systems are open ones, and their boundaries are crossed by external knowledge flows through which the *local buzz* can be combined with their participation to *global pipelines* (Bathelt et al., 2004).

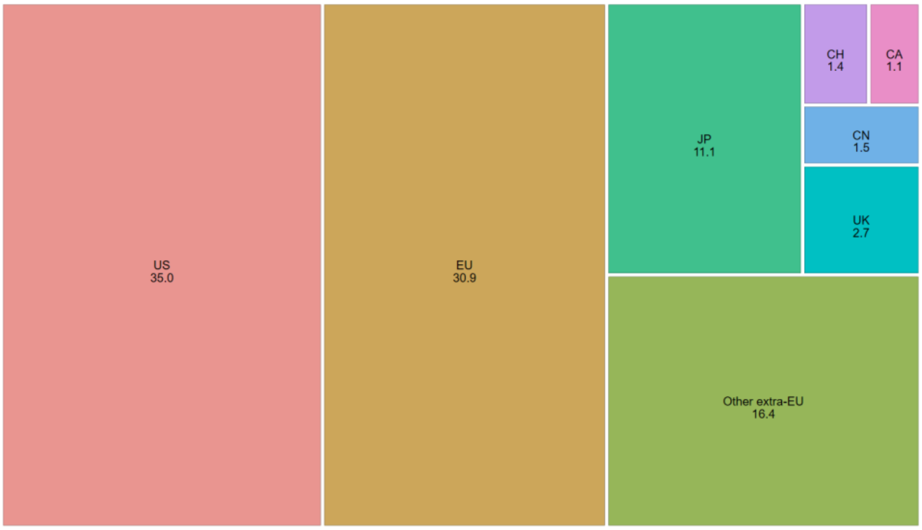
If we consider backward citations of a patent as a proxy of the knowledge inputs that are searched and combined to obtain the respective invention, by looking at the location of cited patents by digital and green EU ones, we can have an interesting map of the geography of their knowledge sources. Figure 5 and Table 6 show that for both kinds of technologies, these knowledge sources are mainly located outside of the EU. The percentage of non-EU patents cited by EU green innovations is above 50% in all EU countries, ranging from 58% in Germany to 77% in Belgium (lower panel of Table 6). A similar pattern emerges in digital patents, where the percentage of non-EU patents cited ranges from 63% in Germany to 82% in Finland (upper panel).

The percentage of non-EU cited patents is slightly larger for digital (69%) than for green (63%) patent applications. The US is the most important source of knowledge for EU inventors in both green and digital technologies. In particular, the US accounts for 26% of the patents cited by EU green patent applications and 35% of the patents cited by EU digital ones. This pattern could be due to the mass of US patents susceptible of being cited as well as to their superior quality. However, irrespective of that, it signals that the knowledge generated in the US innovation system is pivotal for the development of the two technologies at stake and that the geographical distance that separates EU countries/regions from US is not a crucial impediment to benefit from knowledge inputs via citations. Following the US, Japan is the second most important source of knowledge for the development of digital and green technologies outside the EU, accounting for 15% of green and 12% of digital cited patents. Within the EU, Germany is the most important source of knowledge for green and digital technologies, accounting for 25 % and 20 %, respectively, of EU citations.

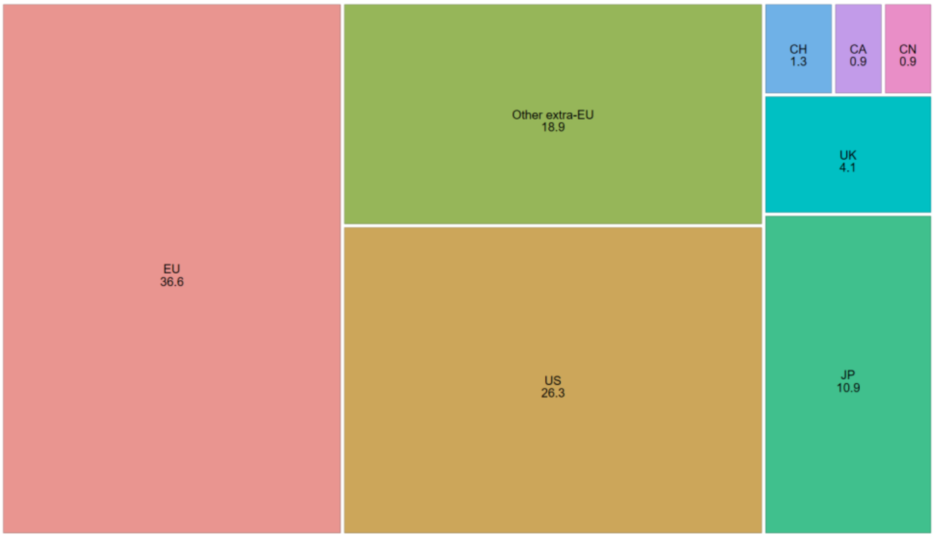
Within-country citations also account for relevant shares of backward patent citations. Particularly high shares are detected in Germany (which reaches about 35% of domestic citations in green and 30% in digital technologies) and France (17% in green and 15% in digital technologies). In the case of other countries, domestic knowledge, in general, plays a relatively minor role in the development of both green and digital technologies in the EU.

The predominant role of non-EU patents as knowledge sources for green and digital inventions also appear at the regional level (Figures B.3 and B.3 in Annex 2). Furthermore, country-level figures appear to hide interesting heterogeneity that is evident at the regional level. Table 7 depicts the knowledge sources for digital (upper panel) and green (lower panel) inventions in the regions accounting for most of the EU patenting activity in the respective domain (see previous Section). Despite a strong regional variance in knowledge sourcing, figures also show an important role of domestic knowledge in patent citations within Europe. On the one hand, for most regions Germany is the main European knowledge source. On the other hand, the home country of the same regions generally hosts the second largest share of cited patents, both in the digital and in the green domain. In particular, the share of patents citing patents of the same country ranges from 2.4% in Barcelona (Spain) to slightly over 33% in Augsburg (Germany) for digital patents, and from 4% in Göteborg (Sweden) to 39% in Stuttgart (Germany) in EU green patents for green patents. Likewise, the percentage of non-EU cited patents ranges from nearly 60% in Augsburg to over 84% in Helsinki (Finland) and Malmö for digital patents, and from 52% in Stuttgart (Germany) to over 80% in Brussel (Belgium) for green ones. US patents are one of the most important sources of knowledge for EU inventors in both green and digital technologies in most EU regions.

Figure 5. Knowledge sources of digital and green inventions by sourced area (%), EU, 2000-2017



Digital patents



Green patents

Source: Authors' calculation based on PatStat.

Table 6 Knowledge sources of digital and green inventions by sourced country (in percentage), selected EU countries, 2000-2017

Digital inventions

Cited ➡ / Citing ⬇	AT	BE	DE	DK	ES	FI	FR	IT	NL	SE	Other EU	Total EU	CA	CH	CN	JP	UK	US	Other extra-EU	Total Extra-EU
EU	0.7	0.4	19.6	0.5	0.3	0.6	4.1	1.6	1.4	1.3	0.4	30.9	1.1	1.4	1.5	11.1	2.7	35.0	16.4	69.1
AT	5.8	0.1	18.0	0.4	0.4	1.4	2.7	1.5	0.3	1.2	0.1	31.9	1.4	2.1	2.7	12.7	2.4	32.4	14.4	68.1
BE	0.3	4.3	12.3	0.0	0.3	0.1	1.7	1.0	1.5	0.2	0.2	21.8	0.8	1.1	2.4	7.4	3.7	46.5	16.4	78.2
DE	0.6	0.3	29.7	0.3	0.1	0.3	3.0	1.0	0.6	1.1	0.2	37.2	1.0	1.3	1.0	11.4	2.7	30.9	14.5	62.8
DK	0.4	0.0	9.4	12.0	0.3	0.1	0.9	1.0	0.2	1.3	0.6	26.3	2.6	0.8	0.6	10.3	2.0	35.5	21.8	73.7
ES	0.4	0.2	11.6	0.5	4.0	0.5	2.8	1.5	0.5	1.2	0.3	23.6	1.3	0.6	3.0	12.3	4.1	36.6	18.5	76.4
FI	0.5	0.0	5.7	0.6	0.0	9.3	0.8	0.2	0.5	0.3	0.4	18.3	1.0	0.7	1.5	11.7	2.4	48.1	16.3	81.7
FR	0.2	0.2	9.1	0.2	0.1	0.1	15.4	0.6	0.7	0.9	0.1	27.6	1.1	1.0	2.3	9.1	2.0	39.5	17.4	72.4
IT	0.3	0.4	15.5	0.1	0.3	0.2	3.5	8.7	0.6	1.1	0.1	30.7	0.8	1.5	1.0	13.1	2.8	33.8	16.3	69.3
NL	0.3	0.5	8.0	0.1	0.2	0.3	2.5	0.8	12.4	1.4	0.2	26.5	1.4	3.6	0.6	9.8	3.0	32.0	23.0	73.5
SE	0.8	0.3	12.7	0.1	0.1	0.4	1.8	0.7	0.8	5.3	0.3	23.3	0.8	1.7	1.3	13.9	2.6	37.1	19.3	76.7
Other EU	0.5	0.6	10.0	0.3	0.2	0.5	2.4	0.6	0.9	0.5	3.1	19.6	1.5	0.8	3.4	7.1	2.6	48.6	16.4	80.4

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding.

Green inventions

Cited ➡ / Citing ⬇	AT	BE	DE	DK	ES	FI	FR	IT	NL	SE	Other EU	Total EU	CA	CH	CN	JP	UK	US	Other extra-EU	Total Extra-EU
EU	0.9	0.6	24.5	0.9	0.5	0.5	5.2	1.5	1.0	0.7	0.4	36.6	0.9	1.3	0.9	10.9	4.1	26.3	18.9	63.4
AT	6.6	0.4	27.0	0.3	0.2	0.4	3.7	1.1	0.8	0.6	0.3	41.3	1.0	1.8	1.2	11.2	3.5	23.0	17.0	58.7
BE	0.3	5.1	10.3	0.3	0.2	0.3	3.7	0.9	1.1	0.4	0.2	22.8	0.9	0.7	0.5	7.5	4.9	31.7	31.0	77.2
DE	0.8	0.3	34.6	0.4	0.3	0.2	3.3	0.8	0.6	0.4	0.2	42.1	0.8	1.6	0.8	11.3	3.8	23.4	16.3	57.9
DK	0.4	0.4	13.6	10.5	1.1	0.3	2.5	0.5	1.4	0.5	0.2	31.4	0.9	0.8	1.2	7.4	4.0	26.5	27.8	68.6
ES	0.4	0.5	14.7	1.5	5.6	0.3	4.7	1.2	1.0	0.6	0.4	30.9	0.9	0.9	1.7	9.0	4.0	30.8	22.0	69.1
FI	0.7	0.3	10.6	0.7	0.1	7.5	3.3	0.7	1.0	1.6	0.2	26.8	1.8	0.9	1.4	10.2	3.8	31.8	23.3	73.2
FR	0.6	0.4	14.1	0.3	0.2	0.3	16.5	0.8	0.7	0.5	0.2	34.7	0.9	0.9	0.8	12.3	4.4	28.1	17.8	65.3
IT	0.7	0.9	16.8	0.3	0.4	0.2	4.8	7.8	0.7	0.5	0.3	33.5	1.0	1.3	0.9	10.9	4.5	27.5	20.6	66.5
NL	0.5	0.6	14.4	0.8	0.3	0.3	4.1	0.9	7.2	0.6	0.2	29.8	1.3	1.3	0.9	8.7	5.0	30.1	22.9	70.2
SE	0.7	0.2	14.9	0.6	0.2	0.6	3.5	0.8	0.6	4.6	0.2	26.8	1.2	1.0	1.0	14.7	4.3	32.4	18.5	73.2
Other EU	0.9	0.4	14.1	0.4	0.6	0.4	3.9	1.1	0.7	0.5	6.3	29.2	1.4	1.0	2.5	10.4	4.7	30.9	19.9	70.8

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding.

Table 7: Knowledge sources of digital and green inventions by sourced country (in percentage), selected EU regions, 2000-2017

Digital inventions

Country	Cited country ➡ / Citing region ⬇	AT	BE	DE	DK	ES	FI	FR	IT	NL	SE	Other EU	Total EU	CA	CH	CN	JP	UK	US	Other extra-EU	Total Extra-EU
DE	Berlin	0.4	0.5	24.1	0.0	0.2	0.7	3.6	0.0	0.5	2.4	0.2	32.6	1.3	3.0	1.5	6.6	3.5	37.8	13.7	67.4
DE	München	0.3	0.3	25.0	0.1	0.3	0.3	2.7	0.6	0.5	0.8	0.2	31.0	1.4	1.1	1.7	8.9	2.6	40.9	12.4	69.0
DE	Frankfurt am Main	0.0	0.4	24.2	0.3	0.1	0.2	2.3	0.9	0.6	0.6	0.2	29.7	1.3	0.7	0.8	12.2	2.2	37.4	15.6	70.3
DE	Stuttgart	0.5	0.2	30.1	0.3	0.0	0.1	4.5	1.0	0.7	0.7	0.1	38.4	0.7	1.1	1.1	14.7	3.3	27.5	13.2	61.6
DE	Nürnberg	0.6	0.3	28.9	0.5	0.2	0.4	0.7	0.3	0.6	0.9	0.1	33.6	1.2	0.9	1.4	11.4	2.2	31.3	18.1	66.4
DE	Augsburg	0.9	0.3	33.4	0.3	0.2	0.0	2.4	0.6	0.4	2.7	0.0	41.2	0.8	0.6	0.3	21.6	0.7	22.0	12.8	58.8
DE	Heidelberg	0.3	0.0	15.0	0.1	0.1	0.0	2.0	0.0	0.0	0.7	0.4	18.6	0.2	0.8	2.2	6.2	2.1	52.3	17.7	81.4
ES	Barcelona	0.3	0.1	9.2	0.1	2.4	1.1	1.1	1.4	0.3	0.7	0.4	17.0	1.9	0.0	2.9	15.1	1.8	42.4	18.9	83.0
FI	Helsinki	0.0	0.0	3.4	0.1	0.1	11.2	0.5	0.0	0.3	0.0	0.1	15.6	0.4	0.0	2.2	11.9	1.9	47.4	20.6	84.4
FI	Tampere	1.0	0.0	6.2	1.3	0.0	5.7	0.3	0.5	0.4	0.5	1.1	16.9	2.4	0.3	0.5	8.7	1.7	58.2	11.3	83.1
FR	Paris	0.1	0.3	6.7	0.1	0.1	0.0	19.9	0.4	0.8	0.4	0.2	28.9	0.9	1.0	2.0	8.8	2.1	38.1	18.2	71.1
FR	Rennes	0.5	0.0	4.1	0.0	0.2	0.5	9.2	0.0	0.5	2.7	0.0	17.8	1.7	0.5	4.7	7.6	2.4	49.0	16.2	82.2
FR	Grenoble	0.0	0.0	5.7	0.0	0.0	0.0	13.9	0.6	0.0	0.6	0.3	21.1	0.9	1.6	2.2	3.2	0.8	54.7	15.5	78.9
IT	Torino	0.0	0.3	16.7	0.0	0.5	0.0	1.9	9.2	0.3	1.4	0.0	30.3	0.3	0.8	0.0	30.2	2.8	24.6	11.1	69.7
NL	Eindhoven	0.4	0.5	7.2	0.0	0.2	0.2	0.5	0.2	7.9	0.5	0.0	17.5	1.2	0.9	0.6	13.4	2.6	44.7	19.1	82.5
SE	Stockholm	0.3	0.1	5.8	0.1	0.3	1.4	0.5	0.9	2.4	4.3	0.6	16.7	0.9	3.6	1.7	5.6	2.7	42.3	26.5	83.3
SE	Göteborg	0.0	0.1	21.0	0.2	0.0	0.2	2.5	1.1	0.4	5.9	0.3	31.8	1.1	0.4	1.6	13.4	2.1	38.5	10.9	68.2
SE	Malmö	0.2	0.3	6.7	0.0	0.2	0.2	1.0	0.2	1.2	5.4	0.2	15.6	0.5	0.2	0.4	10.2	3.5	49.6	20.1	84.4
SE	Västmanlands län	1.9	0.0	16.9	0.0	0.0	0.0	2.4	1.2	0.0	3.4	0.0	25.7	1.1	2.5	0.6	33.0	0.3	23.2	13.7	74.3
SE	Jönköpings län	0.8	0.5	11.4	0.2	0.0	0.0	1.1	0.0	0.2	8.5	0.4	23.0	0.0	0.0	1.5	3.7	3.6	39.9	28.4	77.0
Ot	Other	0.8	0.6	20.4	0.7	0.4	0.4	3.8	2.0	1.7	1.1	0.5	32.4	1.1	1.6	1.5	9.8	3.0	33.7	16.8	67.6

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding.

Green inventions

Country	Cited country ➡ / Citing region ⬇	AT	BE	DE	DK	ES	FI	FR	IT	NL	SE	Other EU	Total EU	CA	CH	CN	JP	UK	US	Other extra-EU	Total Extra-EU
BE	Bruxelles / Brussel	0.2	5.2	6.5	0.3	0.2	0.1	2.5	1.1	0.9	0.2	0.2	17.4	0.6	0.5	0.4	5.5	4.8	31.9	38.8	82.6
DE	Berlin	0.4	0.2	29.0	0.4	0.3	0.1	3.5	0.4	0.6	0.7	0.0	35.6	0.8	3.2	0.7	7.0	5.3	31.9	15.5	64.4
DE	Hamburg	0.5	0.2	31.6	1.6	0.6	0.3	3.2	0.5	0.7	0.5	0.2	39.9	1.2	0.6	1.0	8.1	4.1	28.5	16.6	60.1
DE	München	0.8	0.2	31.8	0.3	0.2	0.2	3.9	0.5	0.6	0.5	0.3	39.3	1.0	1.5	0.9	10.9	4.5	28.1	13.9	60.7
DE	Köln	0.8	0.6	33.2	0.3	0.1	0.2	3.5	1.2	0.6	0.5	0.2	41.0	0.8	1.5	0.5	12.9	3.3	23.2	16.7	59.0
DE	Frankfurt am Main	0.3	0.4	24.8	0.1	0.1	0.2	2.6	0.6	0.6	0.3	0.1	30.2	0.9	1.4	1.5	15.4	3.5	22.5	24.4	69.8
DE	Stuttgart	1.0	0.2	39.4	0.1	0.2	0.2	3.8	1.2	0.3	0.4	0.2	47.1	0.6	1.0	0.3	15.1	3.4	19.5	12.9	52.9
DE	Nürnberg	0.9	0.1	33.8	0.5	0.2	0.2	2.9	0.5	0.5	0.6	0.2	40.4	1.0	1.6	0.7	12.9	2.9	25.7	14.8	59.6
DE	Ruhrgebiet	0.6	0.4	34.2	0.3	0.2	0.4	3.2	0.6	0.7	0.5	0.2	41.3	0.7	3.7	0.7	8.6	4.6	25.8	14.4	58.7
DE	Mannheim-Ludwigshafen	0.5	0.4	22.5	0.2	0.1	0.0	1.8	0.6	0.4	0.2	0.1	26.7	0.6	0.9	0.7	10.8	4.3	27.3	28.5	73.3
DK	København	0.4	0.6	7.4	12.6	0.4	0.3	2.1	0.4	1.6	0.4	0.1	26.4	1.1	1.1	0.5	6.4	3.4	24.9	36.0	73.6
DK	Århus	0.5	0.2	18.8	9.1	1.8	0.3	2.0	0.8	1.1	0.5	0.2	35.3	0.7	0.6	1.9	6.9	3.5	27.2	24.0	64.7
FI	Helsinki	0.5	0.4	8.1	0.8	0.1	8.4	3.5	0.9	1.0	1.1	0.2	25.1	1.7	0.7	1.4	9.9	3.8	31.7	25.7	74.9
FR	Paris	0.6	0.3	14.2	0.3	0.1	0.2	17.2	0.7	0.5	0.5	0.2	34.9	0.8	0.8	0.5	13.9	4.8	28.8	15.4	65.1
FR	Lyon	1.0	0.9	9.3	0.3	0.3	1.1	18.0	1.0	1.1	0.7	0.2	33.9	1.2	1.0	0.5	8.4	4.3	25.9	24.8	66.1
FR	Grenoble	0.5	0.2	8.9	0.2	0.3	0.3	15.4	0.8	0.8	0.3	0.2	27.9	1.4	0.8	1.8	14.3	2.8	32.5	18.6	72.1
IT	Milano	0.6	0.5	13.9	0.5	0.3	0.5	4.5	8.6	0.9	0.7	0.4	31.5	1.5	1.2	1.2	12.6	5.0	29.4	17.6	68.5
NL	Eindhoven	0.5	0.3	9.5	0.1	0.1	0.6	2.3	1.0	6.8	0.7	0.2	22.0	1.2	0.8	2.3	11.1	3.0	40.0	19.5	78.0
SE	Stockholm	0.8	0.2	15.7	0.4	0.1	0.5	4.1	0.7	0.6	4.6	0.1	27.8	1.3	0.6	0.8	12.9	4.0	32.0	20.6	72.2
SE	Göteborg	0.7	0.2	18.4	0.2	0.1	0.6	3.6	1.0	0.5	4.4	0.2	30.0	0.7	0.7	0.7	20.0	4.3	29.5	14.0	70.0
Ot	Other	1.1	0.7	24.9	0.8	0.7	0.4	4.9	1.8	1.1	0.7	0.5	37.6	0.9	1.3	1.0	10.6	4.1	25.7	18.7	62.4

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding.

Furthermore, it is interesting to notice that the geography of EU knowledge sourcing also varies largely with the type of green and digital technological category. As depicted in Table 8, the vast majority of knowledge used in EU digital is derived from extra-EU sources in all the technological fields. Extra-EU knowledge sources are the most relevant for the development of patents in big data (88%) and blockchain (92%), while they are the least important in additive manufacturing (72%). By contrast, backward citations to non-domestic within EU patents are generally the least important source of knowledge to robotics (9%) (AI, 3%). Finally, the use of domestic knowledge sources is more common in additive manufacturing (18.5%) than in other digital fields, and less common, in blockchain.

Looking at green technologies, the share of extra-EU knowledge sources tends to be lower than among digital ones, with the exception of green patents linked to the development of climate change mitigation technologies related to ICT, with 83% of their citations being extra-EU patents. This is consistent with the citation pattern detected above with respect to digital technologies in general. Like in the case of digital technologies, the second most important source of knowledge are domestic patents, followed by knowledge sources from other EU countries. ICT-related climate change mitigation technologies and sustainable ocean economy is the only exception, as the share of domestic citations is the lowest. By contrast, green patents related to environmental management and the development of transportation-related climate change mitigation technologies are the most prone to cite domestic knowledge sources.

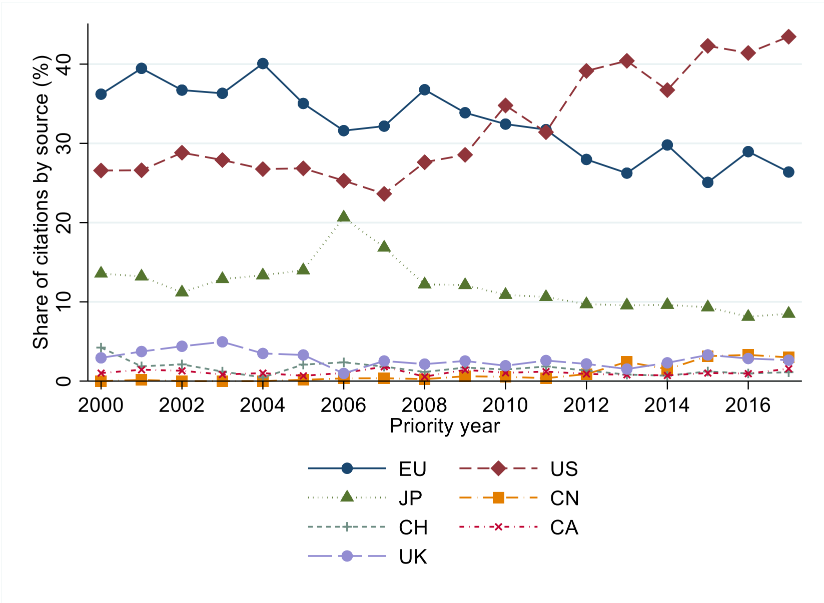
Finally, patent figures also lead us to expect a reduction in the importance of EU knowledge sources for the development of digital inventions in the future. As depicted in Figure 6, the share of EU citations by digital patents has decreased in the recent years, which has been coupled by a greater use of non-European knowledge and, especially, US knowledge sources. The role of China is also increasing in both the digital and green domain. In the period 2000-2017, the share of citations of Chinese patents by digital and green patents, has raised substantially, although still at a relatively low level, from nil to nearly 3% and 4% percent, respectively.

Table 8: Knowledge sources of digital and green inventions by category, 2000-2017

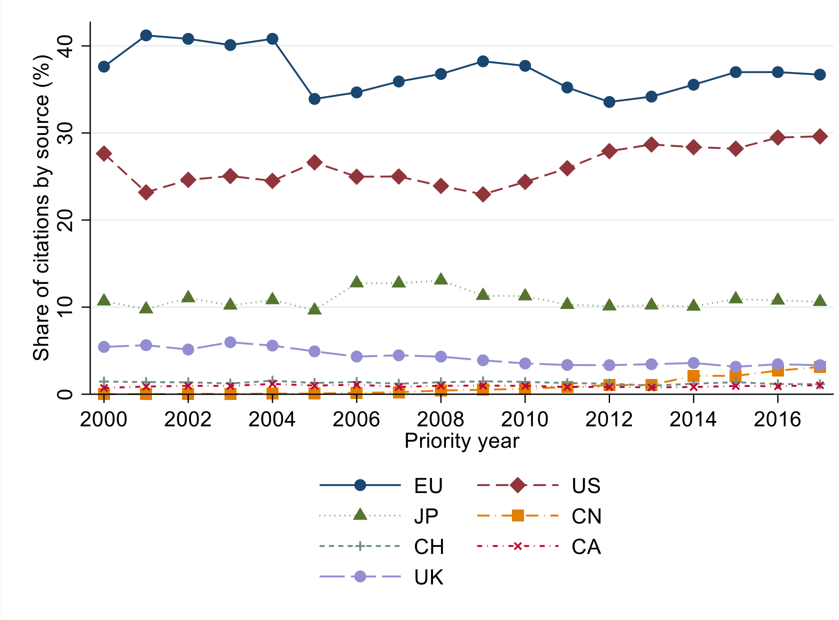
Technological class	Domestic	Foreign, EU	Foreign, Extra-EU
	Digital patents		
Additive manufacturing	18.5	9.0	72.5
AI	10.2	3.3	86.5
Big data	8.4	3.5	88.1
Blockchain	5.1	2.2	92.7
Computing infrastructure	9.3	5.5	85.2
Internet of Things	7.8	6.2	86.1
Robotics	15.8	9.2	74.9
	Green patents		
Buildings-related climate change mitigation technologies	25.3	20.3	54.4
Capture or disposal of greenhouse gases	15.6	13.0	71.5
Climate change adaptation technologies	16.9	13.9	69.2
Energy-related climate change mitigation technologies	21.8	16.3	62.0
Environmental management	25.2	17.8	57.0
ICT-related climate change mitigation technologies	7.8	9.8	82.5
Production of goods-related climate change mitigation technologies	22.4	14.2	63.4
Sustainable ocean economy	14.6	18.3	67.1
Transportation-related climate change mitigation technologies	24.9	14.7	60.5
Wastewater treatment or waste management-related climate change mitigation technologies	21.9	18.8	59.3

Note: See Annex 1 for the description of digital technological classes. Green technological classes are based on the OECD Env-tech classification.

Figure 6. Trend in the compositions of the citations by EPO digital and green patent applications, 2000-2017



Digital patents



Green patents

Source: Authors' calculation based on PatStat

5 Conclusions

Several policy initiatives within and beyond Europe are pushing for the design of new patterns of development to cope with major shocks and challenges the humankind has been facing nowadays. The development and interlinkage of environmental and digital technologies are at the core of these efforts. In this study we provide evidence of EU green and digital technological trajectories at both regional and country level. In particular, we show how the distribution of the two technologies across countries and regions has changed in recent years. Furthermore, we examine the location of the knowledge sources relevant for their development, which we capture using the patent citations of EU green and digital patent applications.

EU digital and green technologies show contrasting diffusion levels and growth, while their geographical patterns are more similar. First, green technologies are much more diffused than digital ones in the EU. Second, after a period of steadily increase in the 2000s, the development of green technologies showed clear signs of stagnation. By contrast, EU digital patents showed no or moderate increases up to 2012, and a marked increase thereafter. Third, this heterogeneity is contrasted by more similar geographical patterns. Germany and, to a lower extent, France, are by far the countries with more patent applications in both technological domains. There are nevertheless signs of recent catching up of other EU countries, especially in digital technologies, with the German share of total EU patent applications falling by about 14 percentage points from 2000-08 to 2009-2017 and other countries, namely France and Sweden, increasing their share.

The development of digital and green inventions in the EU also appears to be driven by a few regions located in central and central-east countries and Sweden. München (Germany), Paris (France) and Eindhoven (The Netherlands) are leading the way for digital inventions in the more recent period (2009-2017), while Paris (France), Stuttgart (Germany), and München (Germany), alone, represented 20% of the total EU production of green patents in 2000-2008 and 15% in 2009-2017.

The knowledge base for the development of both green and digital technologies is largely located outside of the EU. Extra-EU patent citations account for about 69% of EU digital patent applications and about 65% of the green ones. We also find strong geographic concentration of technological knowledge sourcing, with the United States and Japan accounting alone for nearly 46% of citations of EU digital patent applications (35% from the US and11% from Japan) and 37% of EU green ones (26% from the US and 11% Japan). The predominant role of non-EU patents as knowledge sources for green and digital inventions also appear at the regional level, yet with a greater heterogeneity. This study's results also lead us to expect a reduction in the importance of EU knowledge sources for the development of digital inventions in the future, revealing the EU weakness in this domain. Within the EU, Germany is the most important source of knowledge for green and digital technologies.

These findings provide important insights about the European locations that most contributed to the development of digital and green technologies over the last two decades. Their mapping represents important knowledge about the possible hotspots of the digital and green transition, as well as about the places that lag behind. We also provide novel evidence about the knowledge sources that drive the development of digital and green technologies in Europe. The location of these knowledge sources reveals a geography that markedly varies across EU countries and regions and that accordingly requires place-based innovation policies. These policies should be informed by the high, though still geographical heterogeneous, dependence that EU digital and green technologies reveal on extra-EU knowledge sources as well as on a concentrated set of EU knowledge sourcing areas. On this basis, an important component of the (twin) transition policies is represented by the forging of a network of relationships that suitably combine within and extra-EU relationships. Multinational enterprises and Foreign Direct Investments (FDIs) can play a key role in establishing these networks, facilitating the flow of knowledge into EU territories, strengthening the development of digital and green technologies and facilitating a twin transition in the Continent.

Our findings are not free from limitations, the main of which is the exclusive focus on international technological sourcing and on patent-based methods. These limitations indicate a need, but also opportunities, for future research as evidence on the knowledge flows across locations is still limited. Firstly, due to their nature, knowledge flows are difficult to measure. Our work employs information on patent citations, which are in some cases a noisy measure of knowledge diffusion as citations are frequently given by examiners or by patent attorneys (e.g. Jaffe et al., 2000). In this respect, additional patent-based information could be used in future research to map knowledge diffusion across EU countries and regions, like the incidence of collaboration on knowledge creation as revealed by co-patenting activities across locations. Secondly, more empirical work is required to understand what drives these knowledge flows within and outside the EU. As mentioned above, FDIs can serve as a channel through which host and home locations access foreign knowledge. Accordingly, investigating the extent to which the map of the citing patterns we have detected overlap with that of FDIs EU regions and countries make abroad, could be another relevant future line of research.

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List of abbreviations and definitions

AT	Austria
BE	Belgium
BG	Bulgaria
CN	China
CH	Switzerland
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
EL	Greece
ES	Spain
EU	European Union
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
JP	Japan
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom
US	United States

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Annexes

Annex 1. Selection of digital patents

This Appendix provides further detail on the methodology adopted to select digital patents. First, it describes the components of the digital ecosystem, based on which a list of digital keywords was derived. Second, it discusses the validity of a keywords-based approach, as compared to a selection of digital patents based on the identification of digital-related technological classes at the eight-digit level from the International Patent Classification (IPC), which builds on the recent literature in this field (UK IP Office, 2013, 2014a, 2014b and 2014c; and Martinelli et al., 2019).

Digital components

The digital transformation underpins an ecosystem of interrelated digital technologies, which include additive manufacturing, artificial intelligence, big data, computing infrastructure, robotics, Internet of Things, and blockchain. Our list of keywords for the selection of digital patents builds on these categories, which are inspired by those identified in OECD (2019) and Bianchini et al. (2022b)5, as described below.

Additive Manufacturing (AM). Additive manufacturing, or 3D printing, consists in the computer-controlled production of three-dimensional objects by depositing materials, usually in layers, with precise geometric shapes. A technique for rapid prototyping system using photopolymer layers was proposed in 1981 by Hideo Kodama (Nagoya Municipal Industrial Research Institute). Soon afterwards it became possible to create complex models with the help of computer aided manufacturing or computer-aided design (CAM/CAD) software. The procedure came to be known as stereolithography: a liquid resin material is polymerised with a high-precision laser to form each layer, and the process is said to be “additive” because the objects are built layer by layer. The first 3D printing machines turned into a viable commercial product only in the early 2000s, and this paved the way to produce industrial parts on demand.

Today, there are distinct AM processes, each with specific standards (details are largely beyond the scope of this document): vat polymerisation, material jetting, binder jetting, directed energy deposition, material extrusion, powder bed fusion, and sheet lamination. What characterises these processes is that, unlike traditional manufacturing, they do not require machining or other techniques to remove surplus material. The objects produced can achieve much finer details and the production process is more reliable as it can repeatedly achieve high quality results. 3D printed products can serve a variety of different applications ranging from automotive, healthcare, aerospace, and parts replacement.

Artificial Intelligence (AI). Human-like machines are described in many stories and are pictured in sculptures, painting, and drawings already from the Ancient Greeks. Long debate about what might be needed to make machines intelligent are scattered abundantly throughout philosophy, logic, biology, statistics, and engineering from the 16th century, reaching a peak in the mid-20th century with several breakthroughs in computation theory by the English logician and mathematician Alan Turing and the American mathematician, physician and polymath John von Neumann.

The emergence of AI as a full-fledged field of research coincide with three important meetings of the respective community of scientists: a Session on Learning Machines in 1955 (Los Angeles); a Summer Research Project on Artificial Intelligence in 1956 (Dartmouth); and a meeting on Mechanization of Thought Processes in 1958 (UK). The 1956 workshop is considered to be the official beginning of AI, whose overarching goal would have been to “make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves” (McCarthy, Minsky, Rochester, and Shannon, 1956).

Today, AI brings together a number of distinct and often intersecting sub-fields such as machine learning, computer vision, natural language processing (NLP), symbolic reasoning, knowledge representation, and many others. Recent definitions of AI aim to be understandable, technically accurate, technology-neutral and

5 For the purpose of this study, the category “5G networks” is included in “computing infrastructures”. In, Bianchini et al. (2022b), the group “blockchain” is excluded.

applicable to short- and long-term horizons. Here are some examples: “Machines or agents that are capable of observing their environment, learning, and based on the knowledge and experience gained, taking intelligent action or proposing decisions” (EC, 2018); “An AI system is a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments” (OECD, 2019); “Machines that can become better at a task typically performed by humans with limited or no human intervention” (WIPO, 2019).

Although drawing a precise boundary to AI is an ongoing subject of debate, there is a general consensus on the methodological building blocks needed to mechanise human intelligence (Russel and Norvig, 2020). These AI building blocks typically include four elements: machine learning, NLP, computer vision and speech recognition.6

As for machine learning, for instance, we include terms such as “neural network”, “deep learning” and “support vector machines”, which are essentially techniques for predictive analytics. NLP includes terms such as “knowledge representation”, “semantic search” and “sentiment analysis”. Computer vision comprehends, among others, terms such as “image classification”, “object detection” and “pose estimation”. And speech recognition includes, for example, “speech recognition” and “voice recognition”.

Big Data. The term was popularised by computer scientist John Mashey in the 1990s, referring to unusually large and heterogeneous data sets that were difficult to capture and process with commonly used software. More accurate definitions appeared in the early 2000s: “Big data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimisation” (Douglas Laney, 2001).

Today, much the same as for AI, there is no clear consensus on what Big Data is. Definitions often include (at least) three features, commonly referred to as the “3Vs of Big Data”. These are Volume or very large size; Velocity corresponding to the speed of data creation which should be in real-time or nearly-real time; and Variety representing the heterogeneity of data sources (e.g., text from messages, images posted to social networks, readings from sensors). Other Vs are added from time to time, such as Veracity (data quality), Value (value obtained from exploitation), and Variability (rate of change).

For instance, De Mauro et al. (2015) propose that Big Data can be considered as a standalone term referring to those “Information assets characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value”, and as an attribute when denoting its peculiar requisites (e.g., “Big Data Technology” or “Big Data Analytics”).

The terms in our list adhere to this idea of autonomous terms with respect to standalone term vis-à-vis attributes. Indeed, definitions include terms such as “massive data” and “large-scale data” but also technological requisites such as “data centre” and “Hadoop”.

Computing Infrastructures. Computing infrastructures can be referred to as physical and virtual resources that support the flow, storage, processing and analysis of data. An infrastructure can either be centralised within a data center, or it can be decentralised and distributed in several data centers.

Algorithmic advances and the advent of Big Data have changed the way infrastructures are designed and implemented. For instance, demanding users rely more and more often on cloud computing for the provision of flexible on-demand computing services such as storage and processing.

More specifically, cloud computing encompasses the delivery of computing services – servers, storage, databases, networking, software, and analytics – over the Internet (i.e., the “cloud”). Cloud manufacturing embraces the application in manufacturing of cloud technologies, with widespread access, easy and on-demand IT services to support production processes and supply chain management. The concept of infrastructure-as-a-service (IaaS) dates back to the 1960s, but it became fully operational for users in the early 2000s. Recent technologies such as fog-computing and 5G extends the benefits of IaaS, providing a far higher level of performance (high speed and low latency) than the previous generations of computing and mobile communications systems. Furthermore, computational capabilities have experienced a tremendous

[6] A strict separation between methodologies/techniques (e.g., deep neural networks) and applications (e.g., robotic arms with computer vision) remains flawed. AI methods find real-world applications because embedded in physical systems. However, a physical system that performs human actions may not necessarily be regarded as “intelligent”, if we agree that a prerequisite for being classified as intelligent not only implies the ability to perform complex tasks in a given environment but also improve with the experience.

increase in the past decades, and this has been made possible by new computational approaches (many of which are still in an experimental phase) such as quantum computing.

We include terms referring to cloud computing, such as “cloud architecture” and “on-demand computing”, but also terms referring to computing power, such as “hardware accelerator” and “supercomputing”.

Internet of Things (IoT). The idea of connecting a physical object to the Internet dates back to 1982, when a Coke machine was first connected to the Internet at Carnegie Mellon University. In the early 1990s, the idea of a physical connection to the Internet became more and more pervasive.

Today, IoT is a concept describing a wide ecosystem of interconnected devices and services that collect, exchange and process data in order to adapt dynamically to a given context (Atzori et al., 2010). IoT entails networks of physical objects (the “things”) embedded with ambient sensors and dedicated software, and connected via standard communication protocols.

The underlying technologies needed to build an IoT device are semiconductor technologies, sensor technologies and more generally micro-electromechanical systems (MEMS), and of course the Internet. When connected to each other, the network of “things” offers self-identification, localisation, diagnostic status, data acquisition and processing capabilities. Data and information can moreover be collected from a wide variety of sources (industrial products, transport vehicles, etc.). IoT allows objects to interact with other objects and therefore with people in an increasingly digitalised and automatized way.

For IoT, we are also faced with a high degree of technological complexity. Among the terms on our list, we include sensor-related technologies such as “pervasive sensing” and “smart sensor”, and other technologies referring to means of communication, such as “hyper connectivity”. We consider both applications in industry (e.g., “machine-to-enterprise” and “smart factor”) and home automation and domestic appliances (e.g., “connected home” and “smart home”).

Robotics. Robotics encompasses agents with different capabilities to substitute for humans and replicate and automate human actions. Although robotics has a long and rich history, with inventions that intertwined in various scientific domains – information and mechanical engineering, computer science, etc. – and visionary insights, the first commercial robots installed for industrial purposes appeared in the 1960s. But it was only after the 1980s that we witnessed a massive deployment of (multitasking) industrial robots aimed at automatizing the mass production of consumers and industrial goods.

Modern flexible robots, empowered by machine learning systems, can interact with the environment, self-learn from the environment and improve with experience. Robots find applications in various segments of the economy: manufacturing, assembly and packing, transportation, earth and space exploration, surgery and patient healthcare, laboratory R&D, but also household chores.

Industrial robots are often classified in various subgroups, depending on their anthropomorphic characteristics, the type of movements they can perform and the plane of action (e.g., horizontal, vertical, rotary). Among these groups, we typically find SCARA (Selective Compliance Assembly Robot Arm), articulated, Cartesian, dual arm robots and cobots (Nilsson, 2009; Russel and Norvig, 2020)

Our terms are broad in scope and allow to identify physical components of a robot (e.g., “robotic” arm/leg/fingers), some of its functionalities (e.g., “manipulator”), and control systems (e.g., “robot” control/plan/movement). We also consider an increasingly active area of research dealing with autonomous vehicles in various environments such as land, water and air.

Blockchain. Blockchain is a distributed ledger technology (DLT) consisting of a list of records, called blocks, which are chained to one another using advanced cryptography. It enables applications to authenticate ownership and carry out secure transactions for a variety of asset types (OECD, 2019). One of the most widespread applications of blockchain is for cryptocurrencies (e.g. Bitcoin, Ripple), but it starts diffusing in many other sectors, including agriculture, manufacturing, retail, healthcare, energy, transport and the public sector.

In our list, we include terms referring to blockchain, as well as to cryptocurrencies, such as “altcoin”, “bitcoin” and “cryptocurrency”.

Keywords- vs IPC-based selection of digital patents

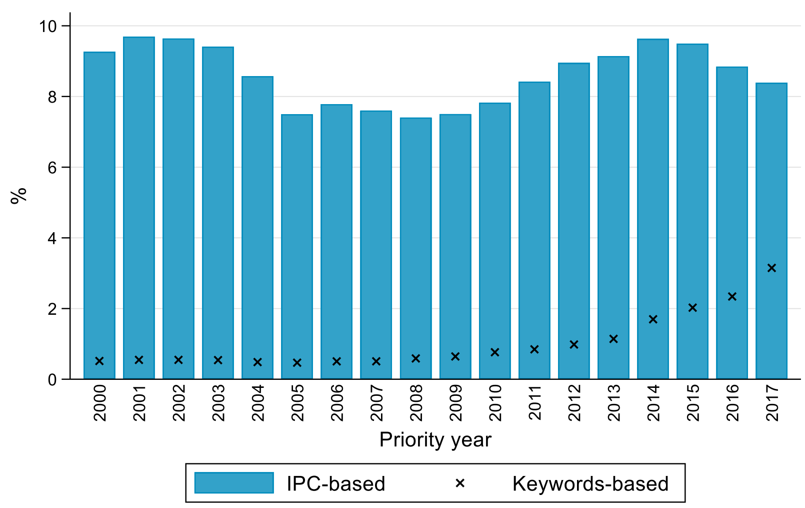
An established methodology to define digital patents does not yet exist in the literature. Recent contributions in this field have relied on hierarchical patent classification systems (e.g., IPC, CPC) following the research initiated by the UK IP Office (2013, 2014a, 2014b and 2014c) and further developed in subsequent studies (Ardito et al., 2018; Fujii and Managi, 2018; Corradini et al, 2021). Other scholars have adopted keyword inclusion/exclusion criteria applied to the text fields of patents or publications (Webb et al., 2018; Van Roy et al., 2020; Bianchini, 2022b), whereas a third stream of contributions have used a combination of both methods (WIPO, 2018; Baruffaldi et al., 2020; EPO, 2020; Martinelli et al., 2021). As the lists of keywords or technological classes adopted in these works are often heterogeneous and not always exhaustive, these studies have often resulted in contrasting selections of digital patents.

In our work, we have opted for a search query on titles and abstracts based on a list of keywords. IPC technological classes are in fact often too wide, so that their use can result in a high selection of false positives, and often fail to capture digital activities in certain fields, such as robotics. We observed the emergence of such issues when comparing our selection of digital patents against the one obtained using a list of IPC codes that are most related to the components of the digital ecosystem described above. In doing so, we referred to the IPC list proposed by the UK IP Office (UK IP Office, 2013, 2014a, 2014b, and 2014c) and Martinelli et al. (2021). Because these studies do not contain information on IPC classes related to computing infrastructures and blockchain, these two categories have been excluded from the analysis.

Figure A1 compares the distribution of the IPC-based and the keywords-based selection of digital patents over time. When a keywords-based search query is adopted in place of filtering patents using IPC classes, the share of digital patents on the total is much lower and shows an exponential growth, which is more apparent in the recent years. In the second case, the share of digital patents shows a rather smooth trend, marked by two falls in 2005 and 2017. Overall, this divergence suggests that a keywords-based selection criterion can better capture patenting activity in more advanced digital technologies being the latter a more recent phenomenon (OECD, 2019b). For instance, by adopting existing details on IPC classes it is not possible to distinguish big data-based inventions from those based on conventional data.

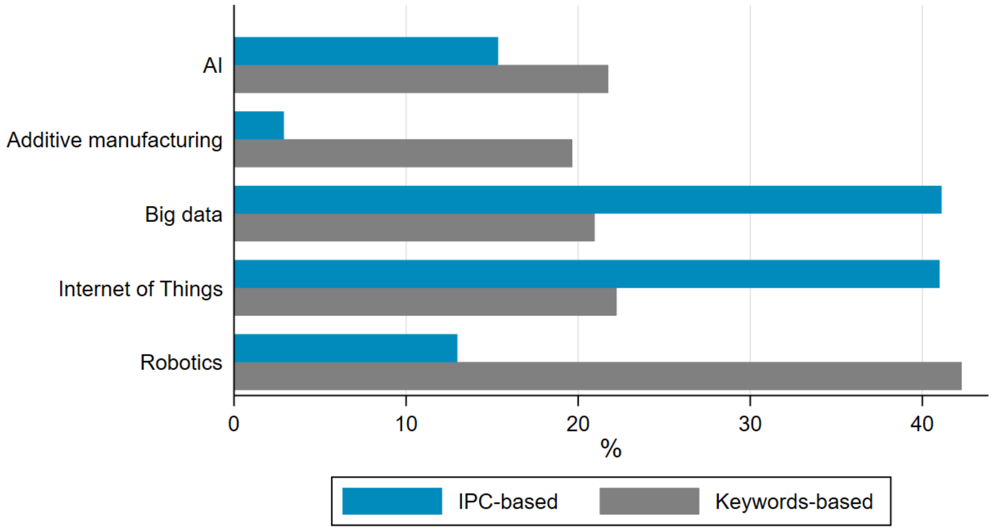
In terms of digital category, nearly half of the keywords-based selection includes patents in robotics, whereas the use of IPC classes results in a higher share of digital patents related to big data and Internet of Things (Figure A2).

Figure A1: Distribution of EPO digital patent applications by selection method, random sample, 2000-2017



Source: Authors' calculation based on PatStat. Note: Bars report the share of digital patents on the total by year. For sake of comparability, the selection of digital patents only refers to the following digital categories: artificial intelligence, big data, Internet of things, robotics and additive manufacturing on which we can derive a list of digital-related IPC classes based on the literature.

Figure A2: Distribution of EPO digital patent applications by selection method and digital category, random sample, 2000-2017



Note: a patent can be assigned to more than one digital category.

To better understand the outcome of both selection methods, we have checked manually a random sample of digital patents. More specifically, we have randomly extracted 15 patents from the group of digital patents that were selected based on the list of digital-related IPC classes and 15 patents from that of digital patents that were identified using our list of keywords and that are not included in the former group. We then inspected the extracted patents to assess the meaningfulness of the assigned categories. Table A1 reports our findings. Overall, the use of IPC classes results in a higher number of false positives as compared to the keywords case (7 versus 1). The largest number of these cases refers to digital patents related to big data mainly because the current IPC classification does not allow for the distinction between use or development of conventional data and that of big data. Moreover, the use of IPC classes in the selection of digital patents also results in a high number of false negatives (14 out of 15, as shown in the bottom panel of the table), the largest majority of which are in robotics. This is mainly because a digital invention which entails the use of robotics is normally classified under the technological class (IPC) related to the field of invention. For instance, an invention related to a robotic device for aiding the motion of subjects with severe motor disabilities is classified under "Medical or veterinary science>Chairs or personal conveyances specially adapted for patients or disabled persons" (A61G005/14) and not under the IPC class (e.g., "Programme-controlled manipulators") used to capture robots.

Table A1: False and true positives in a sample of digital patents

Random sample of digital patents selected using digital-related IPC classes

N		False positive	True positive
15		7	8
		of which (%):	
	Additive manufacturing	0.0	0.0
	AI	28.6	0.0
	Big data	42.9	37.5
	IoT	14.3	87.5
	Robotics	14.3	0.0

Random sample of digital patents selected using a keywords-based search query and corresponding to non-digital IPC classes

N		False positive	True positive
15		1	14
		of which (%):	
	Additive manufacturing	0.0	7.1
	AI	0.0	21.4
	Big data	0.0	7.1
	IoT	0.0	7.1
	Robotics	100.0	64.3

Source: Authors' calculation based on PatStat Note: a patent can be assigned to more than one digital category.

Annex 2. Additional tables and charts

Dataset description

Table B.1: EPO digital patent applications and citations by priority year, EU countries, 2000-2017

	Digital		Green	
Year	Number of patent applications	Number of citations	Number of patent applications	Number of citations
2000	244	625	3,596	10,659
2001	257	700	3,745	10,814
2002	257	691	3,772	9,891
2003	252	735	3,999	11,010
2004	241	694	4,108	10,710
2005	211	619	4,624	15,383
2006	258	971	5,216	16,352
2007	251	824	5,753	17,858
2008	314	981	6,294	19,367
2009	322	1,056	6,960	19,898
2010	379	1,297	7,305	21,328
2011	366	1,098	7,628	22,134
2012	455	1,310	7,554	22,489
2013	426	1,079	7,003	20,322
2014	701	1,643	7,056	19,821
2015	784	1,892	6,742	18,110
2016	1,028	2,335	6,666	15,515
2017	1,253	2,901	6,852	14,722

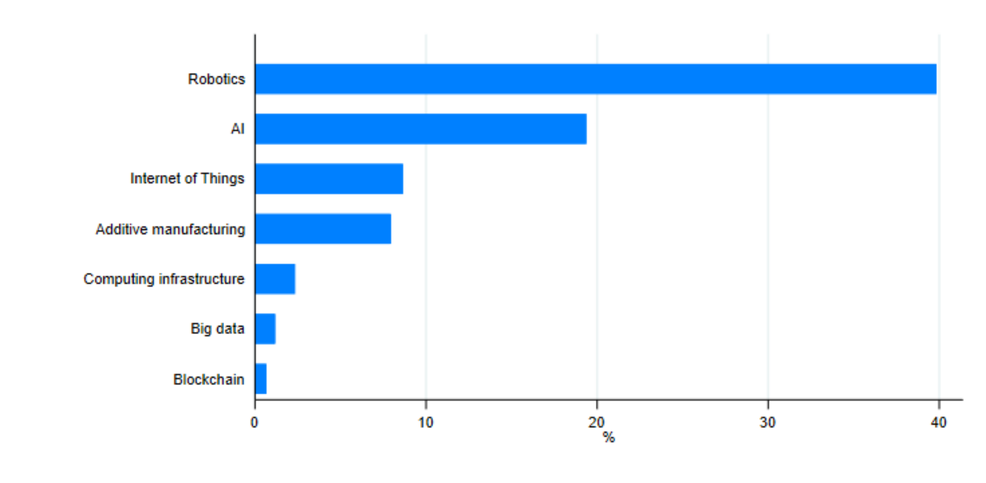
Source: Authors' calculation based on PatStat. Note: Figures are based on fractional counts.

Table B.2: EPO digital patent applications and citations by EU country, 2000-2017

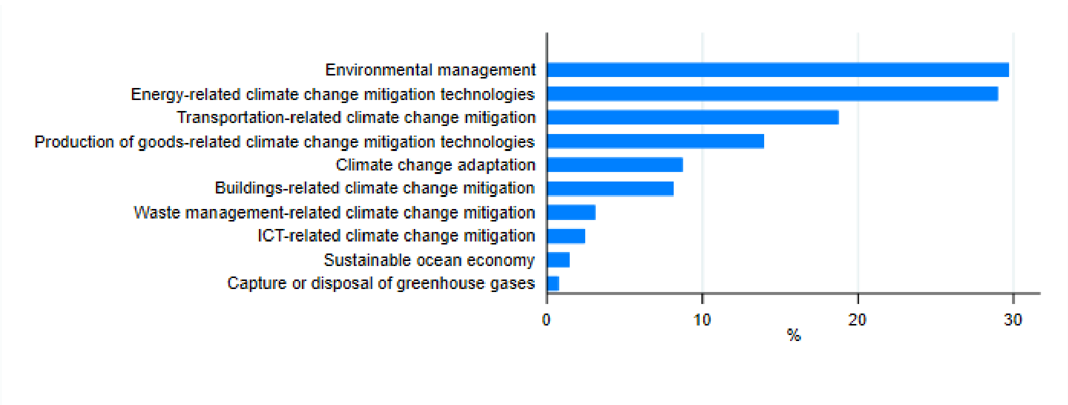
	Digital		Green	
Country	Number of patent applications	Number of citations	Number of patent applications	Number of citations
AT	212	687	3,534	10,866
BE	204	679	3,075	13,976
BG	3	6	58	146
CY	1	3	24	89
CZ	47	184	339	931
DE	3,222	9,728	48,287	143,350
DK	151	445	4,403	12,494
EE	13	38	63	189
EL	11	29	202	417
ES	340	1,003	3,182	11,401
FI	248	579	2,894	7,785
FR	1,217	2,419	17,699	35,752
HR	4	5	37	64
HU	39	84	290	538
IE	70	196	468	1,238
IT	567	1,859	7,848	27,015
LT	4	16	27	85
LU	15	55	216	766
LV	5	23	38	165
MT	0	0	23	43
NL	764	1,370	5,638	11,732
PL	65	331	679	2,470
PT	21	42	254	494
RO	14	66	97	293
SE	747	1,548	5,285	13,538
SI	9	47	136	313
SK	4	10	79	232

Source: Authors' calculation based on PatStat. Note: Figures are based on fractional counts.

Figure B.1: EPO patent applications by EU technological area, 2000-2017



Digital patents



Green patents

Source: Authors' calculation based on PatStat. Note: a patent can be assigned to more than one technological area.

Countries' and regions' *shares and specialisation degrees in green and digital inventions*

Table B.3: EPO digital patent applications and degree of specialisation by technological category, selected EU countries, 2000-2017

Digital patents

	Robotics		AI and Big data		IoT		Additive manufacturing		Other	
Country	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation
DE	43.5	1.1	43.9	1.1	26.3	0.7	46.4	1.2	35.8	0.9
FR	14.2	0.9	15.6	1.0	16.7	1.1	8.2	0.5	18.3	1.2
SE	12.7	1.4	5.2	0.6	10.6	1.1	6.6	0.7	10.9	1.2
IT	8.6	1.2	3.4	0.5	7.6	1.1	5.7	0.8	5.9	0.8
NL	7.1	0.7	9.2	1.0	18.7	2.0	10.4	1.1	3.3	0.3
ES	3.7	0.9	4.3	1.0	2.4	0.6	13.3	3.1	2.7	0.6
AT	3.1	1.2	1.8	0.7	1.4	0.5	2.0	0.7	4.3	1.6
DK	1.8	1.0	1.4	0.7	1.9	1.0	0.2	0.1	2.2	1.1
FI	1.1	0.4	6.4	2.1	7.0	2.2	0.7	0.2	5.2	1.7
BE	1.0	0.4	3.6	1.4	2.4	0.9	3.6	1.4	6.2	2.4

Green patents

	Energy-related climate change mitigation technologies		Environmental management		Transportation-related climate change mitigation technologies		Other climate change mitigation technologies		Other	
Country	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation
DE	47.0	1.0	49.9	1.1	52.5	1.1	41.2	0.9	31.2	0.7
FR	16.0	0.9	14.7	0.9	24.7	1.5	15.1	0.9	18.6	1.1
DK	9.5	2.3	2.1	0.5	0.8	0.2	4.5	1.1	6.6	1.6
IT	5.4	0.7	8.8	1.2	5.0	0.7	7.8	1.0	4.2	0.6
NL	4.6	0.9	4.1	0.8	1.4	0.3	7.9	1.5	10.4	1.9
ES	4.4	1.5	2.2	0.7	1.6	0.5	3.3	1.1	6.7	2.2
SE	3.6	0.7	5.7	1.1	6.7	1.3	5.9	1.2	7.2	1.4
AT	3.1	0.9	3.8	1.1	2.8	0.8	3.7	1.1	2.1	0.6
BE	2.2	0.8	2.8	1.0	1.7	0.6	4.3	1.5	2.4	0.8
FI	2.1	0.8	3.4	1.2	1.7	0.6	3.6	1.3	5.6	2.0

Source: Authors' calculation based on PatStat. Note: A patent can be assigned to more than one technological area. The tables report the countries with the highest number of digital or green patent applications. Shares refer to the total number of patent applications, as a percentage of total EU. A country's specialisation degree in the digital (green) technological area is measured as the ratio of the country's share of digital (green) patents in the specific technological area to the total share of digital (green) patents in the same technological area in the EU (RTA index)

Table B.4 EPO digital patent applications and degree of specialisation by technological category, selected EU regions, 2000-2017

Digital patents

		Robotics		AI and Big data		IoT		Additive manufacturing		Other	
Country	Region name	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation	Share	Degree of specialisation
DE	Augsburg	8.7	2.1	0.2	0.1	0.4	0.1	1.4	0.3	0.0	
FR	Paris	8.3	1.1	5.9	0.8	7.5	1.0	4.8	0.6	18.8	2.5
DE	München	4.5	0.7	9.0	1.4	5.9	0.9	9.0	1.4	13.3	2.1
SE	Västmanlands län	4.5	2.0	0.2	0.1	0.4	0.2	0.3	0.2	0.0	
DE	Stuttgart	3.8	1.1	4.6	1.3	1.7	0.5	1.1	0.3	3.6	1.0
SE	Stockholm	3.0	1.1	1.4	0.5	5.5	2.0	0.5	0.2	6.2	2.3
SE	Jönköpings län	2.3	2.2	0.1	0.1	0.1	0.1	0.0		0.0	
IT	Torino	2.3	1.4	0.4	0.3	1.3	0.8	1.0	0.6	0.0	
NL	Eindhoven	2.2	0.4	7.3	1.3	16.4	2.8	6.6	1.1	0.0	
DE	Frankfurt am Main	1.9	1.3	1.2	0.8	1.0	0.7	2.0	1.4	0.0	
SE	Göteborg	1.4	1.0	0.6	0.4	1.0	0.7	2.3	1.7	2.6	1.8
DE	Nürnberg	1.4	0.7	3.1	1.5	2.1	1.1	2.2	1.1	2.1	1.1
FI	Helsinki	0.6	0.4	2.4	1.5	3.9	2.5	0.2	0.1	5.7	3.6
ES	Barcelona	0.6	0.3	1.6	0.9	0.9	0.5	11.0	5.9	1.3	0.7
DE	Berlin	0.6	0.3	2.5	1.3	2.3	1.2	5.4	2.7	3.3	1.7
SE	Malmö	0.5	0.4	2.2	1.6	2.8	2.0	0.6	0.4	0.9	0.6
DE	Heidelberg	0.5	0.5	2.0	1.8	0.9	0.8	0.3	0.3	2.2	1.9
FR	Rennes	0.4	0.3	3.7	3.0	1.0	0.8	0.0		1.7	1.4
FR	Grenoble	0.4	0.3	2.0	1.7	1.6	1.4	0.5	0.4	1.9	1.7
FI	Tampere	0.1	0.1	3.6	3.5	1.0	1.0	0.0		0.4	0.4

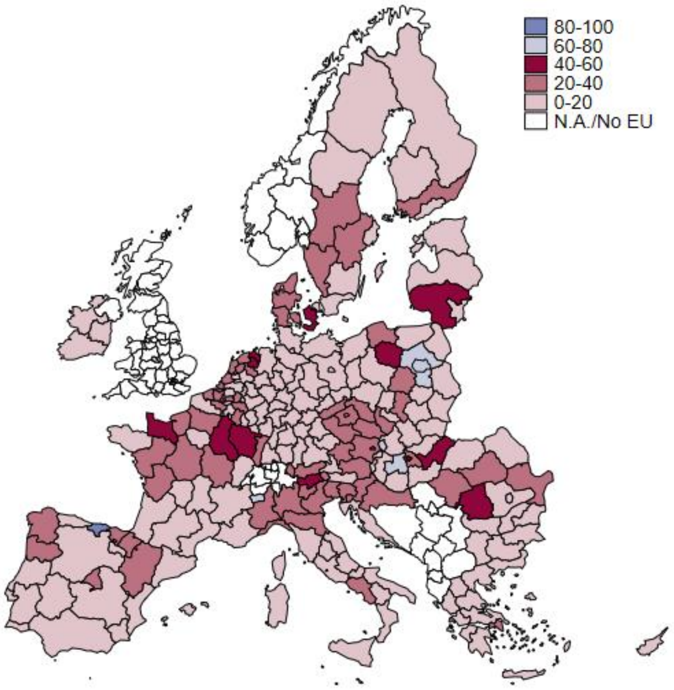
Green patents

Country	Region name	Energy-related climate change mitigation technologies		Environmental management		Transportation-related climate change mitigation technologies		Other climate change mitigation technologies		Other	
		Share	Specialisation degree	Share	Specialisation degree	Share	Specialisation degree	Share	Specialisation degree	Share	Specialisation degree
DE	Stuttgart	4.6	0.7	13.2	2.0	10.8	1.6	2.8	0.4	1.3	0.2
FR	Paris	4.4	0.6	7.1	1.0	16.0	2.3	5.9	0.9	8.9	1.3
FR	Grenoble	3.8	2.3	0.5	0.3	0.9	0.5	1.6	1.0	1.3	0.8
DE	München	3.5	1.0	2.1	0.6	5.9	1.6	4.2	1.2	4.2	1.2
DE	Nürnberg	3.0	1.5	1.0	0.5	1.6	0.8	2.1	1.1	1.0	0.5
DK	Århus	2.9	2.7	0.3	0.3	0.1	0.1	1.0	0.9	0.9	0.9
DE	Frankfurt am Main	2.1	1.3	1.7	1.1	1.1	0.7	1.7	1.1	1.9	1.2
DK	København	1.8	1.4	1.2	0.9	0.5	0.4	1.6	1.2	2.5	2.0
DE	Hamburg	1.7	1.1	0.9	0.6	3.3	2.1	1.0	0.6	2.7	1.7
DE	Ruhrgebiet	1.7	0.9	1.5	0.8	2.0	1.0	2.5	1.2	1.4	0.7
DE	Berlin	1.6	1.0	0.7	0.4	2.8	1.6	2.0	1.2	1.5	0.9
DE	Mannheim-Ludwigshafen	1.5	1.0	1.6	1.0	0.8	0.6	1.6	1.1	1.8	1.2
FI	Helsinki	1.2	0.9	1.3	1.0	0.4	0.3	2.0	1.5	3.6	2.7
FR	Lyon	1.1	1.0	1.2	1.1	0.7	0.7	1.4	1.3	1.8	1.7
IT	Milano	1.0	1.1	1.0	1.1	0.3	0.4	1.3	1.4	0.9	1.0
BE	Bruxelles / Brussel	0.9	0.8	1.3	1.1	0.7	0.5	1.9	1.6	0.9	0.7
DE	Köln	0.8	0.7	1.8	1.8	1.4	1.4	1.0	1.0	0.4	0.4
SE	Stockholm	0.8	0.5	1.9	1.2	2.2	1.4	2.2	1.4	2.2	1.5
NL	Eindhoven	0.7	0.5	0.6	0.4	0.4	0.2	3.3	2.1	0.5	0.3
SE	Göteborg	0.5	0.5	1.6	1.5	2.7	2.4	0.8	0.7	1.8	1.7

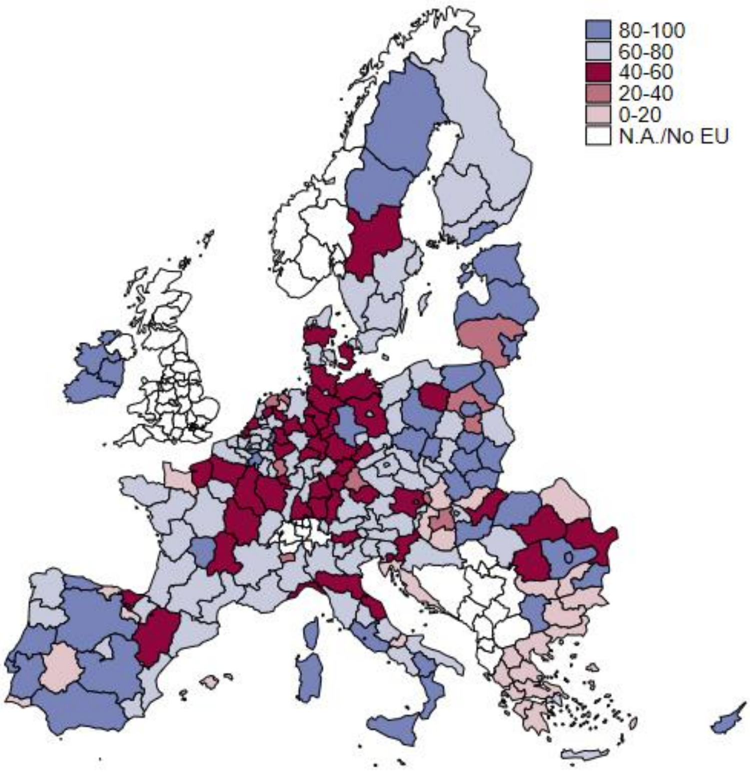
Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding. The tables report the regions with the highest number of digital or green patent applications Shares refer to the total number of patent applications, as a percentage of total EU. A region's specialisation degree in the digital (green) technological area is measured as the ratio of the region's share of digital (green) patents in the specific technological area to the total share of digital (green) patents in the same technological area in the EU (RTA index)

Knowledge sources for green and digital inventions by EU region and sector

Figure B.2: Regional distribution of the share (in percentage) of foreign knowledge sources in digital inventions, 2000-2017

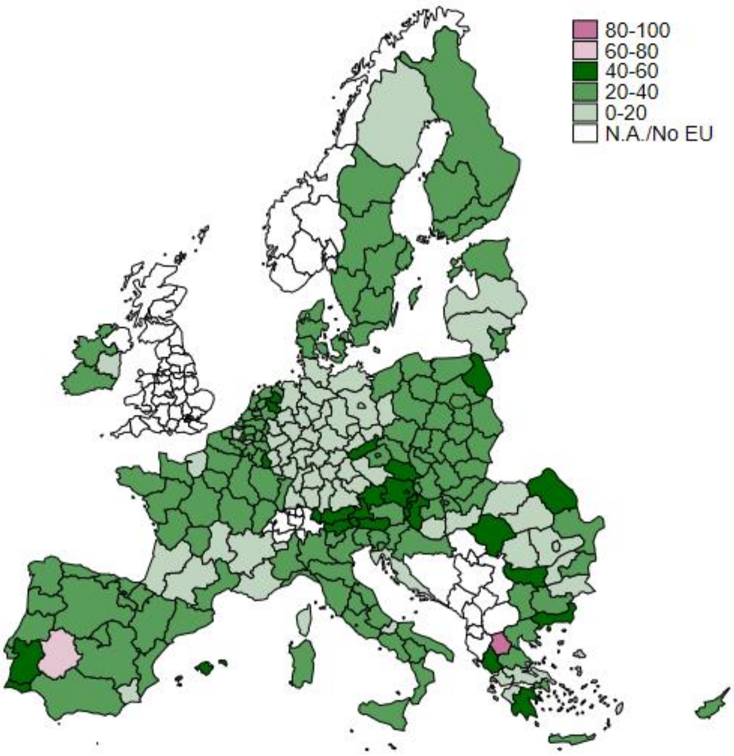


Foreign, EU

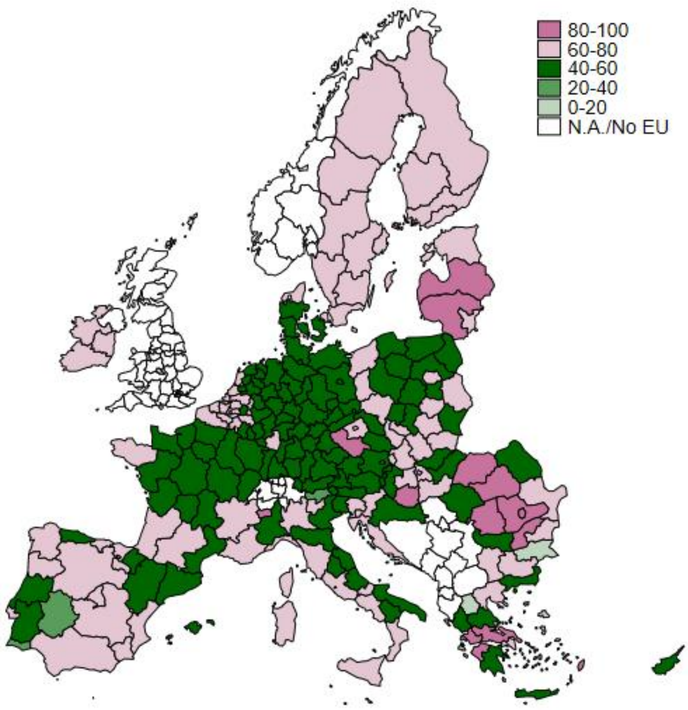


Foreign, extra - EU

Figure B.3: Regional distribution of the share (in percentage) of foreign knowledge sources in green inventions, 2000-2017



Foreign, EU



Foreign, extra-EU

Table B.5: Knowledge sources of digital and green inventions by sourced area and industry, 2000-2017

Industry - NACE code	Industry description	Digital			Green		
		Domestic	Foreign, EU	Foreign, Extra-EU	Domestic	Foreign, EU	Foreign, Extra-EU
10 - 12	Manufacture of food, beverages and tobacco products	31.2	26.2	42.6	15.6	17.5	66.9
13 - 15	Manufacture of textiles, wearing apparel and leather products	24.0	18.7	57.3	25.7	22.0	52.2
16 - 17, 31	Manufacture of wood and paper products and furniture	26.8	23.5	49.7	23.3	26.0	50.7
19 - 20	Manufacture of coke, refined petroleum and chemical products	24.0	17.9	58.0	24.9	18.9	56.3
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	30.9	16.5	52.7	10.6	14.2	75.2
22 - 23	Manufacture of rubber, plastics, and other non-metallic products	28.0	21.6	50.4	26.9	24.5	48.6
24 - 25	Manufacture of basic metals and fabricated metal products,	24.3	23.7	52.0	26.7	18.9	54.4
26	Manufacture of computer, electronic and optical products	21.1	14.5	64.4	25.0	18.3	56.6
27	Manufacture of electrical equipment	20.7	19.3	59.9	25.4	20.2	54.5
28	Manufacture of machinery and equipment n.e.c.	24.0	22.2	53.7	29.3	24.6	46.2
29	Manufacture of motor vehicles, trailers and semi-trailers	24.4	24.6	51.0	32.2	24.0	43.8
30	Manufacture of other transport equipment	25.7	18.4	55.9	26.5	22.0	51.5
18,32, 33	Other manufacturing	24.2	14.8	61.0	26.1	22.2	51.7
35	Electricity, gas, steam and air conditioning supply	19.5	23.3	57.2	26.4	23.0	50.6
36	Water collection, treatment and supply	25.2	20.6	54.1	25.0	23.1	51.9
37 - 38	Sewerage, waste collection, treatment and remediation activities	24.0	25.6	50.5	24.8	28.7	46.4
41 - 43	Construction	20.8	14.9	64.3	22.6	16.0	61.3
45 - 47	Wholesale and retail trade	8.4	14.1	77.5	21.6	15.9	62.5
49 - 53	Transportation and storage	25.5	19.7	54.7	18.4	25.3	56.3
55 - 56	Accommodation and food service activities	18.7	16.0	65.3	24.3	24.6	51.1
58-63	Information and communication	17.8	13.2	68.9	13.5	22.0	64.6
64 - 68	Financial, insurance and real estate activities	7.9	14.1	78.0	21.5	14.3	64.3
69 - 75	Professional, scientific and technical activities	14.9	15.0	70.1	21.3	19.3	59.4
77 - 82	Administrative and support service activities	13.0	15.1	71.9	20.7	24.0	55.3
84	Public administration and defence; compulsory social security, education	12.3	13.5	74.2	14.9	12.7	72.3
85	Education	13.7	9.1	77.2	21.6	20.1	58.3

Industry - NACE code	Industry description	Digital			Green		
		Domestic	Foreign, EU	Foreign, Extra-EU	Domestic	Foreign, EU	Foreign, Extra-EU
86	Human health activities	16.2	12.2	71.5	15.2	18.3	66.5
87 - 98	Other services	9.1	16.6	74.3	22.0	22.4	55.6

Source: Authors' calculation based on PatStat. Note: Percentages may not total 100 due to rounding.

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