Green innovations

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1 Introduction

Mitigation of climate change and Finland's climate neutrality target require a quick transformation from using fossil fuels to renewable energy sources. In the new geopolitical circumstances, this transition is even more urgent. Energy transition requires development and adoption of new technologies, e.g., in reducing emissions, utilizing renewable energy, balancing electricity systems, and integrating energy markets.

The main economic instrument in climate policy is putting a price on greenhouse gas emissions, either by emissions trading or by tax instruments. An emission tax or emission allowance price internalizes the negative externality caused by greenhouse gas emissions and provides incentives for polluting firms to reduce their emissions and develop clean technologies. In addition to carbon pricing, we need other policies when promoting energy transition. When firms develop new technologies, they create new knowledge. The new knowledge spills over to other firms that have not invested in technology development. Hence, knowledge spillovers reduce firms' incentives to technology development, unless public sector support research and development (R&D). E.g., Acemoglu et al. (2016) show that optimal climate policy includes both carbon pricing and clean technology R&D support. Optimal technology R&D support is high at the beginning of the energy transition and declines over time, whereas optimal carbon price increases during the transition.

There are several phases in the process of developing new technologies, all of which have positive externalities in the form of knowledge spillovers, such as research and innovation, the commercialization of new technologies or the market penetration. Moreover, getting funding can be very challenging for companies developing new technology, especially if they are new and small (Popp et al. 2020). Different policy tools are needed for different phases (see, e.g., Bloom et al. 2019, Takalo and Toivanen 2018). It is, thus, unclear what are the best instruments and how should they be targeted, when supporting green technology R&D and market penetration of new energy technologies.

During the last decade, R&D expenditure as a share of GDP has fallen in Finland: in 2009 the share was 3.7 percent and ten years later, in 2019, it was 2.8 percent (Ali-Yrkkö et al. 2021). Einiö et al. (2022) assessed the growth and welfare implications of the Finnish innovation policies using macroeconomic model. R&D subsidies increase welfare, but policies should target more to companies with the highest innovation capacity. The analysis was conducted at the macroeconomic level and impacts of direct support on green technologies was not evaluated.

Despite the declining R&D expenditures (as the share of GDP), the number of green patent applications per capita in Finland has been one of the largest in OECD countries (OECD 2021a). In developing clean energy technologies, different countries have specialized in different technology fields. In particular, the share of patents related to wastewater treatment, waste management, and bioenergy is relatively large in Finland. This is partly due to the historical reasons (Berg et al. 2020). For the same reasons, Denmark is strong in wind energy and Germany in solar energy patenting.

Somewhat unexpectedly, after rapid growth, patenting in environment-related technologies has declined in the last ten years in Finland, but also to some extent in other OECD countries.[1] Reasons for this development are still without answers. According to Popp et al. (2020) this development, especially in energy-related technologies, may be driven by changes in electricity markets towards more decentralized and weather-dependent energy production. New energy technologies require different smart solutions, and energy technologies have become integrated with information technologies in recent years (Popp et al. 2020, Kangas et al. 2021). At the same time, companies developing new energy technologies are smaller than before, which can have a negative impact on, among other things, their financial costs.

Takalo and Toivanen (2018) have recently reviewed the literature on optimal R&D policies and assessed the policy recommendations based on the literature for promoting technology innovation in a small open economy, such as Finland. Their statistical analysis, however, is necessary to complete with a more detailed examination of policies focusing particularly on promoting green technologies.

To give a comprehensive view on the used policy measures, we first collect all current policies trying to promote green technology innovation in Finland. Second, we make a descriptive statistical analysis of clean technology innovation using patent data. Analyzing the real causal links between different R&D policies and their subsequent outcomes is very challenging and is outside the scope of this study. However, we analyze in which technology fields Finland has most patents and compare Finnish patenting with peer countries. Not all patents are equivalent. Therefore, we weight patents using indicators for patent values (such as patent citations and family size). In the patent analysis, we also assess those technology fields where the patenting of clean technologies has declined in recent years.

[1] OECD Statistics: https://stats.oecd.org/.

2 Methods and data

We have collected data on R&D policies used in Finland from different administrative sources. In patent analysis, we have utilized European Patent Office's Patstat database (Spring 2022 edition), which is a bibliographical database related to more than 100 million patent documents from leading developed and developing countries. It contains patent information regarding, e.g., applications, publications, applicants and inventors, citations, patent families, technological classifications, and legal status. At some points, we also use OECD statistics on patent data, because Patstat data lacks some information related to some patent offices. For example, the inventor's country is largely missing from the information on applications submitted to Japanese or Chinese patent offices (see de Rassenfosse and Seliger 2021).

3 Policies to promote green technology innovation in Finland

Ways to promote innovation, innovation policies in general and in Finland, have been introduced thoroughly, e.g., by Takalo and Toivanen (2018) or Ali-Yrkkö et al. (2021). Here we only shortly give an overview of general trends in R&D expenditures and policies in Finland. However, after that we take a more focused view on policies promoting green innovation.

Environmental pollution problems and attempts to solve them are associated with several market failures. The main market failure is the pollution externality, i.e. the damage caused by pollution, which is not taken into account otherwise in the economy by markets. This can be corrected, for instance, by pollution taxes. Other market failures are associated with the technology development when solving the pollution problems. The stages of technology innovation process can be separated into basic research, pre-commercial development, commercialization, and market entry and diffusion. There are two specific market failures associated with the different stages of the innovation process. Firstly, innovation produce new knowledge, which also spills over to firms other than those developing new technologies. Knowledge spillovers are positive externalities induced by innovative firms. Thus, technology developers cannot get all the benefits of the innovation process for themselves. This reduces developers' incentives to invest in R&D or to adopt new technologies in production processes. Secondly, innovation requires funding, but the success of innovation processes involves a lot of uncertainty. Thus, getting funding for innovation is challenging, especially for small and newly established firms. Due to knowledge spillovers and financial constraints, firms do not carry out as much R&D as would be socially optimal. Governments should therefore encourage companies to engage in innovation using different innovation policies. (Bloom et al. 2019.)

Government can support basic research by university funding and research grants. Other stages of innovation process can be supported, e.g., by subsidized loans, tax credits, direct subsidies, intellectual property policies, or pro-competitive policies. For more comprehensive discussion about policies to promote innovation, see e.g., Bloom et al (2019), or in the Finnish context, Takalo and Toivanen (2018).

3.1 R&D in Finland

R&D expenditure as a share of GDP has been high in Finland when compared to other OECD countries. However, in recent years R&D expenditure share has fallen. This can be seen from Figure 1, which shows the shares of R&D expenditures in Finland, Sweden, Denmark, Germany and on average in OECD countries between 1990-2019. The share has been increasing in most countries since 1990. In Finland the share was highest in 2019, when it was 3.7 percent. However, after that the share has fallen rapidly and in 2019 the share was 2.8 percent. Also, in Sweden the R&D expenditure share peaked around millennium, but its has been more stable than in Finland since then. Finland aims to increase R&D expenditure to four percent of gross domestic product by 2030.

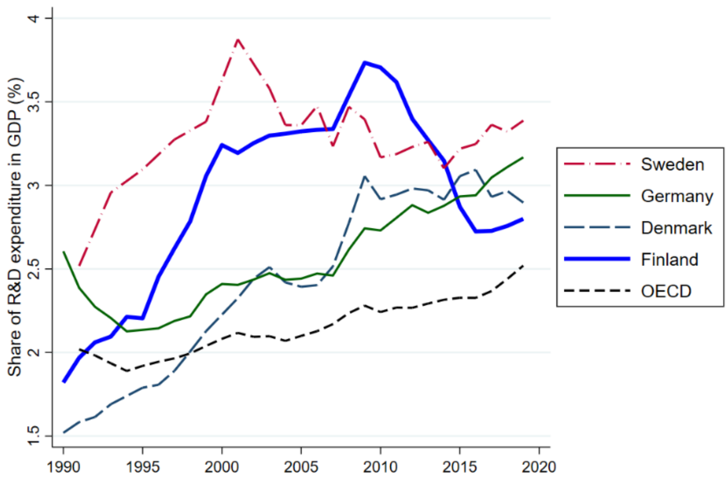

Figure 1. Share of R&D expenditure in GDP (%) in Finland, Sweden, Germany, Denmark, and OECD countries between 1990-2019. Source: OECD.

The decrease in R&D expenditure has not only occurred as a share of GDP. There has also been a decrease in the total amount of R&D expenditures since 2010. Figure 2 shows R&D expenditures in million euros in the private, public and university sectors in the years 2011-2022. The decrease in R&D expenditures after 2010 is mainly related to the development of private sector companies' R&D expenditures. This, in turn, can be explained by the decrease in Nokia's influence (Ali-Yrkkö et al. 2021). Total R&D expenditures of university and public sectors have remained stable or increased moderately. In 2021, total R&D expenditures accounted 7491 million euros. Private sector R&D expenditures covered 69 percent of the total, while the share of the university sector was 23 percent and public sector 8 percent of total Finnish R&D expenditures. Three largest industries in terms of R&D expenditures in 2021 were the electronics industry (29%), the software industry (12%) and the machinery (12%). These accounted more than half of all private sector R&D expenditures (53 %). Also, most R&D are conducted in large companies.

In 2021, most of the R&D expenditures were funded by Finnish and foreign firms with 57 percent and 10 percent shares, respectively, of the total funding (see Table 1). Finnish public funding accounted 29 percent, and EU and other foreign funding 5 percent of the total R&D funding.

Private sector receives most of the public R&D funding through Business Finland. The industries receiving the most R&D grants and loans from Business Finland in 2021 were the software industry (25%), the electronics industry (11%), scientific research and development (10%), and the machinery (9%).

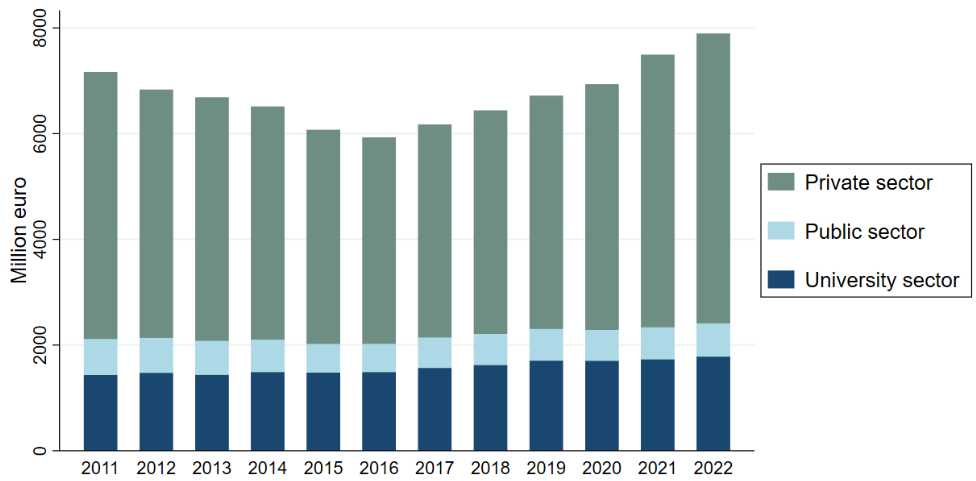

Figure 2. Expenditure on R&D (million euros) by private, public and university sectors in Finland between 2011-2022. Source: Statistics Finland.

Table 1. Funding of Finnish R&D by research sector and funding source in 2021. Source: Statistics Finland.

Funding source	Research sector, M€			Total	
	Private sector	Public sector	University sector	M€	%
Finnish firms	4158	33	57	**4248**	**57 %**
Foreign firms	657	23	37	**717**	**10 %**
Budget funding	-	261	736	**997**	**13 %**
Academy of Finland	-	42	354	**396**	**5 %**
Business Finland	242	25	61	**328**	**4 %**
Other public funding and funds	32	149	291	**472**	**6 %**
- Ministry of Economic Affairs and Employment	-	10	41	**50**	
- Ministry of the Environment	-	9	5	**14**	
- Ministry of Agriculture and Forestry	-	16	7	**23**	
EU funding	48	63	170	**281**	**4 %**
Other foreign funding	16	11	27	**53**	**1 %**
Total	**5153**	**607**	**1731**	**7491**	
%	**69 %**	**8 %**	**23 %**		

Total Finnish public R&D funding in 2021 was 2236 million euros (see Figure 3). Of this, 32 percent went to universities, 23 percent of the public R&D funding was allocated to Business Finland and 22 percent was distributed through the Academy of Finland. Government research institutes received 10 percent of the total public R&D funding.

There have been several structural reforms in the Finnish R&D infrastructure after 2010, which are partly reflected in the public R&D funding. In 2010 there was a university reform, followed by a reform of universities of applied sciences in 2015. The R&D funding received by university sector has increased steadily. In 2013 there was a reform of government research institutes, in which part of the funding allocated directly to research institutes was transferred to be allocated through other funding instruments, such as the newly established Strategic Research Council (Academy of Finland). In 2018 Business Finland was founded on the grounds of Tekes and Finpro. R&D funding of Tekes / Business Finland decreased after 2010, but has since then started to increase. However, Business Finland’s funding amounts for the years 2000-2022 are exceptional, as they also include additional R&D funding granted due to the covid crisis.

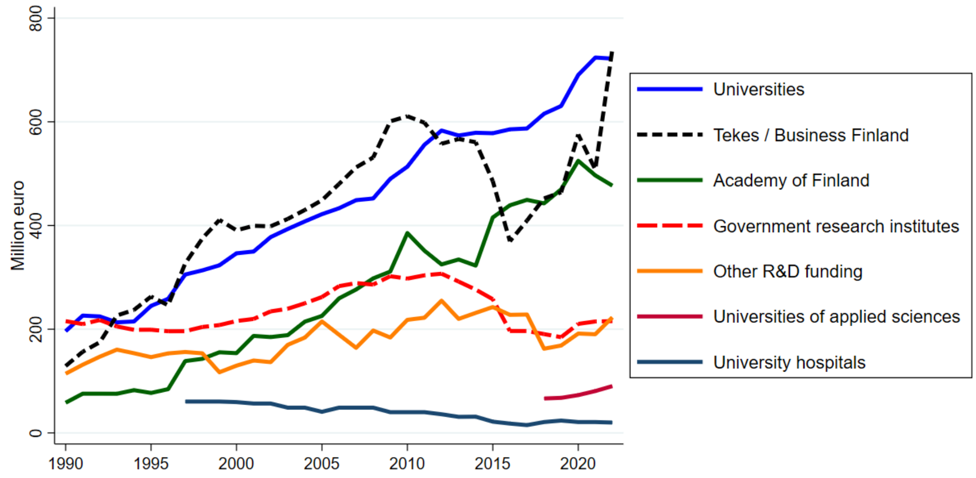

Figure 3. Government R&D funding by organization in Finland between 1990-2022 (million euros, current prices). Source: Statistics Finland.

Finland has mostly used direct subsidies to promote innovation, either by direct funding or loans granted by Business Finland. There was an experiment for R&D tax incentive in 2013-2014, but it lasted for a very short time. However, at the beginning of 2023, a new R&D tax incentive was introduced, according to which companies can deduct part of the R&D expenses in their taxation.

3.2 Policies to promote green R&D

What kind of innovation policies should be implemented in a small open economy like Finland? Or what kind of innovation policies should be implemented in a small open economy trying to be climate neutral by 2035? Takalo and Toivanen (2018) discuss about the first question. Should governments actively try to steer research, development and innovation in the directions they want. Or instead of such a top-down or mission-oriented approach, should governments approach innovation policy from the bottom up and just create the right institutional environment by only solving existing market failures, and let the private sector decide the direction of research, development and innovation. Takalo and Toivanen recommend that the Finnish innovation policy should more explicitly be based on a bottom-up approach. This would allow the resources to agglomerate into most successful sectors and regions.

However, climate change brings new perspectives to the choice of innovation policy. We have a very limited time to make a radical technological change from using fossil fuels to renewable energy sources. This creates a need for the government to direct research and development away from technologies that utilize fossil energy.

In addition to direct R&D subsidies, energy markets and environmental policies also affect the innovation of energy technologies. For example, Popp (2019) provides a good literature review on the topic. Both environmental taxes and EU emissions trading system have had a positive effect on patenting (Franco and Marin 2017, Calel ja Dechezleprêtre 2016), as have energy prices (e.g., Popp 2002). Targeted renewable energy price schemes like feed-in-tariffs and investment incentives are also enhancing innovation. Targeted feed-in-tariffs have had a positive effect on patenting especially of those technologies that are still in early developing phase (Johnstone et al. 2010, Böhringer et al. 2017). Similarly, public R&D policies are not necessarily important for more mature technologies, but public R&D is important for promoting the development of new technologies (Costantini et al. 2015). In addition, balanced and comprehensive use of demand-pull and technology-push policy instruments both within and between countries affects positively innovation (Costantini et al. 2017). It is also an interesting observation that in a survey for Finnish companies, the companies think that environmental regulation has an impact on their R&D activities (Ali-Yrkkö et al. 2021).

3.2.1 Environmental policy instruments

In climate change, the pollution externality is corrected mainly by two key policy tools. Greenhouse gases are priced either by carbon taxes or by emission allowance price induced by emissions trading. According to estimates of High-Level Commission on Carbon Prices, the 2 degrees goal of the Paris Agreement would be achievable if the global price of carbon dioxide emissions would be at least 50–100 USD/tCO2 by 2030 (World Bank 2017). If we want to achieve the goal of a temperature rise of less than 1.5 degrees, carbon neutrality on a global level should be achieved by 2050. This, in turn, would require, according to estimates, carbon prices of around 120 euros/tCO2 in 2030, if the price mechanism for carbon dioxide emissions were a key control instrument (OECD 2021b). Carbon pricing induces firms to reduce GHG emissions and invest in clean technologies.

Finland has both carbon pricing policies in use. In Finland, energy taxes are paid for transport and heating fuels. Energy taxes include three components: 1) energy content tax, 2) carbon dioxide tax, and 3) strategic stockpile fee. The carbon dioxide tax is based on emission values of 77 EUR/tCO2 for transport fuels, and 53 EUR/tCO2 for heating fuels. However, when other components of the energy tax are also included, the effective carbon prices are significantly higher. For example, effective carbon prices for transport fuels (petroleum and diesel oil) are over 300 EUR/tCO2.

Electricity production and energy-intensive industries are part of the EU emissions trading system, which has been working since 2005. After a long period of low prices, the price of the EU emission allowances (EUA) has increased since 2017. In 2022, the EUA price has been on average around 80 EUR/tCO2.

In addition to correcting pollution externality, carbon pricing also incentivizes polluters and technology developers to innovate new and more efficient or fossil-free technologies in manufacturing and electricity generation. However, carbon pricing must be supplemented with other policy instruments to fully correct the knowledge externality.

To support the technological change from the use of fossil fuels to renewable energy sources, Finland, like many other countries, introduced a feed-in tariff system supporting renewable energy in 2011. Tariff system included onshore wind, biogas and wood fuel power plants and electricity produced by wood chips, but the most subsidies were paid to onshore wind power. The tariff levels proved to be too generous, and after the introduction of the tariff system, a large number of wind power projects began to be planned and built in Finland. The feed-in-tariff system has already been phased out. Feed-in-tariff system was followed by one round of tenders for feed-in-premium in 2019. All the winning projects in the tender were wind power projects, and the winning bids for the feed-in-premium remained at a very low level. Currently, onshore wind power is being built without support in Finland.

3.2.2 Green R&D funding

Most of the public funding granted for the promotion of green R&D as well as the green transition is channeled through the administration of the Ministry of Economic Affairs and Employment. In addition, at least the Ministry of the Environment and the Ministry of Agriculture and Forestry finance some green R&D activities.

Ministry of Economic Affairs and Employment

Table 2 shows the actors financing the green transition under the Ministry of Economic Affairs and Employment. The table taken directly is from TEM (2022). The main actor that provides funding for green R&D is Business Finland. Other main instruments granting funding for technology development and pilot projects are Energy Aid Scheme (Energy department), and the Finnish Climate Fund. Other instruments financing green transition provide either regional aid (Regions and growth services department), financing for the start-up, growth and internationalization of business operations (Finnvera), or investments in private equity funds and directly in growth companies (Tesi). These are not directly funding R&D activities.

Table 2. Actors under the Ministry of Economic Affairs and Employment in financing the green transition. Source: TEM (2022).

Actor	Task	Method of operation	Estimated funding volume, annually	Funding supporting the green transition, annually (%)
Regions and growth services department (Ministry of Economic Affairs and Employment)	Sustainable and vibrant regions	Regional subsidies, e.g. research and innovations, infrastructures, new technology, business subsidies	380 M€ (2021)	70 %
Business Finland	Research, development and innovation funding	Grants, loans, investments in capital funds	720 M€ (2021)	50 % (2020)
Energy Aid Scheme, Energy department (Ministry of Economic Affairs and Employment)	Supporting investment and pilot projects of energy solutions	Energy and investment subsidies	190 M€ (2021)	100 %
Finnvera	Development of regional business and export (Export Credit Agency)	Loans and guarantees	5000 M€	Will be detailed, 67 % of the portfolio always falls within the scope of the green taxonomy
Climate Fund	Mitigating climate change and promoting digitalization	Capital loans and other instruments	80 M€, projects of significant size (1-20 M€)	100 %
Finnish Industry Investment Ltd (Tesi)	Development of capital investment markets, promotion of entrepreneurship and the economy	Capital investment (direct investments, fund investments)	Investment commitments about 150 M€ annually, whole portfolio 2200 M€	Not known exactly

Business Finland provides loans and grants for research, development and innovation activities for firms and research units. In addition to innovation funding, Business Finland offers internationalization services and promotes tourism and investments in Finland. In 2021, Business Finland granted funding for firms and research over 700 million euros, of which almost 350 million euros went to R&D activities (not including loans due to the covid). Altogether Business Finland gave almost 4000 positive funding decisions in 2021.[2]

Business Finland (and Tekes before 2018) has been the largest public funding source for energy R&D in Finland. According to Hjelt et al. (2020), Business Finland and Tekes accounted for about 83 percent of all

[2] See Business Finland, Results and Impact 2021 (https://www.businessfinland.fi/en/for-finnish-customers/about-us/results-and-impact).

public funding for energy R&D activities in Finland in 2006-2019. Energy-related funding has accounted approximately one third of total innovation funding granted by Business Finland (or Tekes) in 2006–2019.

Energy Aid Scheme is administrated by Ministry of Economic Affairs and Employment together with Business Finland. Energy aid can be granted for investments that support the production or use of renewable energy, energy saving, the efficiency of energy production or use, or the related introduction of new technology. However, for renewable energy projects, project must promote new technology and its commercialization or commercial exploitation, or be an investment in a new plant, or increase the production volume significantly. Energy aid can also be granted for technology demonstration projects related to the production or use of transport biofuels. In 2021, the granted energy aid was 158 million euros.

In 2021, the first round of energy investment subsidies according to Finland's Recovery and Resilience Plan also opened for applications. These investment subsidies are part of EU funding from the Recovery and Resilience Facility (RRF). Finland's share of funding from the EU's Recovery and Resilience Facility is 1.8 billion euros (at current prices). From that amount 695 million euros is allocated to projects under Green transition program. Green transition projects include, for example, clean energy production, industrial circular economy solutions and low-emission innovations, adoption of new technologies, services and practices in the construction sector, support for the public charging infrastructure for electric vehicles, or nature-based solutions, such as gypsum treatment of arable land to reduce the nutrient load in the Baltic Sea.[3]

Finnish Climate Fund started its operations in 2021. It is a state-owned special-assignment company. Climate fund uses capital loans and other instruments to fund projects aimed at combating climate change, boosting low-carbon industry and promoting digitalization. In 2021, Climate Fund made seven investment decisions with a total funding volume of 45.5 million euros. Climate Fund does not award direct grants or subsidies. The annual financing volume is approximately 130 million euros.[4]

Ministry of the Environment

The main objective for R&D under the administration of the Ministry of Environment is to ensure an adequate knowledge base for law preparation and decision-making. The single most important R&D partner of the ministry is the Finnish Environment Institute, which conducts environmental-related research on a wide scale. Ministry awards Special grants, e.g., to projects for an experimental, introductory, research or

[3] See: https://vm.fi/en/green-transition.
[4] See: https://www.ilmastorahasto.fi/en/.

development project or some other project with a defined purpose. The Ministry of the Environment is responsible for coordinating work of The European Regional Development Fund (ERDF), and one of the national priorities for it in 2021–2027: the green transition. The Ministry of the Environment is responsible for three national themes: energy efficiency and reducing greenhouse gas emissions (11.5 million euros), climate change adaptation and mitigation measures (4 million euros), and a carbon-neutral circular economy society (11.5 million euros).

Ministry of Agriculture and Forestry

The Ministry of Agriculture and Forestry steers two research institutes: the Natural Resources Institute Finland (Luke) and the National Land Survey of Finland. The Finnish Food Authority also participates in research activities. In addition, the Ministry also steers the Finnish Environment Institute (SYKE) In activities concerning the management and utilization of water resources. Ministry funds directly research and development projects annually. In addition, the Development Fund for Agriculture and Forestry (Makera) grants R&D funding for research activities that benefit the agri-food sector across a broad front. The main focus is on research concerning the sustainable development of the profitability and competitiveness of livelihoods.

4 Patenting

A patent offers its holder a temporary exclusive right to use the patented innovation. This exclusivity generates rent for the patent holder, which then shows in an increase in the firm's market value. There is an observed association between patents and the market value of companies (e.g., Hall et al. 2005). Innovations create economic growth by improving productivity. However, the impact of innovations on employment can be twofold. On the other hand, innovation can create jobs, but at the same time new innovations can displace old jobs. At least, according to Van Roy et al. (2018), it seems that the job-creating effect is greater, especially in high-tech sectors, while in lower-tech sectors and the service sector, innovations have no impact on jobs.

4.1 Global patenting in environmental-related technologies

Patents are a measure of innovation outputs and patent data have been widely used in studying innovation activity. However, there are limitations in using patent data. Not all inventions are patented and the propensity to patent differs across time, technology fields and countries. The relevance of patent data as innovation indicator therefore also varies. In addition, the value of patents varies between patents. There are many indicators for patent value: such as, patent scope, patent family size, grant lag, backward citations, forward citations, claims, breakthrough inventions, generality, originality, radicalness, patent renewal (e.g., Squicciarini et al. 2013). When making comparisons between Finland and other inventor countries, we consider two patent value indicators in addition to the count of inventions: the size of the patent family and forward citations.

New inventions are built on the knowledge of previous inventions. Thus, patent citations represent the importance or value of previous inventions. At the same time citations indicate the development of knowledge transferring between old and new inventions. Citation counts have been widely used in studying patent values and knowledge spillovers between patents (Jaffe and de Rassenfosse 2016). Patent citations have also positive effect on firms' market values (Hall et al. 2005).

One invention may have many patent applications in different countries and patent offices. Applications related to one invention is called patent family. Family size is one metric of the value of the invention. It also signals the market size of a new technology and international diffusion of technologies. Firms want to protect their innovative products or technologies by patenting when entering into new markets (e.g. Eaton and Kortum 1999, Dechezlepretre et al. 2017, Harhoff et al. 2003). Moreover, if a patent has applications in all three major patent offices, i.e., in the European Patent Office, the United States Patent and Trademark Office and the Japan Patent Office, it is called a triadic patent.

Solid lines in Figure 4 show the development of clean technology patenting for inventions with a family size of one or more (all inventions), two or more, and triadic patents. The left panel shows global patenting, and the right panel shows inventions having a Finnish inventor. The dashed lines below the solid lines, on the other hand, show the development of the inventions whose applications have been granted. When comparing all inventions and inventions with at least two applications (family 2), the difference grows heavily during the years for global patents. For Finnish patents the divergence is not that drastic. Also, the share of granted patents is low when looking all global inventions. When looking at inventions with a patent family size greater than one, the proportion of granted patents is much higher. Again, for Finnish inventions, the shares of granted patents do not differ that much when comparing all inventions and inventions with higher family sizes.

If inventors in one country are prone to patent their innovations more eagerly especially in their own country, this can cause bias when comparing patenting in different countries. On the other hand, we want to survey clean technology innovations as widely as possible. For this reason, to avoid the home bias, we focus on inventions that have patent family size of two or larger. Hence, we do not consider domestic patents that have applied for patent protection in only one country, which is most likely the "home country" of the invention. This way we can also exclude singleton patents of very low value. Moreover, for inventions with family size two or more, the share of granted patents is relatively high. Only for the last few years the share of non-granted patents increases. This is probably because there is a lag for patents to be accepted. To avoid the time bias due to the lag of acceptance, we analyze all inventions, and do not focus only granted patents.

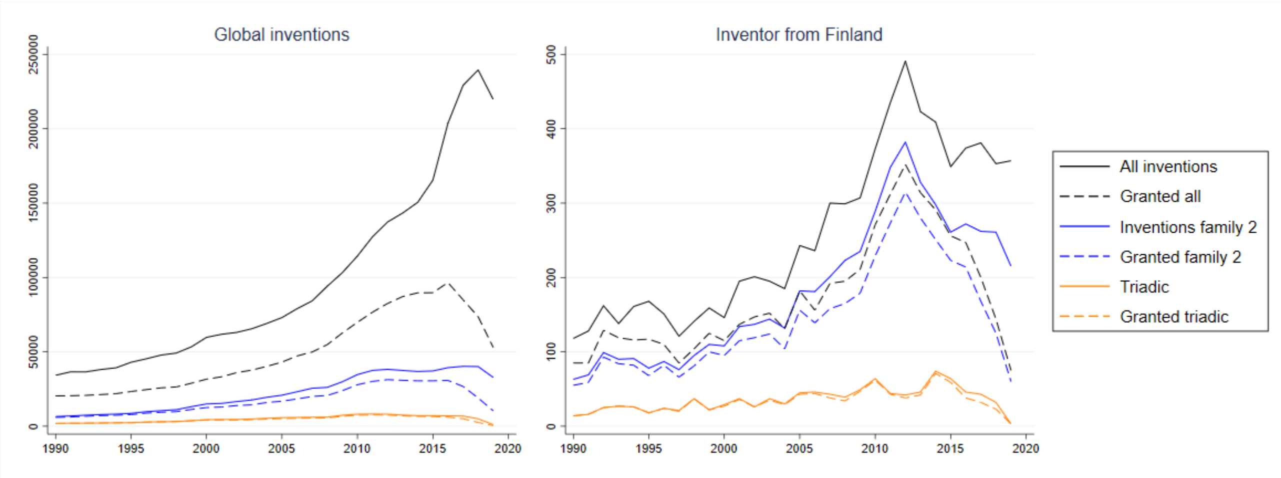

Figure 4. Environmental-related technology inventions globally (left) and for inventions having Finnish inventor (right): i) all inventions, ii) inventions with family size two or more, and iii) triadic patents. Solid lines present inventions, and dashed lines inventions having granted patent. Source: Patstat.

Table 3 shows the total number of environmental-related technology inventions in different technology fields in Finland, OECD countries and worldwide between 2000-2019. Figure 5 shows the evolvement of clean technology inventions between 1990-2019.[5] Clean technology inventions are divided into different technology fields according to the classification used by the OECD. More granular classification is presented in Appendix. In total, between 2000 and 2019, more than half million clean technology inventions have been patented worldwide and four and half thousand in Finland (inventions with patent family size two or more). If counting all inventions, there are almost three million clean technology inventions patented in total between 2000 and 2019 and almost eight thousand in Finland.

Globally, largest number of inventions are on environmental management, which includes, e.g., air and water pollution abatement and waste management technologies. Since 2000, patenting in environmental-related technologies has increased rapidly, and especially the number of climate change mitigation technology (CCMT) inventions has increased significantly. In climate change mitigation technologies largest number of

[5] The numbers in Table 3 and Figure 3 do not match. Unlike Table 3, Figure 5 shows the fractional values of different technology fields. If the invention belongs to, for example, two different technology fields, its value is 0.5 in each of these technologies in Figure 5. In Table 3, the invention is calculated with the value 1 in both technology fields.

inventions are in technologies related to i) energy generation, transmission or distribution, ii) production or processing of goods, and iii) transportation. In Finland, the share of inventions in climate change mitigation technologies related to information and communication technologies is also large. On the other hand, in climate change mitigation technologies related to energy or transportation, patenting activity is lower in Finland than in OECD countries on average or globally.

Largest inventor countries in clean technology patents are Japan, USA, Germany, Korea and China. Together, inventors from these five countries are involved in almost 75 percent of clean technology inventions between 2000-2019, as shown in Figure 6.

Table 3. Environmental-related technology inventions in 2000-2019 by OECD classification (patent family size two or more). CCMT is an abbreviation for climate change mitigation technologies. Source: Patstat.

	Inventions in Patstat (2000-2019)		
Technology field	**Finland**	**OECD**	**Total**
1. Environmental management	1 795	115 417	164 345
2. CCMT: Energy generation, transmission or distribution	1 028	144 183	204 926
3. CCMT: Capture, storage, sequestration, or disposal of GHGs	24	4 887	6 100
4. CCMT: Transportation	478	85 916	120 475
5. CCMT: Buildings	308	34 076	50 776
6. CCMT: Wastewater treatment or waste management	283	13 973	19 492
7. CCMT: Production or processing of goods	940	73 784	105 062
8. CCMT: Information and communication technologies (ICT)	798	25 097	37 612
9. Climate change adaptation technologies	201	17 638	24 475
10. Sustainable ocean economy	202	9 285	12 947
Total (patent family size two or greater)	**4 593**	**410 446**	**583 793**

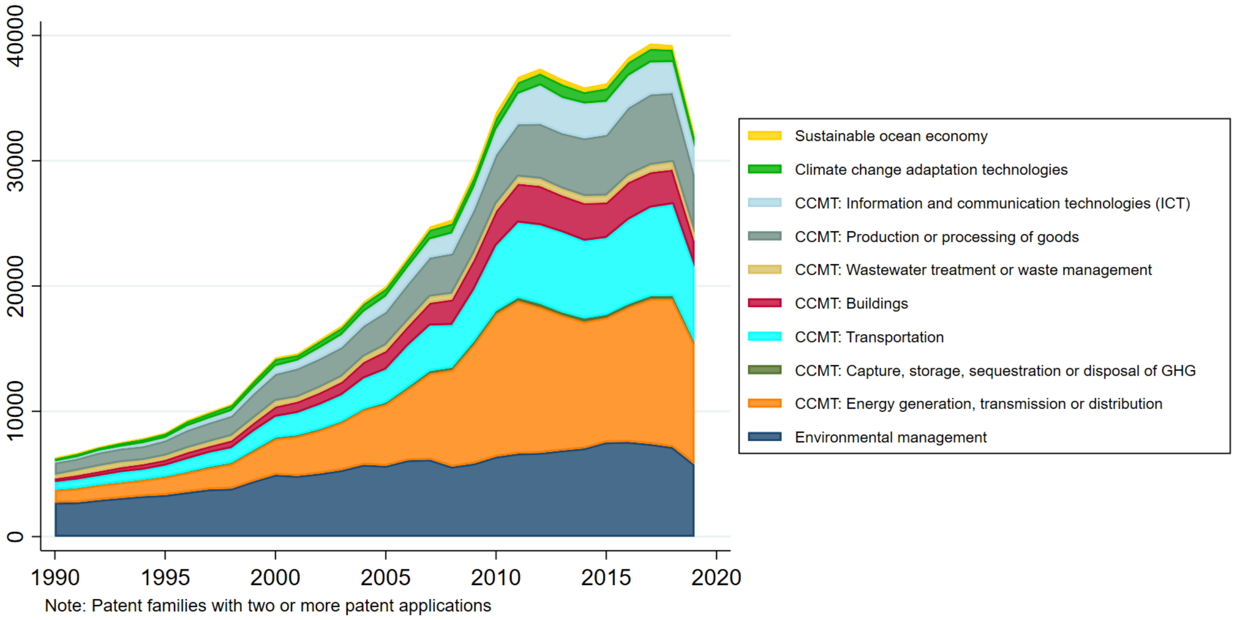

Figure 5. Evolvement of global environmental-related technology inventions in different technology fields between 1990-2019 (patent family size two or more). Fractional values of different technology fields. Source: Patstat.

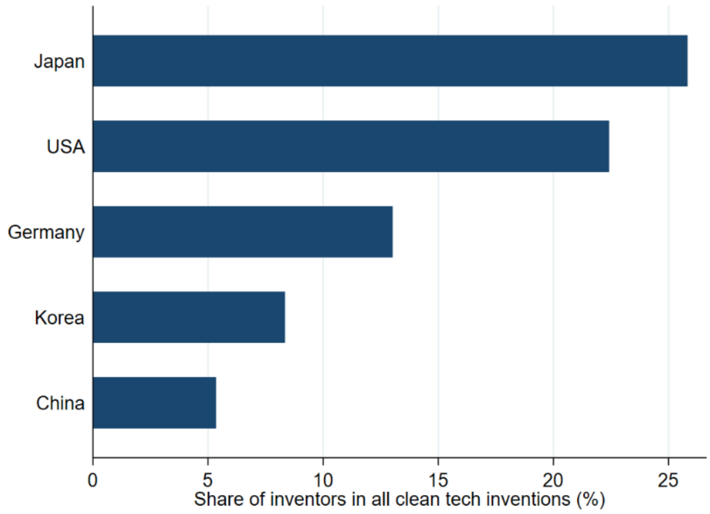

Figure 6. Main five inventor countries in environmental-related technologies between 2000-2019 (patent family size two or more). Source: OECD statistics.

Japan, Korea, and Germany are large inventor countries also when counting inventions in relation to population. Figure 7 presents average annual inventions per million population in total patenting (x-axis) and patenting in environmental-related technologies (y-axis). Figure 7 includes 30 largest inventor countries of clean technology inventions and all EU and OECD countries. Red lines show the average values of OECD countries and dashed line is the simple linear fit on the data. In addition to Japan (JPN), Korea (KOR) and

Germany (DEU), the Nordic countries, Denmark (DNK), Finland (FIN) and Sweden (SWE) have produced a lot of patents, but also in the fields of clean technology. Especially in Denmark, the share of environmental-related technologies is relatively large, when compared to total patenting. Finland and Sweden are close to each other (as well as Austria, AUS). However, there are slightly more clean technology inventions per capita in Finland than in Sweden. From the big inventor countries, the United States (USA) is bit higher than OECD average in both dimensions of Figure 7, but due to the large population, China (CHN) is lower than OECD averages. Also, Norway (NOR) is at the lower level than OECD averages in total patenting and clean technology patenting, when counting inventions per capita. Switzerland (CHE) and Israel (ISR) are large inventor countries, but their share of clean technology inventions is much smaller than in other OECD countries.

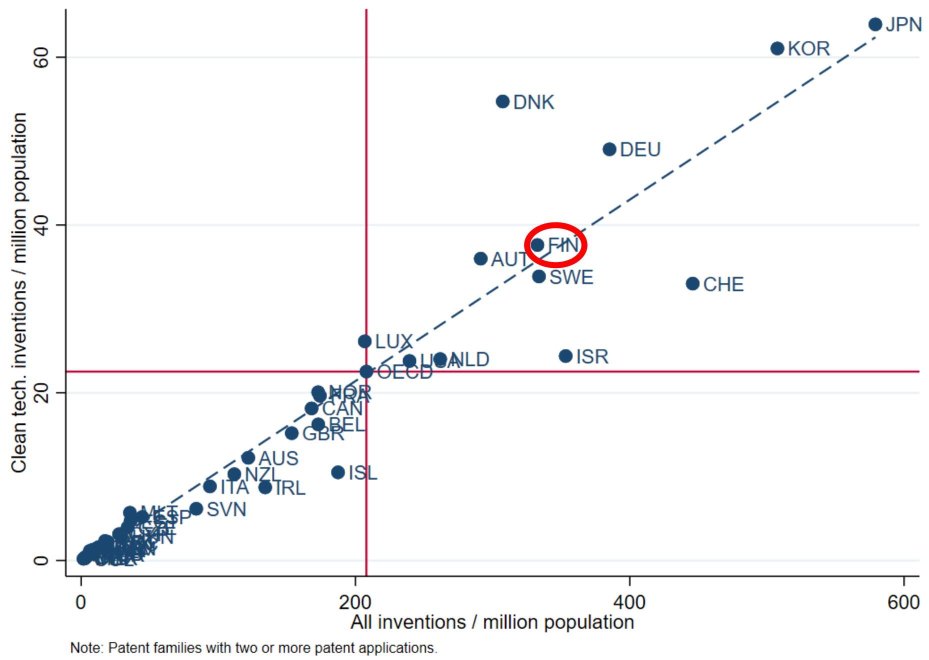

Figure 7. All inventions (total patenting) and inventions in environmental-related/clean technologies (patent family size two or more) per million population in 30 largest inventor countries in clean technology patents, and in EU and OECD countries. Annual averages between 2000-2019. Red lines show OECD averages and dashed line is the linear fit on the data. Source: OECD statistics.

4.2 Energy-related climate change mitigation technologies

According to IPCC (2022), approximately 34 percent of total GHG emissions came from the energy supply sector in 2019. The energy sector is in a very important role in the transition to a fossil-free world. Before moving to the detailed country analysis, where we compare Finland to other countries, we look at the patenting in climate mitigation technologies related to energy generation, transmission or distribution. Against many expectations, patenting in energy technologies aiming to mitigate greenhouse gases found decreasing in 2010s after the sharp increase after millennium. This can be seen in Figure 8, which shows the development of CCMT energy inventions between 1990-2019 for all inventions (left) and inventions with patent family size two or more (right). Especially for inventions with patent family size higher than one, there was a drop in patenting after 2010. This was mainly due to decrease in patenting of solar energy patents. After 2015 patenting of energy-related climate change mitigation technologies has again started to rise. The main driver for this turn has been the strong increase in patenting of enabling energy technologies and in particular energy storage technologies, such as batteries.

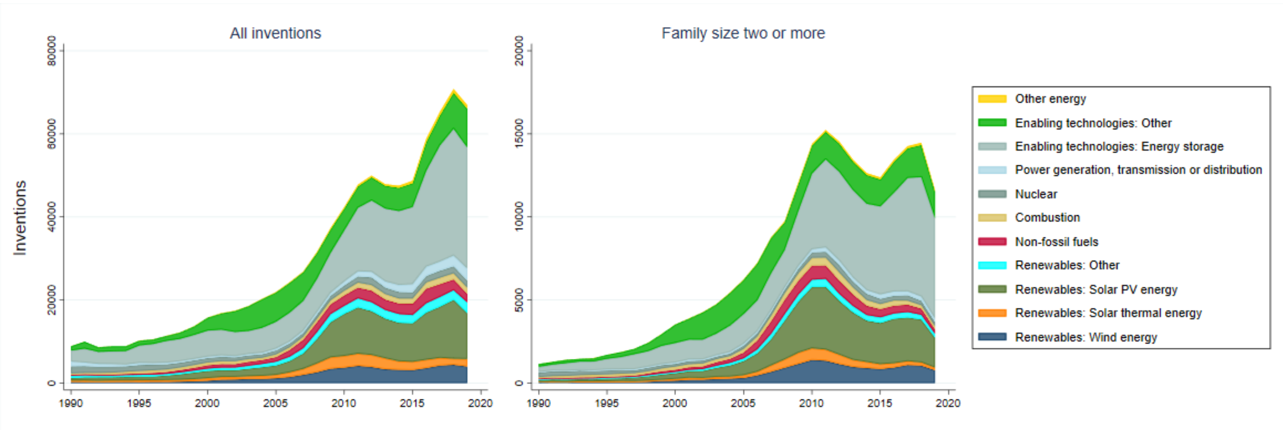

Figure 8. Evolvement of global environmental-related technology inventions in climate change mitigation technologies related to energy generation, transmission or distribution between 1990-2019: All inventions (left) and inventions with patent family size two or more (right). Fractional values of different technology fields. Source: Patstat.

There is no clear reason, why did clean energy patenting drop after 2010, but Popp et al. (2020) discuss about some explanations for this. The possible explanations include the rise of hydrofracking in the United States, and changes in energy markets due that, weakened carbon pricing and renewable energy support in the US and Europe, possible clean technology bubble before 2010, diminishing returns of research and decreasing costs of renewable energy technologies, and increased importance of enabling technologies and IT solutions in energy sector due to, e.g., the increased share of electricity generated by intermittent renewable power (i.e., wind and solar). Companies developing new energy technologies are smaller than before, which can have a negative impact on, among other things, their financial costs and thus also on patenting. However, the increased importance of enabling and high-technology solutions in energy sector shows in increase of energy storage inventions in Figure 8.

There has been a change in renewable energy markets after 2000. Especially, the market change of solar PV technologies can be seen in patenting. Figure 9 shows the patenting of solar PV technologies in five major inventor countries (and in rest of the world, ROV) between 1990-2019. The United States, Japan, and Germany have been three largest inventor countries in PV technologies before 2010. The development trace back to the oil crisis of the 1970s, which gave a push to different R&D policies to promote solar technology. Technological development was further promoted by different feed-in-tariffs in many countries in 1990s and the early 2000s. For example, in Germany, the feed-in tariff system was renewed in 2000, and in only ten years the installed solar PV capacity was the highest in the world thanks to generous feed-in-tariffs. However, since 2010, levels of renewable energy support, and the patenting in PV technologies have decreased in many countries. Despite that, the solar electricity market has grown steadily in many countries, but in China the development has been staggering. According to IRENA[6], the installed solar PV capacity in China was over 300 GW in 2021. The growth has been fast. The installed solar PV capacity in China was less than 1 GW in 2010. For comparison, in 2012 the installed capacity of solar PV was 34 GW in Germany, and in 2021 it was 58 GW. In the USA, which has the second largest installed capacity of any country, had a total installed solar PV capacity of 94 GW in 2021, and it was 3 GW in 2010. Reflecting the change in solar markets, China and also Korea have increased their solar PV technology patenting and in last few years they have produced more solar PV inventions than the USA, Japan or Germany (patent family size two or more).

The increase in the capacity of renewable and weather-dependent energy sources and the increase in the share of electric vehicles in transport sector can be seen in the development of the patenting of batteries and energy storage technologies. Figure 10 shows the patenting of battery technology in the five largest inventor countries between 1990-2019. Patenting has increased in all these countries. Patenting appears to have declined in Japan and Korea in recent years, but this may be due to a lag in patent data.

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[6] International Renewable Energy Agency (IRENA), IRENASTAT: https://www.irena.org/Data/Downloads/IRENASTAT.

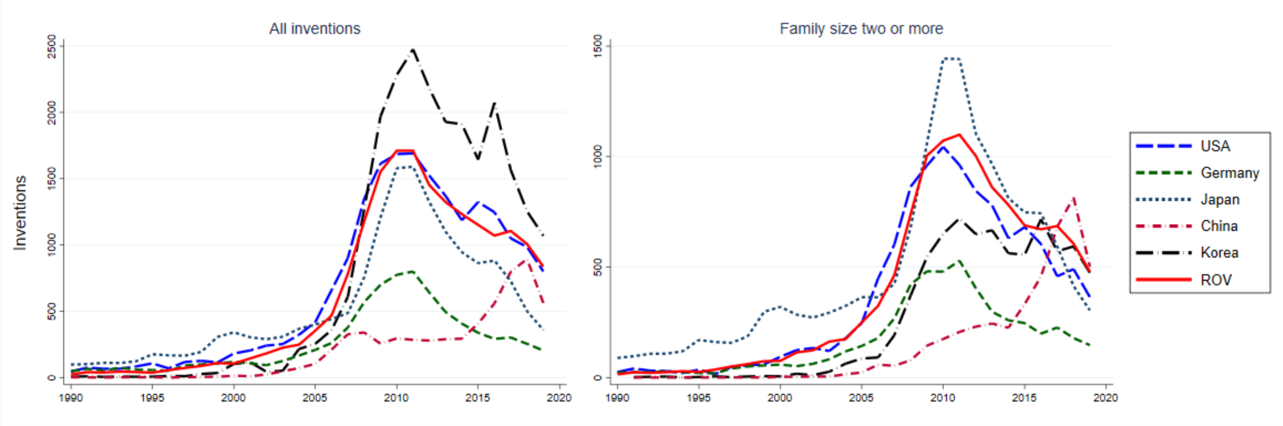

Figure 9. Inventions of solar photovoltaic (PV) energy technologies in major inventor countries between 1990-2019: All inventions (left) and inventions with patent family size two or more (right). ROV is an abbreviation for rest of the world. Source: OECD.

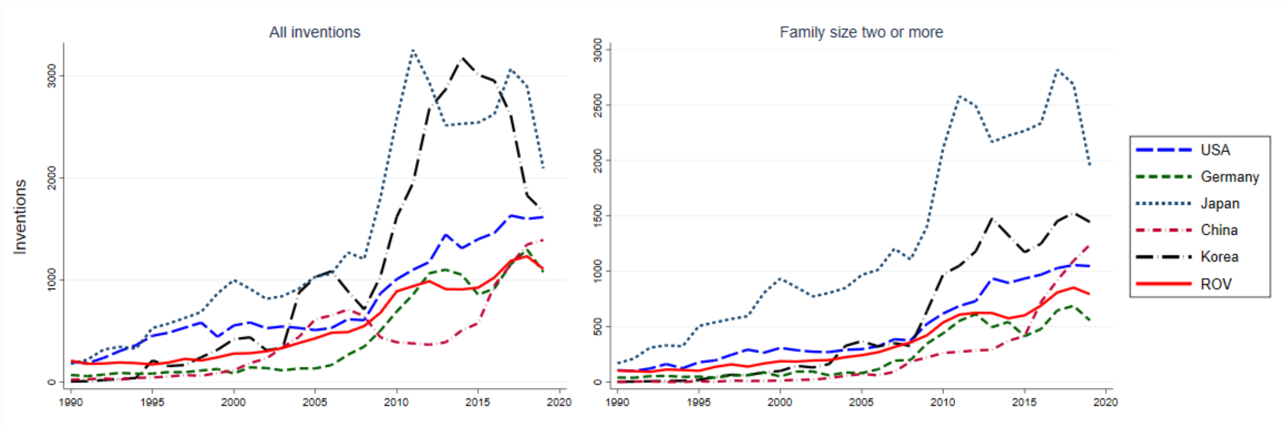

Figure 10. Inventions of battery technologies in major inventor countries between 1990-2019: All inventions (left) and inventions with patent family size two or more (right). ROV is an abbreviation for rest of the world. Source: OECD.

4.3 Comparing Finland to other countries in clean technology patenting

Figures 11 and 12 collect the development of environmental-related technology inventions as five-year averages in Finland, other Nordic countries, and some major inventor countries: Germany, USA, and Korea (and in OECD countries on average). Figure 11 compares clean technology inventions (per million population) to total patenting, and Figure 12 to the share of R&D expenditure in GDP. In Finland the share of R&D expenditure in GDP has been decreasing during the years 2011-2016, and it is thus interesting to see how this development is related to patenting and whether similar trends can be seen in other countries. The first observation from Figures 11 and 12 is that they look very similar, indicating that R&D spending and total patenting go hand in hand in these countries.

The second observation is that there has been a similar development in Finland and Sweden, as total patenting has increased during 1990s together with R&D expenditure, while clean technology patenting has remained at the same level. However, after 2000, there has been a sharp increase in clean technology patenting in both countries. At the same time, levels of total patenting and the share of R&D expenditure in GDP have remained stable. Only difference between Finland and Sweden comes during the period between 2015-2019, when clean patenting and total patenting decreases together with R&D expenditure in Finland. In Sweden, on the other hand, there are no noticeable changes in the five-year periods before and after 2015.

The third observation from figures 11 and 12 is that in other countries, the patenting in clean technologies, total patenting as well as the shares of R&D expenditures have grown steadily over the last thirty years. In some countries this growth has been more moderate, but especially in Denmark and in Korea the increase in clean technology patenting has been very rapid since 2000.

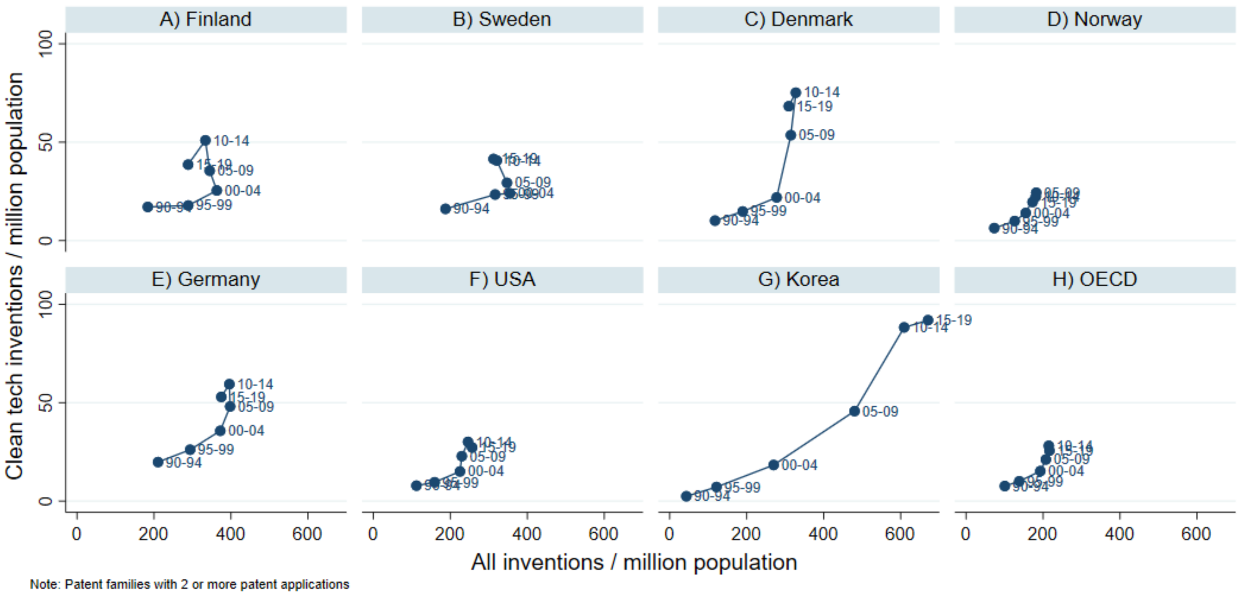

Figure 11. All inventions (total patenting) and inventions in environmental-related technologies per million population in Finland and some other countries (patent family size two or more). Five-year averages between 1990-2019. Source: OECD statistics.

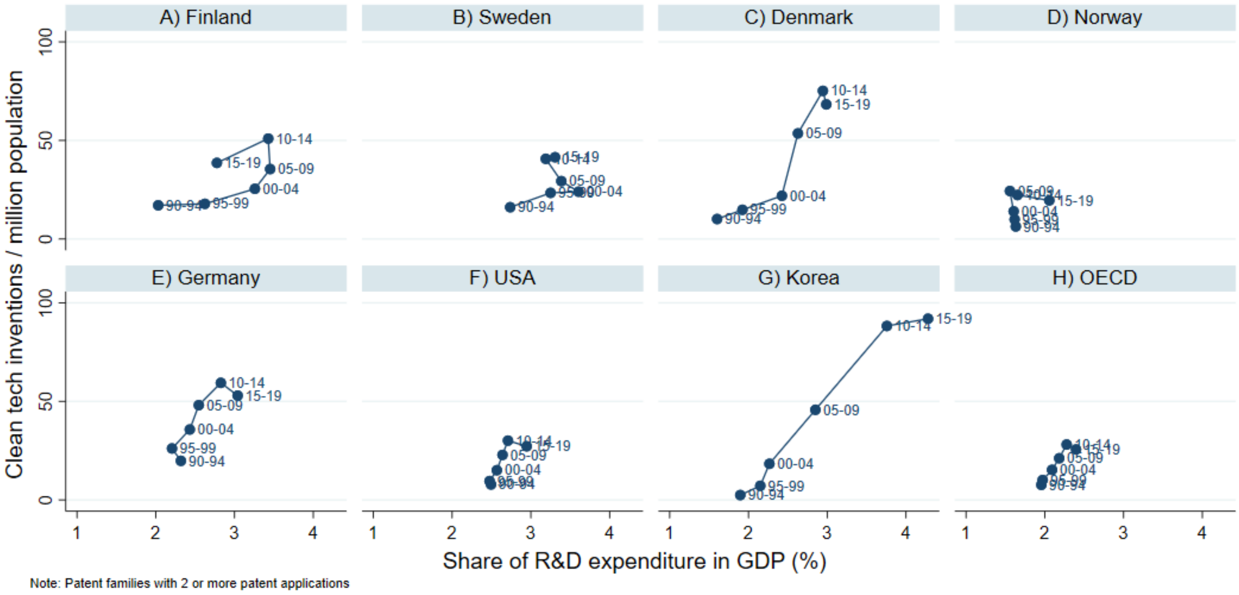

Figure 12. Share of R&D expenditures in GDP (%) and inventions in environmental-related technologies per million population in Finland and some other countries (patent family size two or more). Five-year averages between 1990-2019. Source: OECD statistics.

In Figure 13, we look at the development of clean technology inventions per capita between 1990-2019 in different countries. Again, the development and composition of clean technology inventions have been very similar in Finland and Sweden. Before the year 2000, the largest share of inventions in both countries was in environmental management technologies, i.e., technologies related to air and water abatement, and waste management. After 2000, the increase in clean technology patenting has been mainly due to climate change mitigation technologies. However, there are two clear differences between Finland and Sweden. First, the number of inventions has declined in Finland after the peak in clean technology patenting, which was around 2010. In Sweden, the level of clean technology patenting has remained stable after the strong increase in patenting between 2000 and 2010. Second, the share of climate change mitigation technologies related to transportation is much higher in Sweden than in Finland.

Denmark is an outlier when comparing clean technology patenting with other countries in Figure 13. In addition to the fact that Danish inventors have patented more than inventors in other countries, most inventions are from energy-related climate change mitigation technologies. The explanation for that is wind power. Denmark has been one of the leading countries in the innovation and use of wind power technologies, and most of the Denmark's clean energy inventions are wind power technologies. Another strong technology field in Denmark is climate change mitigation technologies related to production or processing of goods.

Germany appears to be a very similar to the average OECD country in inventing clean technologies. Main technology fields are environmental management technologies, and related to climate change mitigation, energy technologies and technologies related to transportation, and production and processing of goods. The share of transportation is a little bit higher in Germany than in OECD countries on average, and there are less inventions in climate change mitigation technologies related to ICT in Germany.

Among the major inventor countries, the composition of clean technology inventions in the USA also corresponds to OECD averages, although the number of inventions per capita is slightly higher. In Korea, the growth of clean technology inventions has been very strong since 2000, especially in energy-related clean technology inventions.

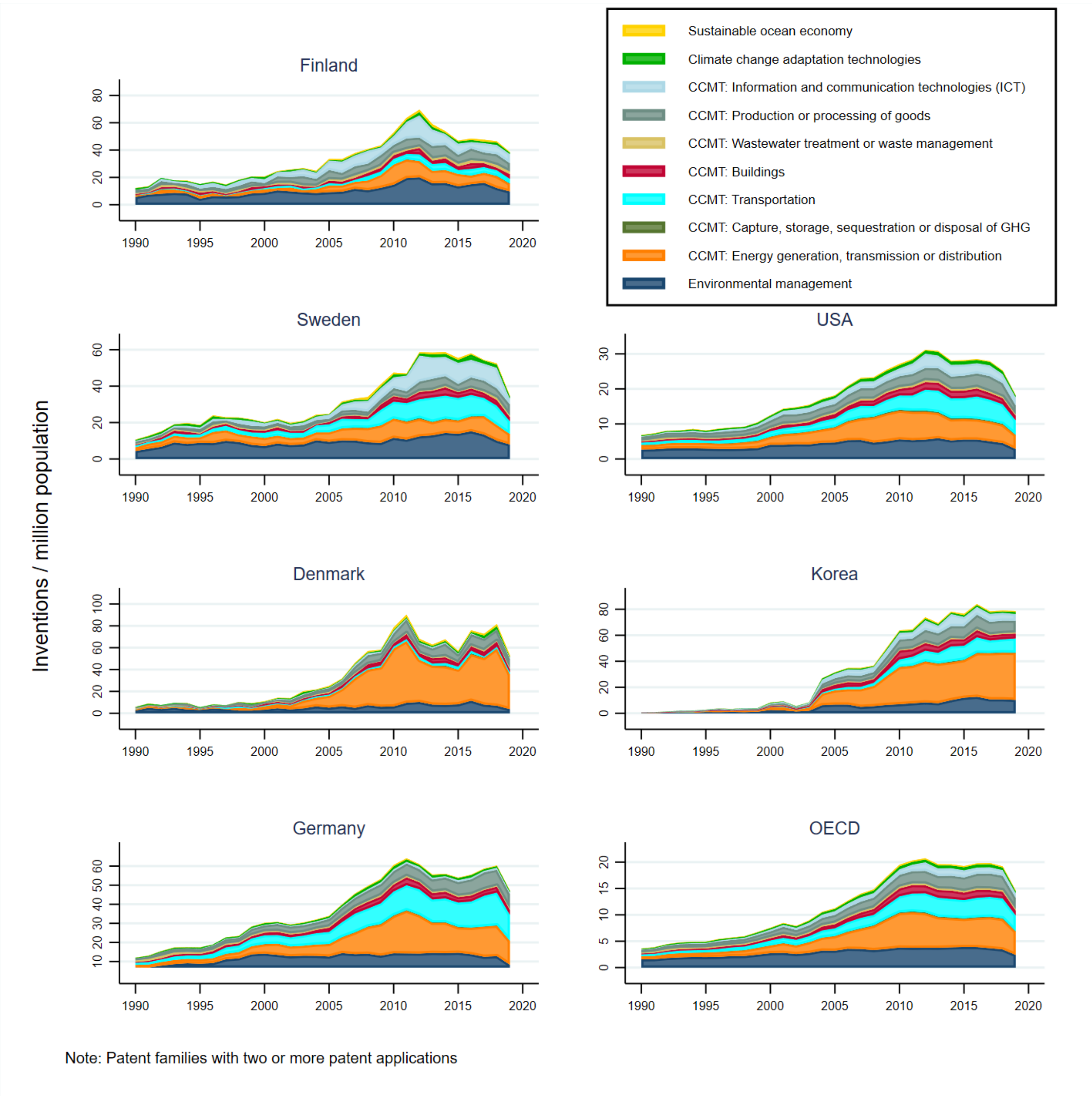

Figure 13. Inventions in environmental-related technologies per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

We next take a closer look at how patenting has developed in different clean technology fields in Finland and in similar European countries Sweden, Denmark, Germany. We compare Finland also to major inventor countries Korea and the United States and OECD countries on average. We look at three indicators related to patenting: 1) share of clean inventions in total patenting, 2) average family size of inventions, and 3) average number of forward citations. The share of clean inventions in total patenting indicates the size of the country in innovating different fields of clean technologies, while the size of the patent family and the number of citations indicate the value of patents in these fields, and thus the importance of inventions. By looking at these indicators related to clean technology patenting, we can consider in which fields of clean technologies Finland has particularly strong expertise compared to other similar countries.

Figure 14 shows the average values of the patent indicators for our comparison countries. Dashed lines in Figure 14 show the OECD averages. Finland is close to an average OECD country in the share of clean technology inventions, whereas Denmark has clearly the highest proportion of clean technology inventions. However, Finnish clean technology inventions have the highest average family size, but the difference to, e.g., Sweden, Denmark or USA is not large. Inventions made by German or Korean inventors are patented in fewer countries on average.

For citations we have two metrics in Figure 14. “All citations” is a count of citations inventions have received from other inventions within five years after first filing of the patent application. Citation count is determined as from-invention-to-invention. One invention can cite the same invention multiple times in different patent applications, but we count only one of these citations. Furthermore, we exclude self-citations, i.e., citations an inventor makes to one of his own inventions. As shown in Figure 14, US inventions have received far more citations than inventions made in other countries. This may be due to different citation practices between countries, and we therefore need to take that into account. In addition, citation practices may have changed over time, and recently filed patents have not had the same amount of time to receive citations. We take the office and time bias into account by normalizing citation counts.

To normalize the count of citations, we first calculate average citations made by all applications filed in each year and in each patent office. We use these average office-year citation numbers as weights when calculating normalized citations. Let’s say, for example, that a Finnish invention has received a citation from a patent application filed in the US patent office in 2010. We first calculate how many citations have been made by all patent applications filed in the US patent office in 2010. Let’s assume these applications have made an average of ten citations. Then, instead of using a citation count of one, we use a weighted count of 1/10 when calculating normalized citation counts for citations from patents filed in the United States in 2010.[7] In addition to reducing absolute citation counts, weighting equalizes citation counts between different countries, which can be seen when looking normalized citations in Figure 14. On average, Finnish inventions receive less (normalized) citations than inventions made in other OECD countries and in Denmark, Korea and USA. Swedish and German inventions receive approximately the same number of (normalized) citations on average than Finnish inventions.

[7] If the average citation count for some office in some year would be less than one, then weighted count is one. Otherwise, some citations would get a very high weight.

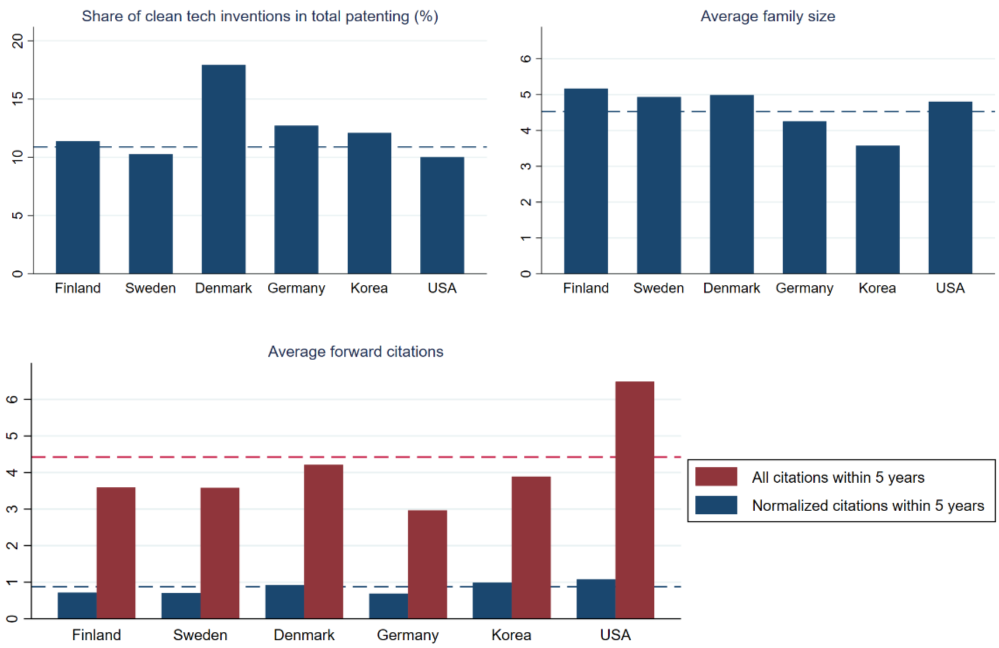

Figure 14. Shares of environmental-related technology inventions in total patenting, average family size and forward citations of environmental-related technology inventions (patent family size two or more) in Finland, Sweden, Denmark, Germany, Korea, and USA between 2000-2019. Dashed lines show the OECD averages. Source: Patstat.

In next figures and tables, we examine the patent indicators of environmental-related technologies with a more detailed technology classification. Each main field of environmental-related technology is divided in sub-fields using OECD classification. However, we leave those technology fields out of this examination, in which there are only few Finnish inventions, such as (9) climate change adaptation technologies, (10) technologies related to sustainable ocean economy, and (3) climate change mitigation technologies related to capture, storage, sequestration or disposal of greenhouse gases. However, many inventions in these fields are also included in some other field of environmental-related technology.

We first look at the intensity of patenting in different clean technology fields. For comparison between countries, we have calculated the relative difference in patenting of different technology fields in relation to OECD averages. More specifically, the relative differences express differences in the shares of clean technology patenting in total patenting between the sample country and the average OECD country. For example, the difference of Finnish inventions relative to the OECD average in clean technology field j is calculated as follows:

$$RD_{j,fi} = \frac{E_{j,fi}}{T_{fi}} \Big/ \frac{E_{j,oecd}}{T_{oecd}} = \frac{E_{j,fi}/E_{j,oecd}}{T_{fi}/T_{oecd}},$$

where $RD_{j,fi}$ is an abbreviation for relative difference, $E_{j,fi}$ and $E_{j,oecd}$ are number of inventions in technology field j, and T_{fi} and T_{oecd} are number of total inventions (total patenting) in Finland and OECD countries, respectively. If the relative difference is greater than one, patenting of clean technology is more extensive in Finland than in OECD countries on average, when the difference in total patenting is taken into account.

Figure 15 shows logs of relative differences (to OECD averages) of environmental-related technology inventions in selected countries according to 2-digit technology classification by OECD. If log value of relative difference is higher than zero, then there are more inventions in that technology field (relative to total patenting) than in OECD countries on average. Moreover, in Table 4 are collected all technology fields where the patenting of clean technologies has been larger in Finland than in the average OECD country. Table A1 in the Appendix presents the relative differences in patenting between Finland and OECD countries on average for all fields of environmental-related technologies.

In (1) environmental management technologies, Finnish inventors have been active especially in water abatement pollution and waste management technology innovation. In air pollution abatement technologies Finland has more inventions relative to average OECD country, but lags behind Sweden and Germany. In (2) energy-related climate change mitigation technologies, Finland is outperforming OECD averages and other comparison countries in (2.2) energy generation from fuels of non-fossil origin (biofuels and fuel from waste) and in (2.3) combustion technologies with mitigation potential. Denmark is a very innovative country in many energy technologies related to climate change mitigation, in addition to wind power technologies, where Denmark is one of the leading countries in the world. In (4) transportation, Finland is not a major innovator country, except in (4.4) maritime or waterways transport where Finland has almost nine time more inventions than an average OECD country. In (5) CCM technologies related to buildings, Finland is close to the OECD averages. Even if there is no (2-digit level) technology field where Finland is performing particularly well, in sub-field (5.2.4) energy efficient elevators, escalators and moving walkways, Finland has almost 33 times more inventions than the average OECD country (see Appendix Table A1).

As was the case in technology fields (1.2) water pollution abatement and (1.3) waste management, in (6) wastewater treatment and waste management technologies related to climate change mitigation, Finland performs again well. For instance, in different (6.2) solid waste management technologies, such as (6.2.4) bio-organic fraction processing, (6.2.5.6) paper recycling or (6.2.5.8) recovery of fats or other fatty substances Finnish inventors have relatively many inventions. In technologies related to (7) production or processing of goods, Finland is performing relatively well in many sub-fields, such as in technologies related to (7.1) metal processing, (7.3) oil refining and petrochemical industry or (7.5) agriculture. Finally, Finland is very strong inventor country, together with Sweden, in (8) climate change mitigation technologies related to ICT, and especially in (8.2) energy efficiency in communication networks.

To conclude, Finland seems to be good in innovating traditional water pollution and waste management technologies. Related to climate change mitigation, Finland is strong in technologies related to non-fossil fuels, and combustion technologies. There are also some individual technology fields in which Finland patents a lot, such as technologies related to waterways transport, energy efficient elevators, oil refining, metal processing or energy efficient communication networks. However, according to Patstat data, Finland is innovating less than many other similar countries, for example, in solar PV energy and enabling technologies related to energy (e.g., storages) or transport (e.g., electric vehicle charging). Also, in road transport technologies (e.g., hybrid or electric vehicles) and in technologies related to final industrial or consumer products Finland is performing poorly when comparing other high innovative countries.

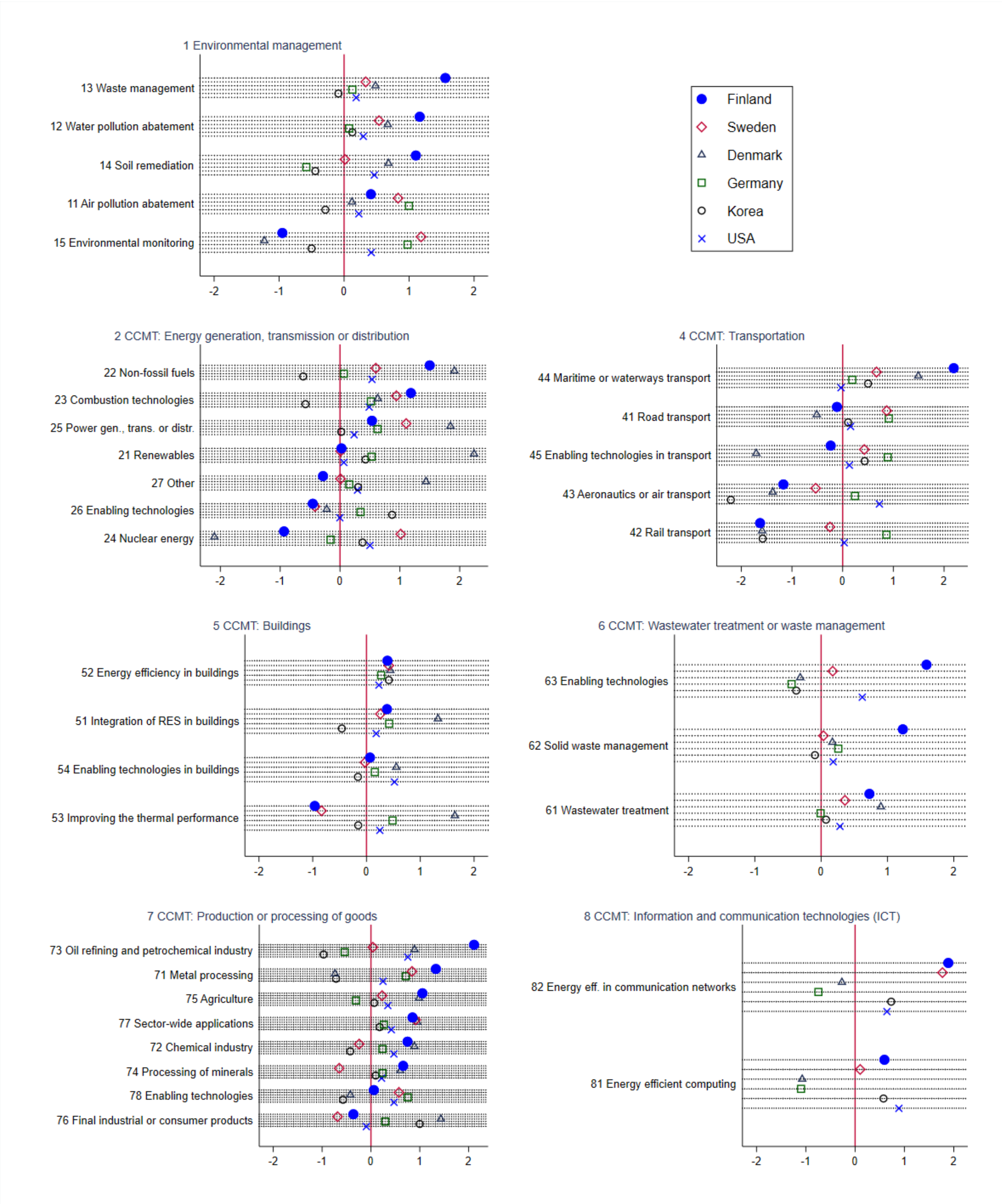

Figure 15. Relative difference in patenting - Log of share of environmental-related technology inventions in total patenting (patent family size two or more) relative to OECD average in Finland, Sweden, Denmark, Germany, Korea and USA in 2000-2019. Source: Patstat.

Finnish patenting started to decrease after the year 2010. Figures A1-A9 in the Appendix show the development of different technology sub-fields of environmental-related technologies between 1990-2019 in our comparison countries (Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries). The change in patenting has been rather similar in largest technology subfields in Finland. Number of inventions has decreased in accordance with the general development in (1) environmental management technologies and related to climate change mitigation in (2) energy and (8) information and communication technologies. This is different compared to other major innovating countries, except for energy technologies where patenting has also decreased slightly in some other countries.

In one of the largest clean technology fields in Finland, (7) climate change mitigation technologies related in the production or processing of goods, the patenting has remained stable since 2010. However, there is one interesting detail. Inventions in (7.1) clean metal processing technologies have decreased some amount after 2015 in Finland, while at the same time there has been a clear increase in other countries, such as Sweden, Germany and the USA. Another field with sharp increase in inventions in countries like Denmark, Germany, USA and Korea, is (7.6) technologies in the production process for final industrial or consumer products. In Finland, on the other hand, decreasing amounts of (7.1) metal processing inventions have been replaced by inventions in (7.3) oil refining and petrochemical industry.

Next, we look at two qualitative indicators: size of patent family and citations. On average, Finnish clean technology inventions are patented in wider market area and thus the family size of Finnish inventions (5.17) is higher than inventions in other OECD countries on average (4.53), for inventions with patent family size is two or more. However, Finnish inventions are rarely cited when compared to inventions from other OECD countries, when the average normalized citation is 0.77 for Finnish inventions and 0.88 for OECD inventions.

Figure 16 shows the log values of average family sizes relative to OECD averages and Figure 17 the log values of normalized citations relative to OECD averages for different clean technologies and different countries. Almost in all technology fields where Finland has lots of inventions, the inventions are also seeking patent protection from many markets and the patent family size is higher than in most comparison countries. Only exceptions are inventions in the fields of (7.2) technologies relating to chemical industry, and (8.2) energy efficiency in communication networks. On the other hand, there are technology fields where patenting is not very active in Finland, but patented inventions are perhaps very relevant in several market areas, as their average patent family sizes are much larger than in comparison countries. Examples are the inventions of (4) climate change mitigation technologies in transport sector.

Finnish inventions are cited rarely than most of the inventions invented in comparison countries, which can be seen in Figure 17. However, there are few technology fields where Finland has: 1) relatively many patents, 2) patents are seeking patent protection from several markets and 3) inventios are important because they are being cited more often than other inventions in same technology fields invented in other countries. According to Table 4 such technology fields are (4.4) maritime or waterways transport technologies, (7.3) technologies relating to oil refining and petrochemical industry, and (7.5) technologies relating to agriculture, livestock or agroalimentary industries. It is also worth noting that (7.1) metal processing technologies, which have been patented a lot in Finland and whose average patent family size is relatively large, are cited much less often than inventions from other countries. Finally, Finnish (8) information and communication technologies receive on average relatively many citations.

When looking at other countries, it is interesting that Korea inventions have smaller average patent family size also in those technology fields where Korea is patenting extensively, but Korean inventions are cited more often than inventions, e.g., from Finland, Sweden, Denmark or Germany. Inventions invented in USA have larger patent families and are being cited relatively often in almost all technology fields when comparing to OECD averages or European countries.

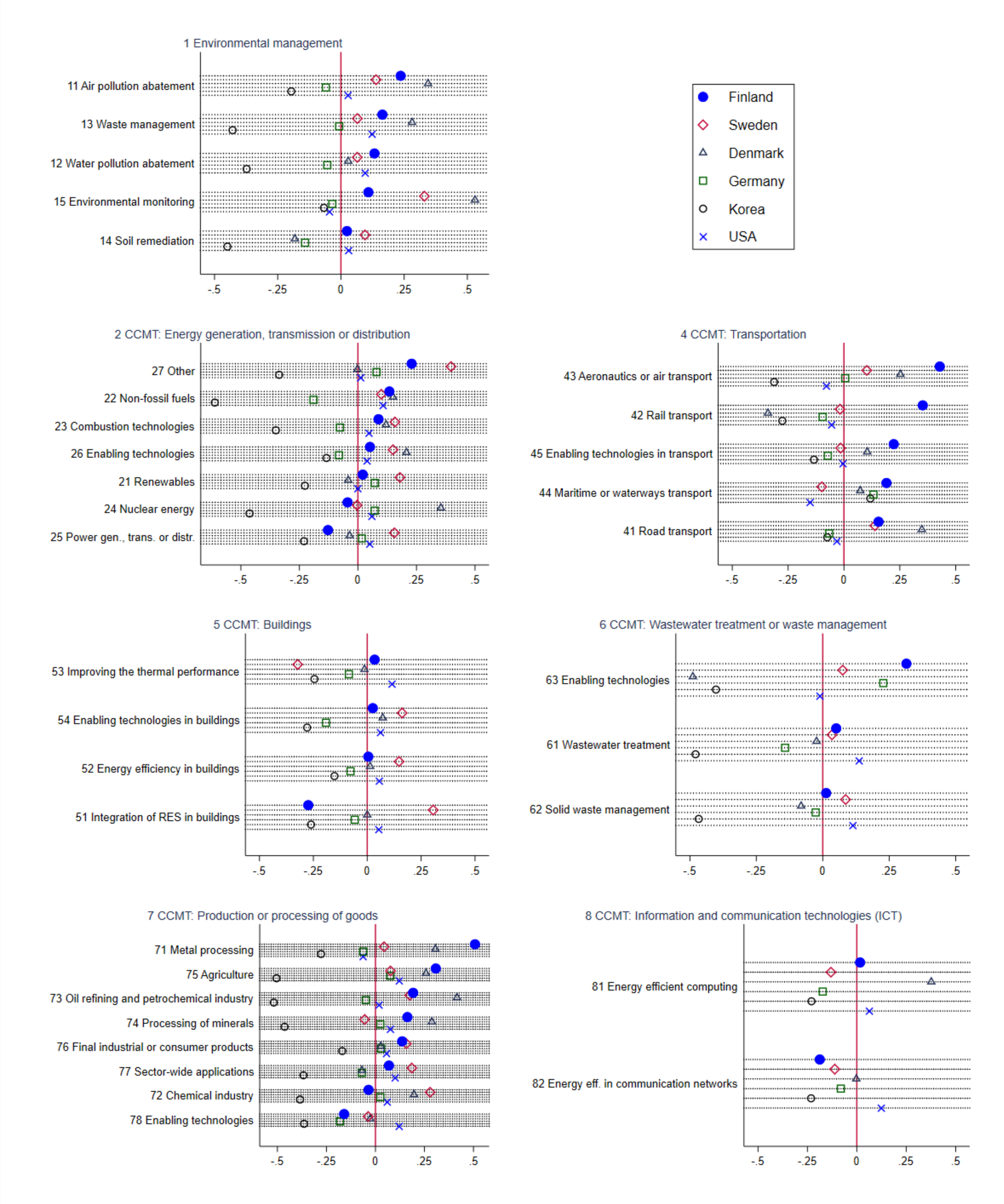

Figure 16. Log of average patent family size of environmental-related technology inventions (patent family size two or more) relative to OECD average in Finland, Sweden, Denmark, Germany, Korea and USA between 2000-2019. Source: Patstat.

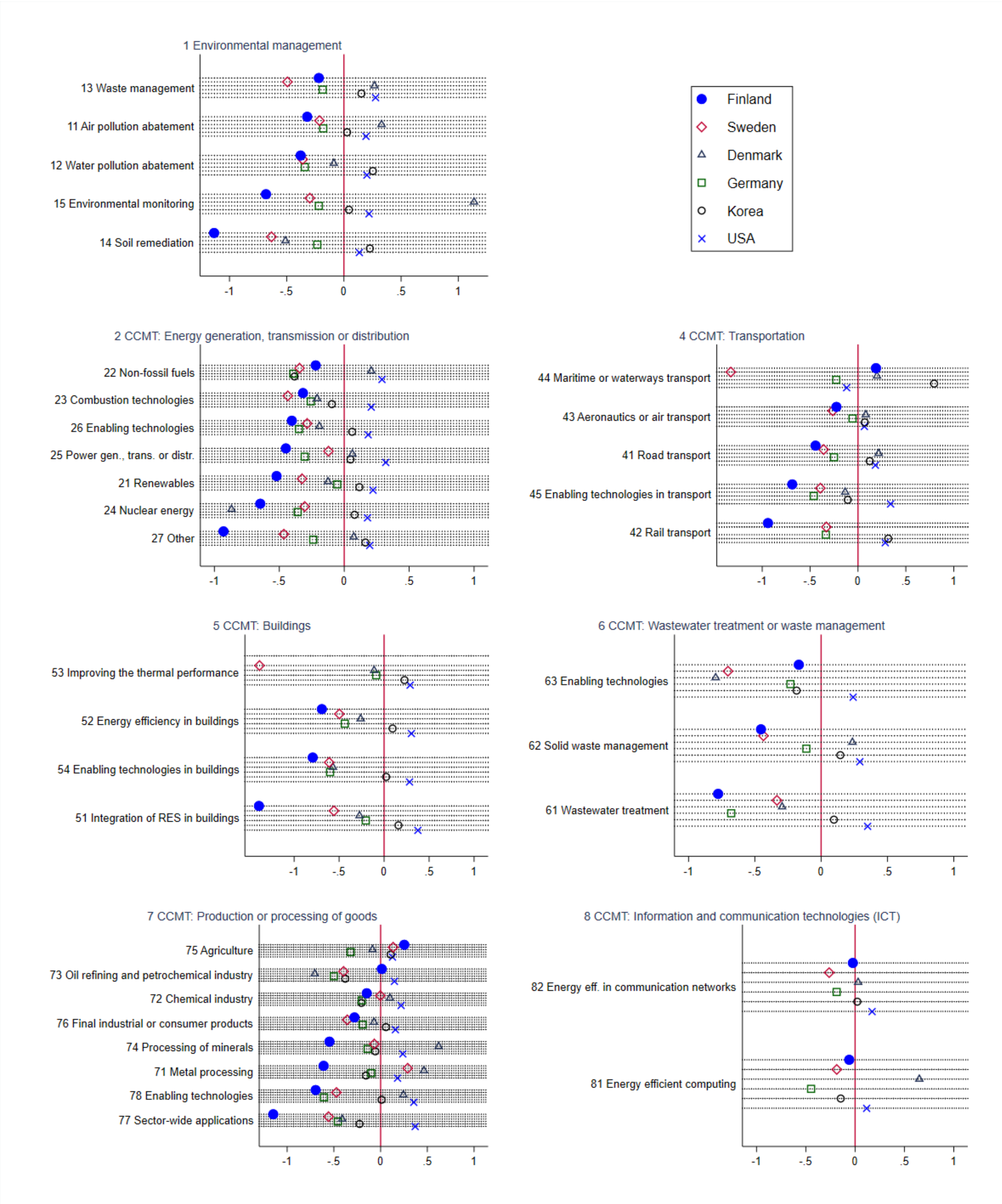

Figure 17. Log of average normalized forward citations of environmental-related technology inventions (patent family size two or more) relative to OECD average in Finland, Sweden, Denmark, Germany, Korea and USA between 2000-2019. Citation counts are normalized by year and patent office of the citing patent. Source: Patstat.

Table 4. Fields of environmental-related technologies (2-digit level) in which Finland have more inventions than OECD countries on average relative to total patenting: Number of Finnish inventions, average family size and normalized citations, and the differences between Finland and the average OECD country (inventions with patent family size two or more). Citations are normalized by the patent office and year of the citing patent. Source: Patstat and OECD statistics.

Technology field	Inventions		Family size		Citations	
	#, FIN	Rel diff, FIN-OECD	Avg, FIN	Diff (%), FIN-OECD	Avg, FIN	Diff (%), FIN-OECD
Environmental-related technologies, total	**4593**	**1.04**	**5.17**	**14.1**	**0.71**	**-18.9**
1 Environmental management	**1795**	**2.3**	**5.4**	**23.3**	**0.5**	**-28.6**
1.1 Air pollution abatement	706	1.5	5.3	26.7	0.5	-27.5
1.2 Water pollution abatement	620	3.2	5.2	14.2	0.4	-31.5
1.3 Waste management	629	4.7	5.8	17.8	0.5	-19.7
1.4 Soil remediation	27	3.0	4.5	2.4	0.2	-67.9
2 CCMT: Energy generation, transmission or distribution	**1028**	**1.1**	**5.1**	**13.4**	**0.7**	**-30.6**
2.1 Renewable energy generation	345	1.0	4.5	2.1	0.6	-40.6
2.2 Energy generation from fuels of non-fossil origin	250	4.5	6.6	14.4	0.9	-19.7
2.3 Combustion technologies with mitigation potential (e.g. using fossil fuels, biomass, waste, etc.)	107	3.3	5.5	9.2	0.6	-27.2
2.5 Technologies for an efficient electrical power generation, transmission or distribution	32	1.7	3.8	-12.0	0.6	-36.2
4 CCMT: Transportation	**478**	**0.8**	**4.9**	**22.4**	**0.7**	**-24.6**
4.4 Maritime or waterways transport	65	9.0	6.0	21.0	1.2	20.7
5 CCMT: Buildings	**308**	**1.4**	**4.0**	**-2.8**	**0.5**	**-52.8**
5.1 Integration of renewable energy sources in buildings	59	1.5	3.1	-23.9	0.2	-75.1
5.2 Energy efficiency in buildings	251	1.5	4.1	0.5	0.5	-49.9
5.4 Enabling technologies in buildings	23	1.1	4.7	2.6	0.5	-54.8
6 CCMT: Wastewater treatment or waste management	**283**	**3.1**	**5.1**	**5.8**	**0.4**	**-38.4**
6.1 Wastewater treatment	64	2.1	5.0	5.2	0.3	-54.0
6.2 Solid waste management	199	3.4	4.9	1.3	0.4	-36.5
6.3 Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation	28	4.9	6.1	37.0	0.6	-15.5
7 CCMT: Production or processing of goods	**940**	**1.9**	**6.7**	**30.5**	**0.8**	**-22.5**
7.1 Technologies related to metal processing	255	3.8	8.3	66.2	0.5	-45.6
7.2 Technologies relating to chemical industry	229	2.1	6.0	-3.4	0.8	-13.8
7.3 Technologies relating to oil refining and petrochemical industry	180	8.3	7.4	21.2	1.2	1.3
7.4 Technologies relating to the processing of minerals	42	1.9	6.7	17.7	0.5	-42.1
7.5 Technologies relating to agriculture, livestock or agroalimentary industries	57	2.9	6.8	36.1	1.0	28.8
7.7 Climate change mitigation technologies for sector-wide applications	33	2.3	5.2	7.1	0.4	-68.3
7.8 Enabling technologies with a potential contribution to GHG emissions mitigation	54	1.1	3.7	-14.8	0.5	-50.1
8 CCMT: Information and communication technologies	**798**	**4.8**	**4.2**	**-11.1**	**1.4**	**5.5**
8.1 Energy efficient computing	127	1.8	4.3	1.7	1.0	-5.8
8.2 Energy efficiency in communication networks	703	6.6	4.2	-17.1	1.4	-2.3

5 Conclusions

To prevent the dramatic effects of climate change, we must quickly reduce emissions and adopt cleaner technology. In the energy sector, this means the widespread introduction of renewable and carbon-free energy sources. The need for technological development is enormous.

Although radical innovations are often the most valuable, new innovations are largely built on top of previous knowledge. Path dependence often applies in innovation. Finland is a strong innovator in technologies related to wastewater treatment, waste management, and bioenergy, Denmark is strong in wind power technologies, Germany in solar power or in car technologies.

After rapid growth, patenting in environment-related technologies has declined in the last ten years in Finland. This has occurred in together with declining R&D expenditures. In other OECD countries there was seen a similar trend in energy-related patenting after 2010. But unlike in Finland, patenting has not decreased at the same pace since 2015. In some countries, the patenting of clean technologies has even been very strong.

The increase in weather-dependent energy production poses challenges to the electricity market already now and especially in the future. Matching electricity production and consumption may become difficult. At the same time, the demand for electricity storage technologies is increasing. In other fields than environmental technologies, Finland has long invested in innovation, e.g., in the software industry and the electronics industry. In these technology fields, Finland may indeed have a lot to offer. The demand for joint energy and ICT-based solutions may grow very strongly soon.

Finland has set the goal of increasing R&D spending to four percent of gross domestic product by 2030. This target together with new R&D funding instruments, such as Green Transition funding according to Finland's Recovery and Resilience Plan will hopefully put Finland back on the track where Finland is one of the leading countries looking for solutions to fight against climate change.

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Appendix

Table A1 shows the fields of environmental-related technologies based on the classification by OECD. Table A1 also shows number of Finnish inventions (with patent family size two or more), average family size, and average number of normalized citations, as well as differences to OECD countries. Green color in column "Relative difference" of Table A1 indicates that those clean technologies are patented more in Finland than in OECD countries relative to total patenting. The larger the relative difference, the stronger Finland is in innovating in that field of clean technology compared to other OECD countries. Similarly, green color in columns of "Family size" and "Citations" means that the average value of patent family size or normalized citations is higher in Finland than in OECD countries on average.

Table A1. Environmental-related technologies and number of Finnish inventions, family size and normalized citations, and the differences between Finland and the average OECD country (inventions with patent family size two or more). Relative difference of inventions is the relative difference between Finland and OECD countries in the shares of clean technology inventions in total patenting. Citations are normalized by the patent office and year of the citing patent. Source: Patstat and OECD statistics.

Technology field	Inventions		Family size		Citations	
	#, FIN	Rel diff, FIN-OECD	Avg, FIN	Diff (%), FIN-OECD	Avg, FIN	Diff (%), FIN-OECD
Environmental-related technologies, total	**4593**	**1.04**	**5.17**	**14.1**	**0.71**	**-18.9**
1 Environmental management	**1795**	**2.3**	**5.40**	**23.3**	**0.48**	**-28.6**
1.1 Air pollution abatement	706	1.5	5.33	26.7	0.51	-27.5
1.1.1 Emissions abatement from stationary sources (e.g. SOx, NOx, PM emissions from combustion plants)	298	2.7	6.05	18.0	0.53	-40.1
1.1.2 Emissions abatement from mobile sources (e.g. NOx, CO, HC, PM emissions from motor vehicles)	303	1.0	4.80	17.7	0.55	-22.8
1.1.3 Air pollution abatement - Not elsewhere classified	258	1.4	5.14	18.7	0.52	-34.0
1.2 Water pollution abatement	620	3.2	5.24	14.2	0.43	-31.5
1.2.1 Water and wastewater treatment	580	3.0	5.29	15.2	0.44	-29.3
1.2.2 Fertilizers from wastewater	29	12.7	4.24	-15.7	0.53	-29.5
1.2.3 Oil spill and pollutant clean-up	55	10.0	4.36	3.2	0.22	-57.4
1.3 Waste management	629	4.7	5.82	17.8	0.50	-19.7
1.3.1 Solid waste collection	121	6.6	7.57	109.8	0.62	36.2
1.3.2 Material recovery, recycling and re-use	278	4.3	6.05	11.1	0.56	-15.2
1.3.3 Fertilizers from waste	83	5.1	4.05	-14.7	0.40	-42.9
1.3.4 Incineration and energy recovery	121	6.0	4.96	2.5	0.36	-36.5
1.3.6 Waste management – Not elsewhere classified	117	3.5	6.11	15.7	0.55	-20.2
1.4 Soil remediation	27	3.0	4.48	2.4	0.20	-67.9
1.5 Environmental monitoring	11	0.4	4.18	11.5	0.40	-49.4
2 CCMT: Energy generation, transmission or distribution	**1028**	**1.1**	**5.06**	**13.4**	**0.69**	**-30.6**
2.1 Renewable energy generation	345	1.0	4.48	2.1	0.65	-40.6
2.1.1 Wind energy	89	1.0	4.46	1.2	0.67	-35.2
2.1.2 Solar thermal energy	42	0.9	3.38	-18.0	0.20	-77.7
2.1.3 Solar photovoltaic (PV) energy	148	0.7	4.97	12.7	0.84	-32.1
2.1.4 Solar thermal-PV hybrids	2	0.6	2.00	-53.0	0.00	-100.0
2.1.5 Geothermal energy	18	3.7	3.78	-1.3	0.32	-52.0
2.1.6 Marine energy, e.g. using wave energy or salinity gradient	59	3.8	4.85	-0.9	0.58	-29.2
2.1.7 Hydro energy	34	2.2	4.94	1.5	0.48	-30.2

2.2 Energy generation from fuels of non-fossil origin	250	4.5	6.59	14.4	0.90	-19.7
2.2.1 Biofuels, e.g. bio-diesel	188	4.5	6.76	11.6	0.96	-19.4
2.2.2 Fuel from waste, e.g. synthetic alcohol or diesel	112	4.5	5.77	7.9	0.71	-33.1
2.3 Combustion technologies with mitigation potential (e.g. using fossil fuels, biomass, waste, etc.)	107	3.3	5.47	9.2	0.57	-27.2
2.3.1 Technologies for improved output efficiency (combined heat and power, combined cycles, etc.)	58	2.7	5.36	8.1	0.57	-31.9
2.3.2 Technologies for improved input efficiency (efficient combustion or heat usage)	56	4.2	5.43	4.6	0.58	-22.6
2.4 Nuclear energy	10	0.4	4.70	-4.3	0.27	-47.6
2.4.1 Nuclear fusion reactors	7	2.1	4.57	-23.3	0.27	-56.0
2.4.2 Nuclear fission reactors	4	0.2	5.25	9.0	0.21	-60.4
2.5 Technologies for an efficient electrical power generation, transmission or distribution	32	1.7	3.75	-12.0	0.61	-36.2
2.5.1 Superconducting electric elements or equipment	1	0.2	4.00	-12.6	0.03	-95.8
2.5.2 Smart grids as climate change mitigation technology in the energy generation sector	8	1.4	3.88	-5.8	0.34	-72.6
2.5.3 Not elsewhere classified	23	2.6	3.70	-11.9	0.72	-25.1
2.6 Enabling technologies (technologies with potential or indirect contribution to GHG emission mitigation)	327	0.6	4.56	5.3	0.65	-33.2
2.6.1 Energy storage	188	0.5	4.37	1.2	0.72	-30.0
2.6.1.1 Batteries	146	0.5	4.36	0.8	0.73	-30.5
2.6.1.2 Capacitors	26	1.4	5.46	7.0	1.06	-23.0
2.6.1.3 Thermal energy storage	19	1.2	4.47	14.5	0.53	-20.8
2.6.1.4 Mechanical energy storage, e.g. flywheels or pressurised fluids	10	1.3	5.00	17.2	0.59	-26.5
2.6.2 Hydrogen technology	26	0.7	4.96	3.1	0.56	-29.6
2.6.3 Fuel cells	105	0.8	4.82	10.2	0.55	-35.7
2.6.4 High-voltage direct current transmission	0					
2.7 Other energy conversion or management systems reducing GHG emissions	11	0.8	5.36	25.8	0.43	-60.5
3 CCMT: Capture, storage, sequestration or disposal of greenhouse gases	**24**	**0.7**	**4.71**	**-10.7**	**0.45**	**-54.6**
3.1 Capture or disposal of nitrous oxide (N2O)	1	0.3	3.00	-50.1	0.00	-100.0
3.2 Capture or disposal of methane (CH4)	3	1.0	7.33	50.1	0.35	-59.2
3.3 Capture or disposal of perfluorocarbons (PFC), hydrofluorocarbons (HFC) or sulfur hexafluoride (SF6)	1	0.6	3.00	-39.7	0.00	-100.0
3.4 Capture or disposal of carbon dioxide (CO2)	20	0.8	4.40	-15.7	0.48	-51.2
4 CCMT: Transportation	**478**	**0.8**	**4.91**	**22.4**	**0.65**	**-24.6**
4.1 Road transport	385	0.9	4.63	16.7	0.59	-35.8
4.1.1 Conventional vehicles (based on internal combustion engine)	258	1.3	4.40	12.5	0.54	-29.5
4.1.2 Hybrid vehicles	22	0.4	4.95	30.8	0.72	-26.3
4.1.3 Electric vehicles	117	0.7	5.30	28.7	0.67	-39.9
4.1.4 Fuel efficiency-improving vehicle design (common to all road vehicles)	9	0.3	4.56	14.0	0.96	3.3
4.2 Rail transport	1	0.2	6.00	42.3	0.26	-60.9
4.3 Aeronautics or air transport	36	0.3	6.39	53.6	0.57	-20.2
4.4 Maritime or waterways transport	65	9.0	5.98	21.0	1.15	20.7
4.5 Enabling technologies in transport	68	0.8	5.03	25.0	0.57	-49.7
4.5.1 Electric vehicle charging	58	0.9	4.84	19.4	0.56	-54.4
4.5.2 Application of hydrogen technology to transportation, e.g. using fuel cells	13	0.6	5.85	47.5	0.56	-36.8
5 CCMT: Buildings	**308**	**1.4**	**4.03**	**-2.8**	**0.45**	**-52.8**
5.1 Integration of renewable energy sources in buildings	59	1.5	3.07	-23.9	0.24	-75.1
5.2 Energy efficiency in buildings	251	1.5	4.12	0.5	0.48	-49.9
5.2.1 Energy efficient lighting	34	0.7	4.71	7.4	0.73	-41.7
5.2.2 Energy efficient heating, ventilation or air conditioning [HVAC]	110	2.1	3.39	-12.0	0.27	-57.9
5.2.3 Energy efficiency in home appliances	4	0.3	3.25	-21.7	0.11	-86.6
5.2.4 Energy efficient elevators, escalators and moving walkways, e.g. energy saving or recuperation technologies	28	32.7	5.68	4.5	0.52	-15.8
5.2.5 End-user side	78	1.4	4.35	7.3	0.65	-36.6
5.3 Architectural or constructional elements improving the thermal performance of buildings	2	0.4	5.00	3.5	0.00	-100.0
5.4 Enabling technologies in buildings	23	1.1	4.70	2.6	0.53	-54.8
6 CCMT: Wastewater treatment or waste management	**283**	**3.1**	**5.10**	**5.8**	**0.43**	**-38.4**
6.1 Wastewater treatment	64	2.1	5.02	5.2	0.35	-54.0
6.2 Solid waste management	199	3.4	4.94	1.3	0.43	-36.5
6.2.1 Waste collection, transportation, transfer or storage	2	2.8	7.50	114.3	1.01	19.9
6.2.2 Waste processing or separation	3	2.6	4.00	-5.9	0.15	-71.3
6.2.3 Landfill technologies aiming to mitigate methane emissions	2	2.7	3.50	-5.9	0.18	-57.9
6.2.4 Bio-organic fraction processing; Production of fertilisers from the organic fraction of waste or refuse	43	5.7	4.19	-6.3	0.42	-36.2

6.2.5 Reuse, recycling or recovery technologies	143	3.1	5.15	3.4	0.45	-35.5
6.2.5.1 Mechanical processing of waste for the recovery of materials, e.g. crushing, shredding, separation or disassembly	1	0.3	3.00	-36.6	0.04	-93.4
6.2.5.2 Waste management of vehicles	0					
6.2.5.3 Construction or demolition [C&D] waste	0					
6.2.5.4 Glass recycling	0					
6.2.5.5 Plastics and rubber recycling	18	1.3	3.94	-20.3	0.48	-8.0
6.2.5.6 Paper recycling	50	17.4	5.16	3.7	0.44	-16.7
6.2.5.7 Disintegrating fibre-containing textile articles to obtain fibres for re-use	0					
6.2.5.8 Recovery of fats, fatty oils, fatty acids or other fatty substances, e.g. lanolin or waxes	33	19.6	6.27	28.7	0.33	-52.9
6.2.5.9 Recycling of wood or furniture waste	1	4.1	3.00	-14.0	0.49	-7.1
6.2.5.10 Packaging reuse or recycling, e.g. of multilayer packaging	3	0.7	3.33	-30.0	0.26	-49.9
6.2.5.11 Recycling of waste of electrical or electronic equipment (WEEE)	2	1.3	7.00	67.9	0.72	-25.7
6.2.5.12 Recycling of batteries or fuel cells	2	0.9	4.50	-8.3	0.38	-63.0
6.2.5.13 Use of waste materials as fillers for mortars or concrete	36	1.9	4.89	-7.0	0.54	-35.8
6.3 Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation	28	4.9	6.14	37.0	0.62	-15.5
7 CCMT: Production or processing of goods	**940**	**1.9**	**6.66**	**30.5**	**0.75**	**-22.5**
7.1 Technologies related to metal processing	255	3.8	8.29	66.2	0.46	-45.6
7.1.1 Reduction of greenhouse gas (GHG) emissions	17	5.1	9.29	21.9	0.39	-42.9
7.1.2 Process efficiency	241	3.7	8.25	67.9	0.46	-45.7
7.2 Technologies relating to chemical industry	229	2.1	6.05	-3.4	0.79	-13.8
7.2.1 Process efficiency in chemical industry	55	2.2	6.47	8.5	0.68	-33.9
7.2.2 Feedstock	76	4.4	5.18	3.7	0.74	-3.2
7.2.3 Reduction of greenhouse gas [GHG] emissions, e.g. CO2	10	1.1	6.00	13.1	1.12	17.0
7.2.4 Improvements relating to chlorine production	0					
7.2.5 Improvements relating to adipic acid or caprolactam production	0					
7.2.6 Improvements relating to fluorochloro hydrocarbon, e.g. chlorodifluoromethane [HCFC-22] production	0					
7.2.7 Improvements relating to the production of bulk chemicals	3	1.1	7.33	19.8	0.26	-73.9
7.3 Technologies relating to oil refining and petrochemical industry	180	8.3	7.40	21.2	1.24	1.3
7.3.1 Bio-feedstock	178	10.1	7.44	18.9	1.25	-0.9
7.3.2 Ethylene production	3	0.6	11.67	88.1	0.76	-29.4
7.4 Technologies relating to the processing of minerals	42	1.9	6.71	17.7	0.50	-42.1
7.4.1 Production of cement	10	1.8	5.50	-2.4	0.74	-20.5
7.4.2 Production or processing of lime	18	21.5	6.67	22.1	0.25	-66.3
7.4.3 Glass production	12	0.9	7.83	34.1	0.71	-18.1
7.4.4 Production of ceramic materials or ceramic elements	2	1.4	6.50	39.7	0.28	-54.7
7.5 Technologies relating to agriculture, livestock or agroalimentary industries	57	2.9	6.84	36.1	1.02	28.8
7.5.1 Using renewable energies, e.g. solar water pumping	2	1.6	7.00	64.0	0.71	-9.0
7.5.2 Measures for saving energy, e.g. in green houses	15	5.7	10.07	104.6	1.79	52.1
7.5.3 Reduction of greenhouse gas [GHG] emissions in agriculture	23	2.2	6.70	35.6	0.88	11.1
7.5.4 Land use policy measures	0					
7.5.5 Afforestation or reforestation	0					
7.5.6 Livestock or poultry management	0					
7.5.7 Fishing; Aquaculture; Aquafarming	1	1.8	2.00	-63.5	0.00	-100.0
7.5.8 Food processing, e.g. use of renewable energies or variable speed drives in handling, conveying or stacking	18	3.8	4.78	-17.4	0.70	7.2
7.6 Technologies in the production process for final industrial or consumer products	139	0.7	5.30	14.6	0.81	-24.4
7.7 Climate change mitigation technologies for sector-wide applications	33	2.3	5.18	7.1	0.40	-68.3
7.8 Enabling technologies with a potential contribution to GHG emissions mitigation	54	1.1	3.72	-14.8	0.46	-50.1
8 CCMT: Information and communication technologies (ICT)	**798**	**4.8**	**4.20**	**-11.1**	**1.37**	**5.5**
8.1 Energy efficient computing	127	1.8	4.31	1.7	0.96	-5.8
8.2 Energy efficiency in communication networks	703	6.6	4.21	-17.1	1.45	-2.3
9 Climate change adaptation technologies	**201**	**1.7**	**4.68**	**-1.7**	**0.34**	**-50.8**
9.1 Adaptation at coastal zones or river basin	5	1.9	3.40	-24.2	0.09	-88.2
9.1.1 Hard structures, e.g. dams, dykes or breakwaters	3	2.7	2.33	-37.8	0.07	-87.6
9.1.2 Dune restoration or creation; cliff stabilisation	0					
9.1.3 Artificial reefs or seaweed; restoration or protection of coral reefs	0					
9.1.4 Flood prevention; flood or storm water management	1	1.3	7.00	67.1	0.23	-61.5
9.1.5 Controlling, monitoring or forecasting	0					
9.2 Water resource management	88	1.5	4.39	-1.6	0.33	-49.8
9.2.1 Demand-side technologies (water conservation)	38	1.1	4.95	5.3	0.40	-41.0

9.2.1.1 Indoor water conservation	11	1.3	4.36	5.2	0.06	-82.9
9.2.1.2 Irrigation water conservation	8	0.7	4.00	-21.7	1.05	55.9
9.2.1.3 Water conservation in thermoelectric power production	19	1.4	5.68	21.4	0.32	-62.9
9.2.2 Supply-side technologies (water availability)	51	2.1	3.96	-3.9	0.27	-56.6
9.2.2.1 Water collection (rain, surface and ground-water)	8	1.0	2.75	-24.2	0.40	-13.7
9.2.2.2 Water desalination	4	0.5	5.50	15.5	0.69	-20.3
9.2.2.3 Water storage and distribution	4	1.6	2.25	-41.7	0.06	-89.2
9.2.2.4 Water filtration; Water and wastewater treatment	36	5.1	4.25	7.0	0.23	-60.0
9.2.2.5 Protecting water resources	0					
9.3 Adapting or protecting infrastructure or their operation	30	1.8	4.20	-0.9	0.17	-77.0
9.3.1 Extreme weather resilient electric power supply systems	1	1.2	5.00	11.0	0.00	-100.0
9.3.2 Structural elements or technology for improving thermal insulation	6	1.1	3.50	-22.0	0.37	-51.2
9.3.3 Relating to heating, ventilation or air conditioning [HVAC] technologies	7	1.4	3.14	-19.9	0.09	-86.3
9.3.4 In transportation	1	0.6	2.00	-60.4	0.00	-100.0
9.3.5 Planning or developing urban green infrastructure	4	2.0	2.25	-41.6	0.08	-92.9
9.4 Adaptation technologies in agriculture, forestry, livestock or agro-alimentary production	85	2.0	5.09	-7.5	0.39	-46.7
9.4.1 In agriculture	70	2.4	5.04	-13.5	0.37	-50.6
9.4.2 Ecological corridors or buffer zones	1	1.5	11.00	226.2	2.34	441.6
9.4.3 In livestock or poultry	0					
9.4.4 In fisheries management	6	0.6	3.17	-33.7	0.05	-93.1
9.4.5 In food processing or handling, e.g. food conservation	7	1.7	6.29	17.6	0.64	-5.0
9.5 Adaptation technologies in human health protection, e.g. against extreme weather	2	1.5	4.00	8.0	0.98	85.7
9.5.1 Air quality improvement or preservation	26	0.7	6.23	43.2	1.08	18.8
9.5.2 Against vector-borne diseases whose impact is exacerbated by climate change	45	0.7	7.27	-10.5	0.84	-21.4
9.6 Technologies having an indirect contribution to adaptation to climate change	0					
9.6.1 Information and communication technologies [ICT] supporting adaptation to climate change, e.g. for weather forecasting or climate simulation	35	2.0	5.34	-13.8	0.85	-56.0
9.6.2 Assessment of water resources	2	1.3	9.00	74.6	0.61	-31.9
9.6.3 Monitoring or fighting invasive species	0					
10 Sustainable ocean economy	**202**	**3.3**	**5.13**	**8.3**	**0.71**	**-12.4**
10.1 Ocean renewable energy generation	65	2.9	4.65	-1.2	0.58	-34.5
10.1.1 Offshore wind energy	8	1.1	4.75	5.2	0.75	-26.7
10.1.2 Offshore solar energy	0					
10.1.3 Tide, wave, current and other marine energy	60	3.7	4.82	-0.7	0.58	-29.7
10.2 Ocean pollution abatement	78	6.2	4.92	5.3	0.56	-13.4
10.2.1 Ballast water treatment	20	4.5	6.10	23.1	1.12	40.8
10.2.2 Oil spill (and other floating debris) prevention and cleanup	59	7.2	4.49	-0.4	0.37	-35.9
10.3 Climate change mitigation in maritime transport	53	8.5	6.40	26.0	1.32	34.4
10.3.1 Improved vessel design	17	5.7	5.65	25.3	1.13	90.9
10.3.2 Fuel-efficient propulsion or fuel substitution	36	10.8	6.75	20.6	1.40	6.0
10.4 Climate change mitigation and adaptation in fishing, aquaculture and aquafarming	6	0.6	3.17	-33.9	0.05	-93.1
10.5 Desalination of sea water	4	0.5	5.50	15.5	0.69	-20.3
10.6 Climate change adaptation in coastal zones	6	1.7	3.67	-18.9	0.07	-89.0

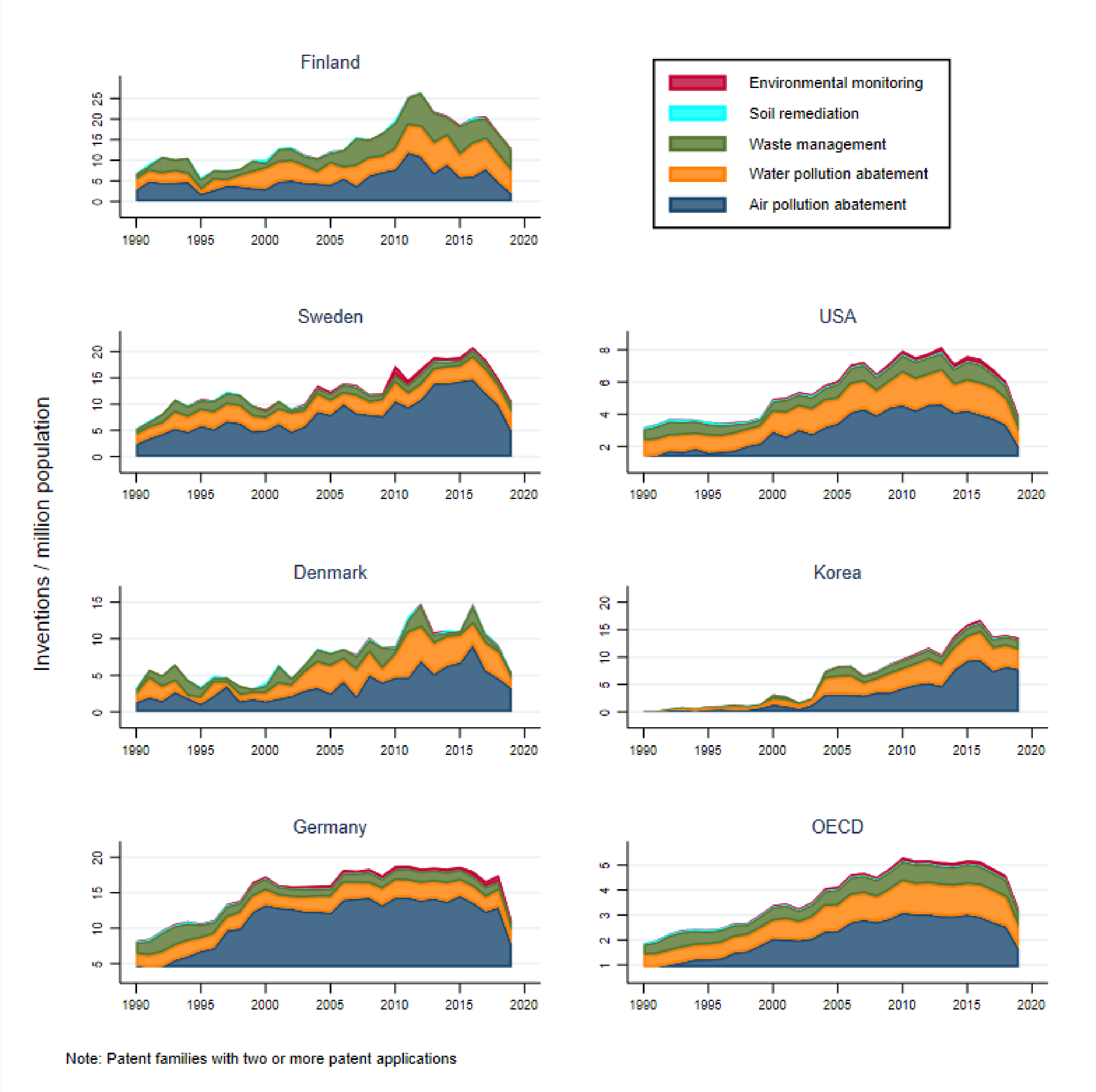

Figure A1. Inventions in (1) environmental management technologies per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

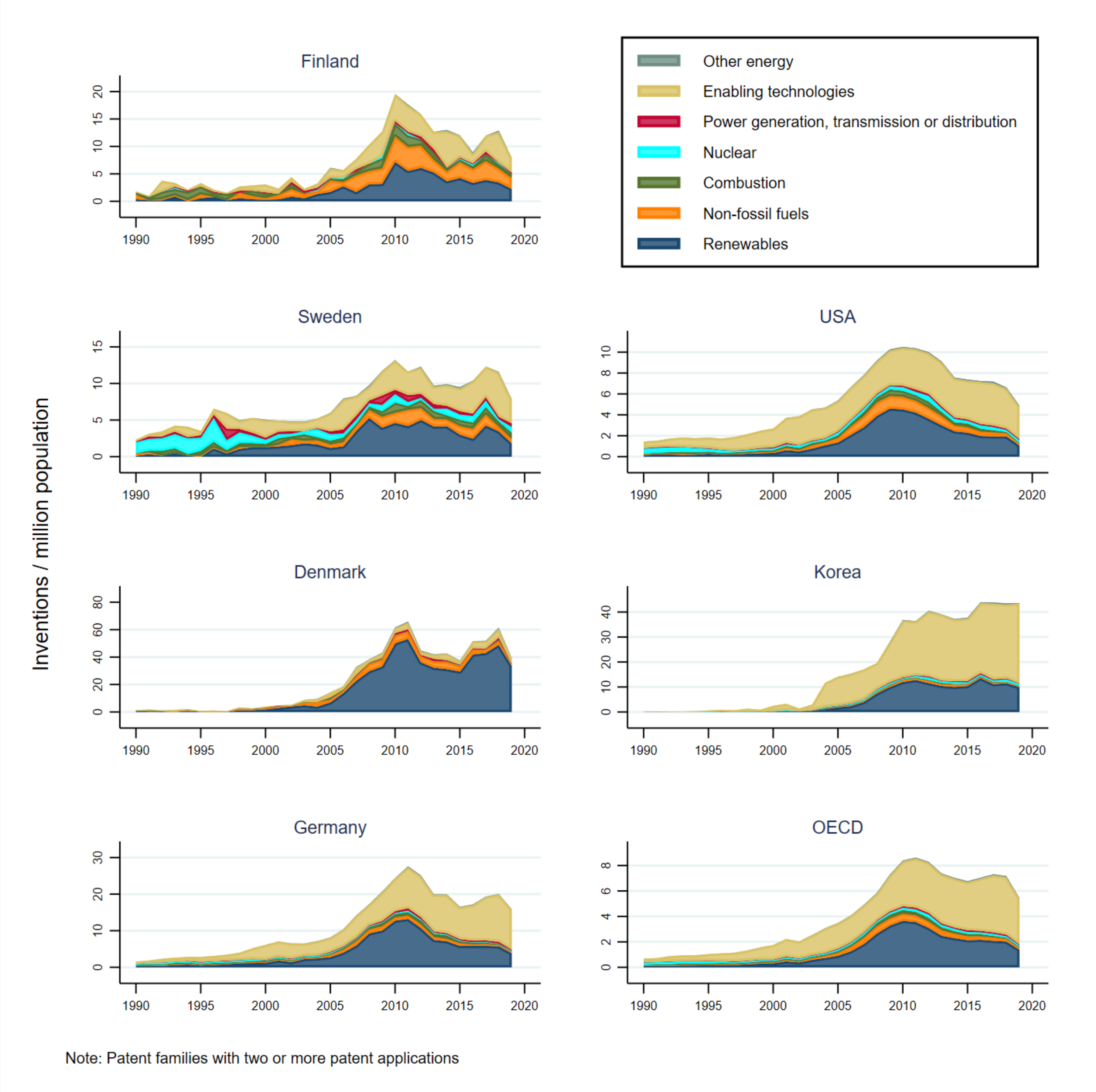

Figure A2. Inventions in (2) climate change mitigation technologies related to energy generation, transmission or distribution per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

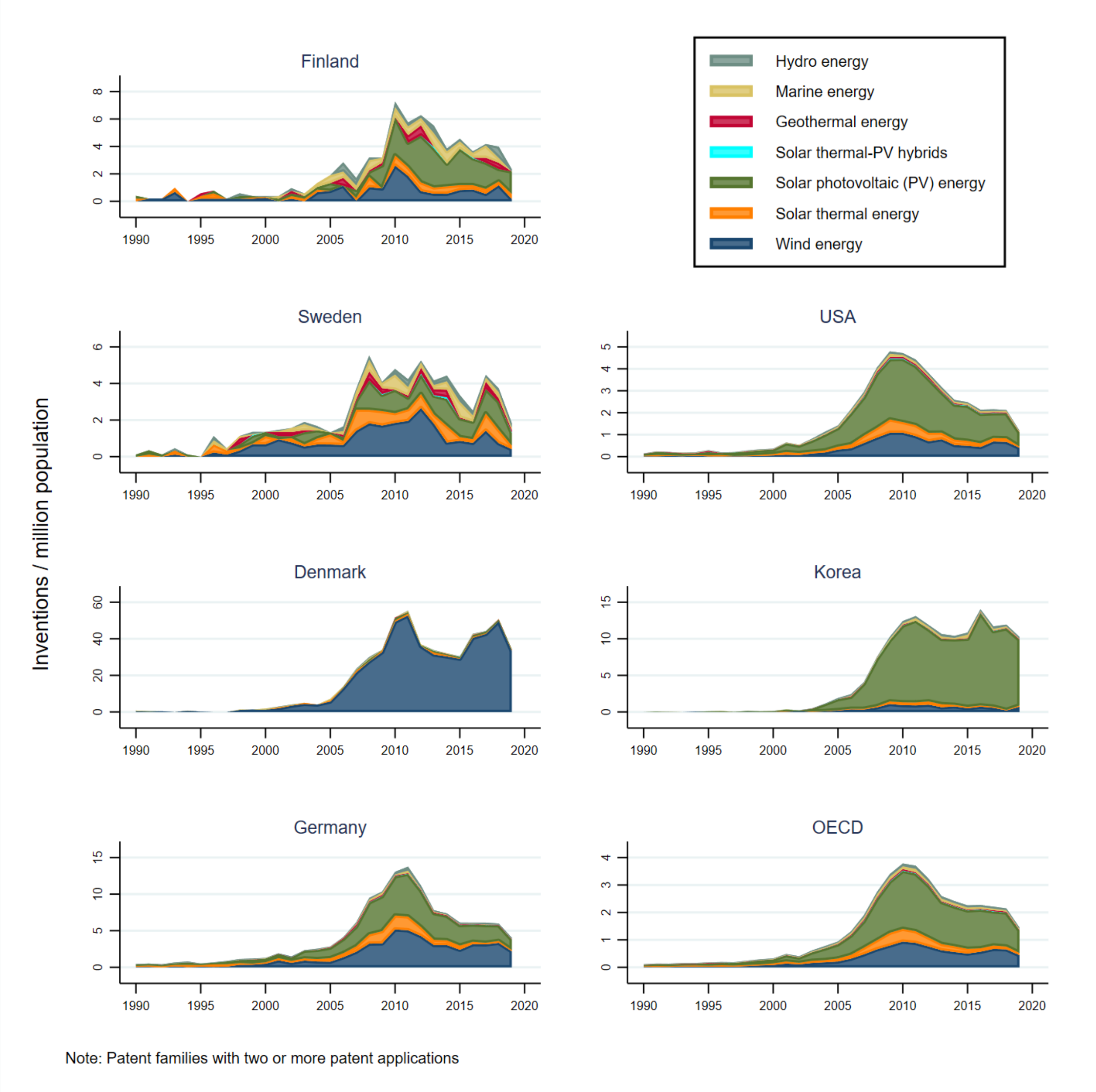

Figure A3. Inventions in (2.1) climate change mitigation technologies related to renewable energy generation per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

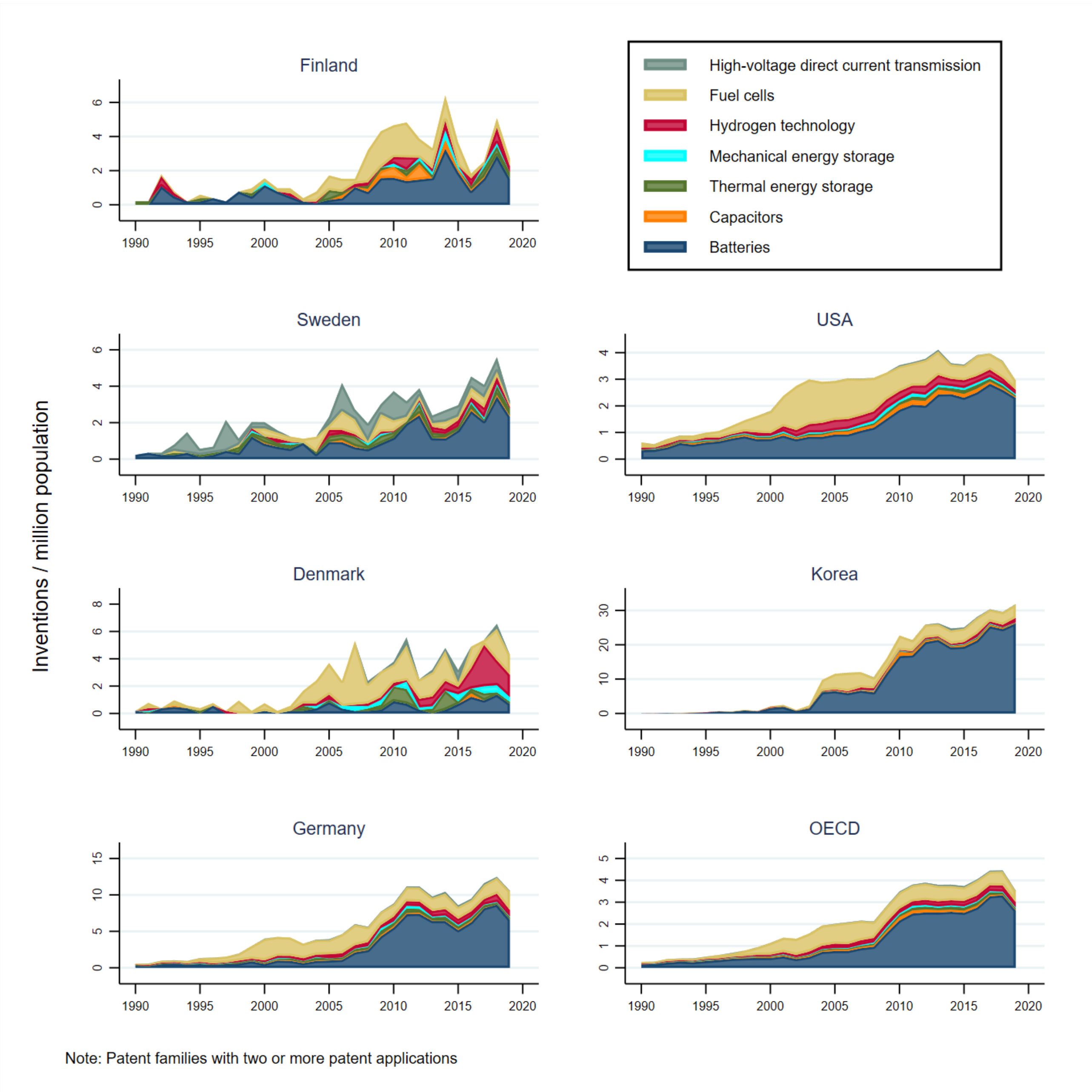

Figure A4. Inventions in (2.6) climate change mitigation technologies related to enabling energy technologies (technologies with potential or indirect contribution to GHG emission mitigation) per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

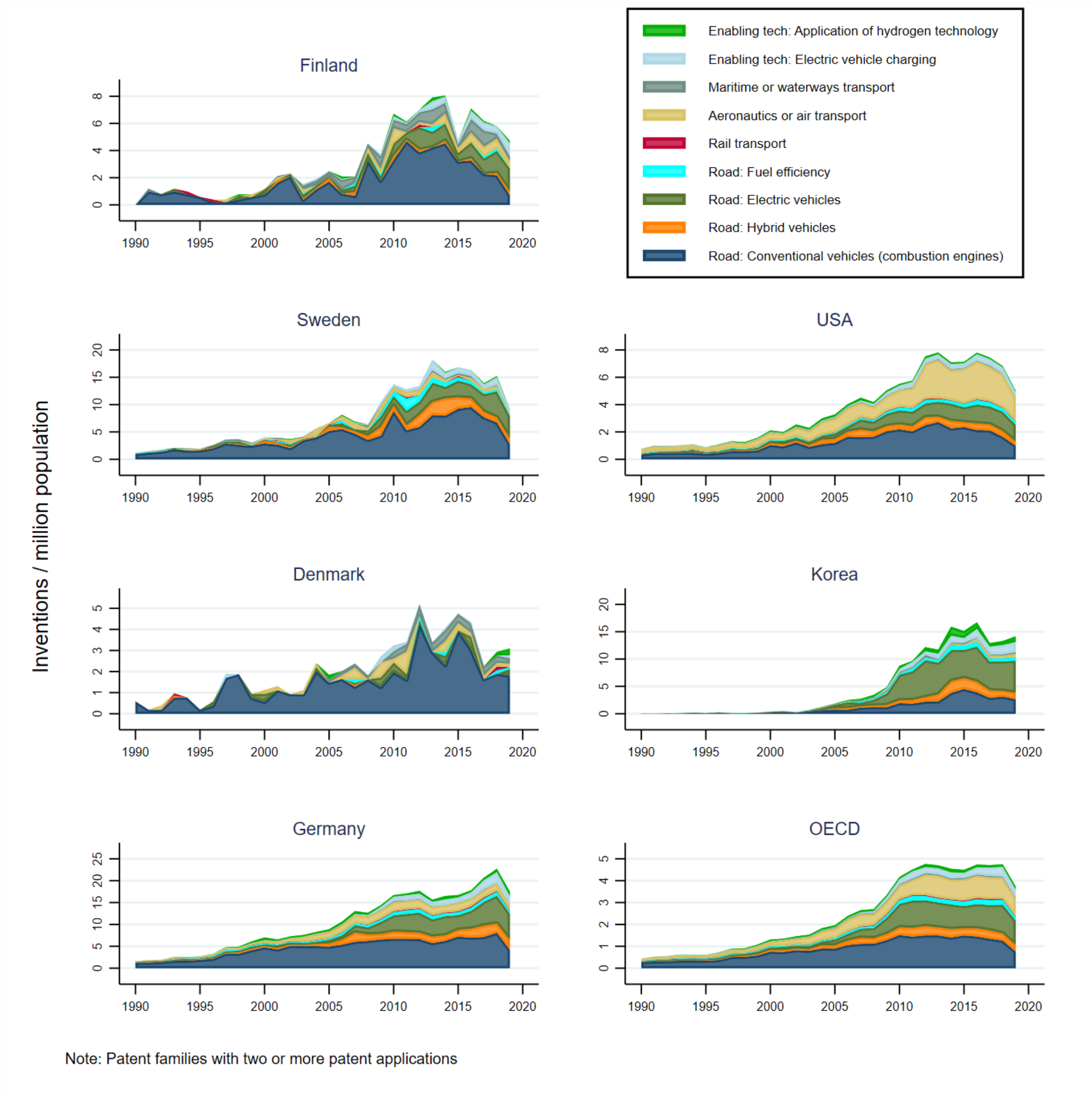

Figure A5. Inventions in (4) climate change mitigation technologies related to transportation per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

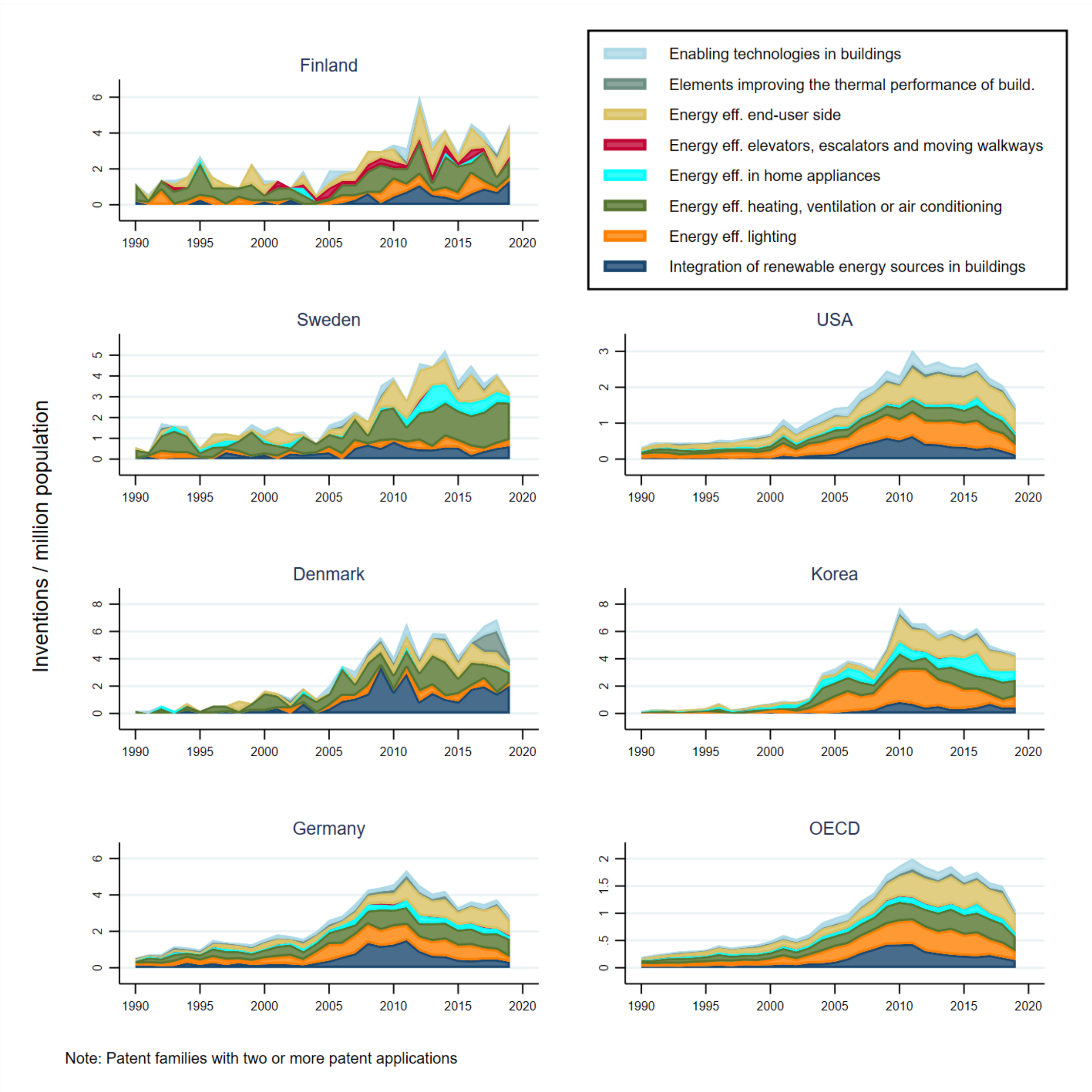

Figure A6. Inventions in (5) climate change mitigation technologies related to buildings per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

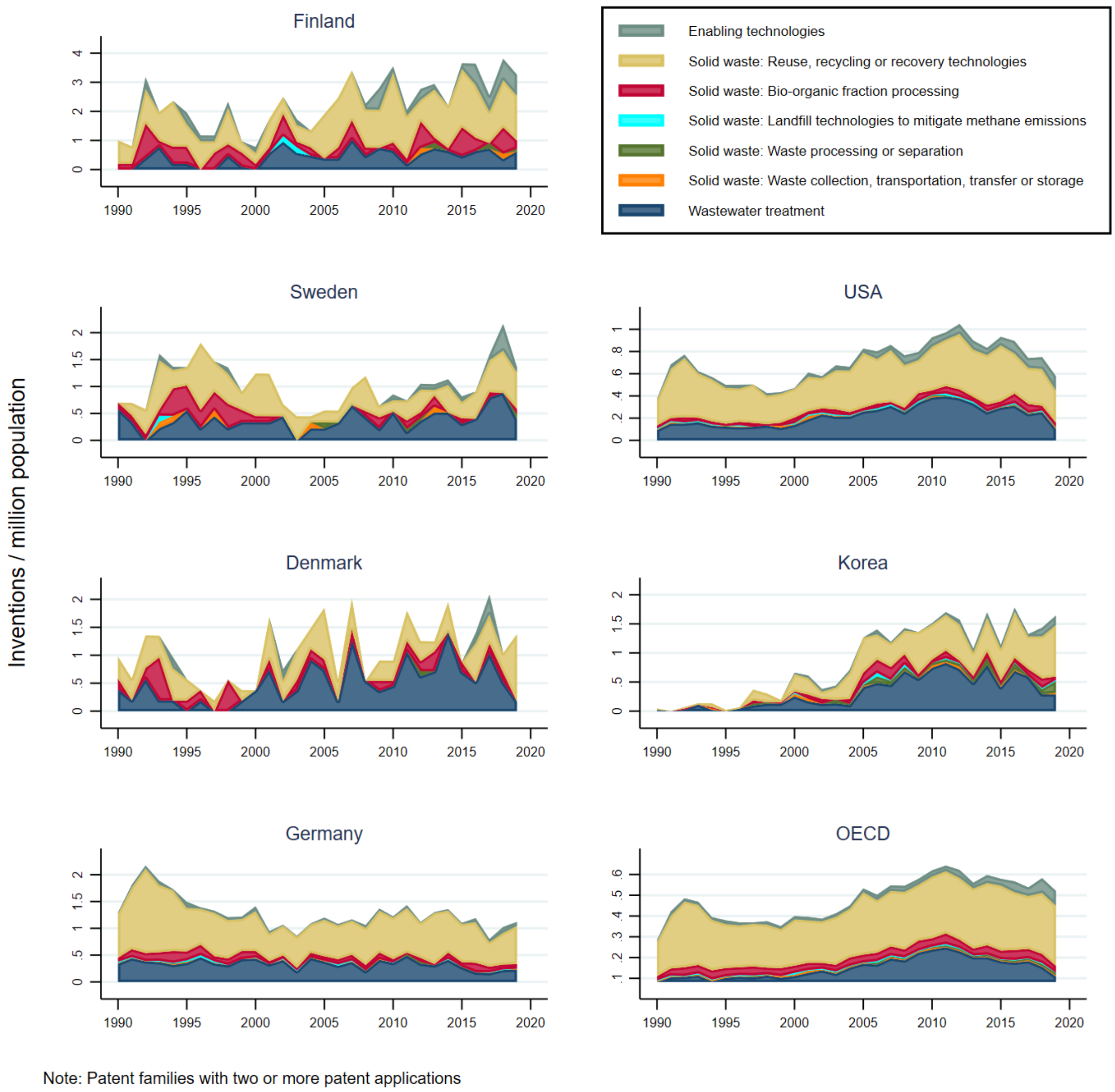

Figure A7. Inventions in (6) climate change mitigation technologies related to wastewater treatment or waste management per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

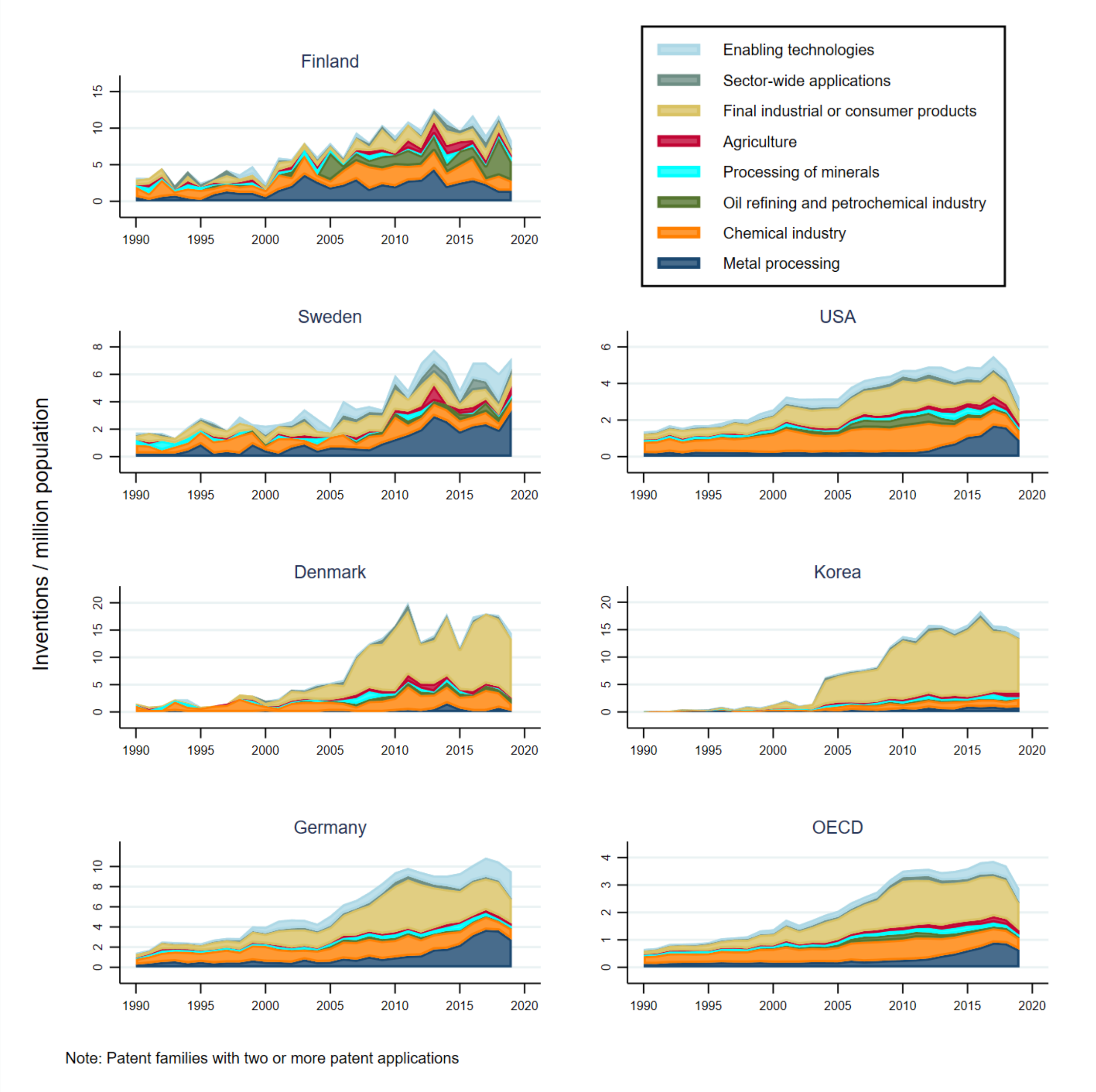

Figure A8. Inventions in (7) climate change mitigation technologies related in the production or processing of goods per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.

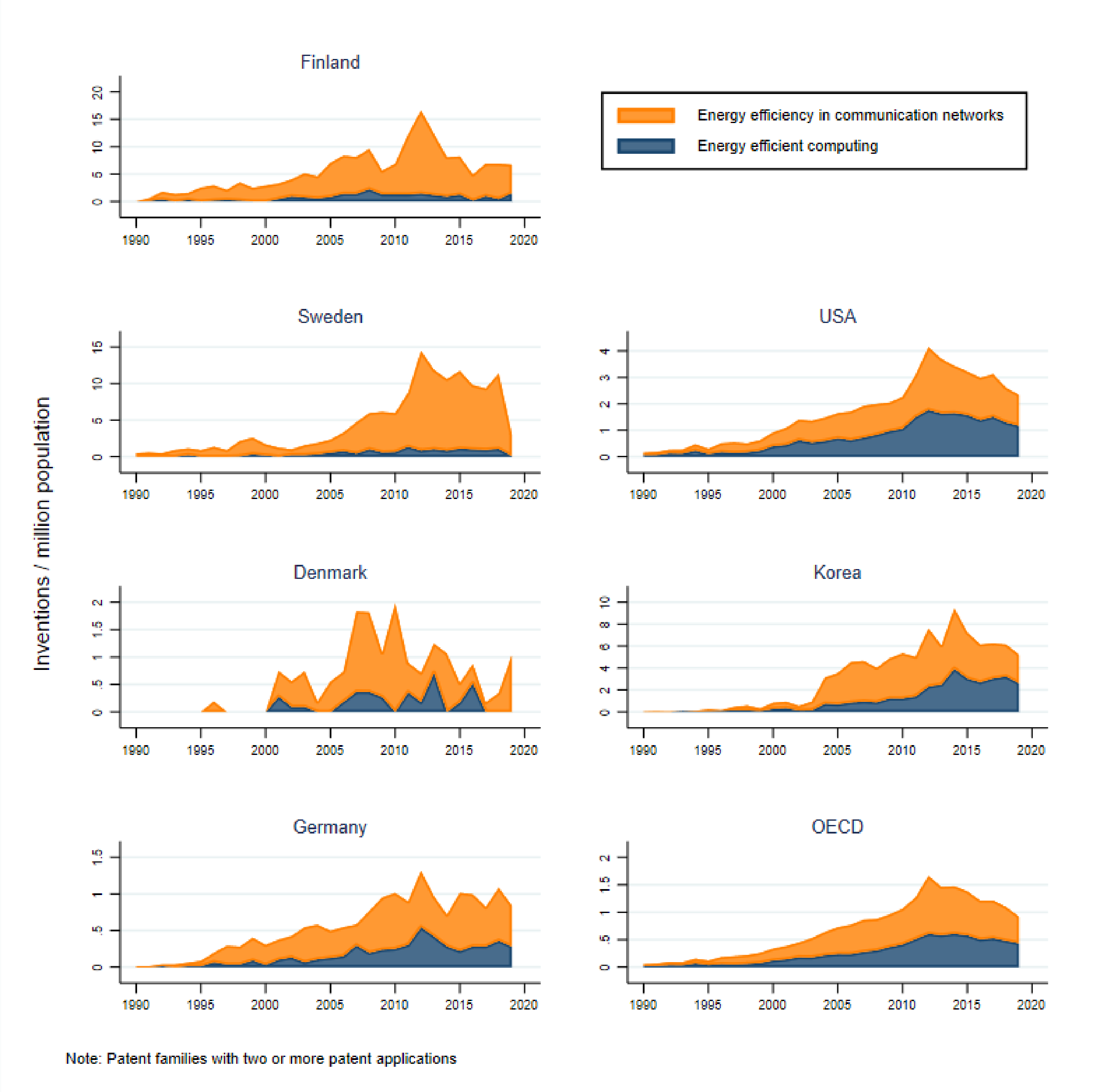

Figure A9. Inventions in (8) climate change mitigation technologies related to information and communication technologies (ICT) per million population in Finland, Sweden, Denmark, Germany, USA, Korea and OECD countries between 1990-2019 (patent family size two or more). Source: Patstat.