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Labour Productivity and Development of Carbon Competitiveness

INDUSTRY-LEVEL EVIDENCE FROM EUROPE

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Abstract

A drastic decline in global greenhouse gas (GHG) emissions is needed to stop the climate change. This requires a variety of political and market mechanisms. Europe is globally at the forefront among the industrialised countries in reducing its GHG emissions. We analyse the development of emission intensities – GHG emissions relative to value added produced – and use a panel data to further our understanding of their evolution at the level of industries in 2008–2020 in Europe. We find that labour productivity is negatively associated with changes in GHG-emission intensities. Furthermore, higher investments, higher carbon prices within the ETS mechanism, and higher environmental taxes are associated with lower GHG-emission intensities. Consequently, policies that promote productivity growth and financial incentives to decrease emissions lead to lower emissions. Finland's carbon competitiveness, as measured by relative GHG-emission intensities, varies by industries.

Tiivistelmä

Työn tuottavuus ja hiilikilpailukyvyn kehitys toimialatasolla Euroopassa

Maailman kasvihuonekaasupäästöjen (khk) määrää on vähennettävä huomattavasti, jotta ilmastonmuutos saadaan pysäytettyä. Tämä vaatii erilaisia poliittisia ja markkinamekanismeja. Eurooppa on ollut teollisuusmaiden joukossa maailman eturintamassa vähentämässä khk-päästöjään. Analysoimme päästöintensiteetin – khk-päästöt suhteessa tuotannon arvonlisäykseen – kehitystä ja käytämme paneeliaineistoa vuosille 2008–2020 ymmärtääksemme sitä paremmin toimialatasolla Euroopassa. Tulostemme mukaan työn tuottavuus liittyy negatiivisesti khk-päästöintensiteetin kehitykseen. Lisäksi korkeammat investoinnit, korkeampi hiilen hinta ETS-järjestelmässä sekä korkeammat ympäristöverot liittyvät alempaan khk-intensiteettiin. Siten politiikkatoimenpiteet, jotka tukevat tuottavuuskehitystä, sekä taloudelliset kannustimet alentaa päästöjä johtavat niiden alenemiseen. Suhteellisella päästöintensiteetillä mitattuna Suomen hiilikilpailukyky vaihtelee toimialoittain.

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Keywords: Greenhouse gas emissions (GHG), GHG-intensity, Carbon competitiveness, Productivity, ETS

Avainsanat: Kasvihuonekaasupäästöt, Päästöintensiivisyys, Hiilikilpailukyky, Tuottavuus, ETS

JEL: C23, O44, Q54, Q56

Contents

Introduction

Global greenhouse-gas (GHG) emissions need to be drastically reduced in the fight against climate change. Even atmospheric-carbon-removing technologies may have to be developed. Europe is at the global forefront in reducing its carbon emissions among the major economies. The annual GHG emissions in the EU27 area declined from over 4.8 billion tonnes in 1990 to 3.3 billion tonnes in 2020, a reduction of 32 per cent. Between 1995 and 2020 emissions decreased by 27 per cent while the volume of GDP increased by 42 per cent. Total emissions have thus declined while GDP has increased, meaning that the GHG intensity (emissions/GDP) of the EU economy has decreased significantly.

In addition to more traditional issues of competitiveness such as production costs, supply chains, product development, marketing, and customer relations, driving down GHG emissions has surfaced as a new strategic dimension for firms. Emissions may be a direct cost for the firm, but they also affect its image and possibly its access to financial markets, among other things.

To study how European industries have managed to improve their carbon competitiveness, we review and analyse the development of GHG-emission intensities (emissions relative to value added produced) and overall emissions. We use an extensive panel data at a disaggregated industry level for the years 2008–2020 covering 31 countries (the 27 EU countries, Iceland, Norway, Switzerland, and the United Kingdom) and 59 industries (see list in Appendix A).

The most important avenue to improving carbon competitiveness is technological change whereby emissions decline through investment in low-carbon technology (see discussion in the next section). It is likely that modern technology is generally more efficient than older technology not just in overall terms and in energy consumption but also in terms of carbon emissions. This development is encouraged with the implementation of the European Emissions Trading System (ETS) that affects certain industries – manufacturing and power industries in particular for now, see e.g. Martin, Muûls, and Wagner (2016) for a review.

Based on the analysis, we find a generally declining trend in GHG-emission intensities. Labour productivity is negatively associated with the change in intensities. Thus, according to our results, the change in emission intensity has on average been more negative when productivity is higher. Higher productivity is likely to mean that the industry is operating closer to the technological frontier and thus its know-how and ability to develop and absorb the newest, probably more energy-efficient and low-emission technology is higher than otherwise.

We also find that higher investments are typically associated with lower emission intensities, albeit the coefficients are very low. Our results further indicate that a lagged rise in the price of carbon is often associated with a decline in emission intensities. The ETS has thus been working and created an incentive for firms to decrease their emissions. Finally, we find that environmental taxes are negatively associated with a change in emissions intensity. The results are due to taxes on energy, resources, and transport.

Consequently, policies that promote productivity growth and financial incentives to decrease emissions lead to lower emissions. One further step forward in this respect is to enlarge the number of industries that take part in the ETS. Productivity growth can be enhanced, among other things, by improving the working of national and EU internal markets, and targeting green-technology R&D.

The structure of the paper is as follows. We first review some relevant literature and discuss regulation and policies that have been implemented in the EU. Then we discuss our model specification and the data we use. This is followed by some descriptive analysis and finally our econometric panel data analysis.

Earlier research

GHG emissions can be thought of as pollution with a negative externality emitted during the production process, much like any other form of pollution. On the other hand, GHG emissions do differ from more ‘conventional’ pollution such as littering, discarded plastic, emissions of heavy metals, chemical leakages, overuse of pesticides etc. in that carbon dioxide acts in an indirect and a not-very visible way slowly warming the climate, which is detrimental to the planet only in the longer term. Many other forms of pollution also remain more local in their impact. Consequently, the impact of GHG emissions is more global and less visible to the plain eye than that of many other forms of pollution and may therefore also need more international political regulation to be contained.

There are different ways to decrease GHG emissions, but we will concentrate on technological change, driven by investment. This is likely to be the most important and typical route to lower emissions, but it is also one that we can somehow test in our empirical analysis.

Earlier research finds that technological change drives the decrease in pollution or emissions. Levinson (2015) finds that the amount of air pollution emitted by US manufacturers fell by two-thirds between 1990 and 2009, a result which is almost completely due to a decline in emission (air pollution in general) intensity of production instead of a shift in the structural composition of output. Also, Levinson (2009) – dividing manufacturing into a very disaggregated 450 industries – finds that the decline in air pollution in the US was mostly due to technological change, while changes in the composition of manufacturing industries played a s smaller role. According to Shapiro and Walker (2018), the decline in air pollution emissions in US manufacturing in 1990–2008 was mostly due to within-product changes in emissions intensity rather than changes in output or in the composition of products produced.

Likewise, Ghosh et al. (2020) find that technological change was the key driver of improvements in emission intensities in 1995–2009, whereas structural changes or changes in the composition of aggregate production had a smaller or even a negative contribution. Kuosmanen and Maczulskij (2022) find that in Finland the firms that continued their operations from one year to the next were the main drivers of carbon productivity growth – the inverse of carbon intensity – in the manufacturing sector in 2000–2019. Meanwhile, the entry and exit of firms to/from the market had a negative impact.

There are some studies on the possible convergence of emissions. Pettersson's et al. (2014) survey of the convergence of per-capita-emissions research finds that there is very little if any convergence in this respect at the global level between countries. This is intuitive given the different levels of economic development, production structures, and national energy and other resources.

Bai et al. (2019) conducted an analysis using a dataset of 88 countries and regions from 1975 to 2013. They identified five distinct convergence clubs with significant differences in carbon productivity growth. According to their results, economies with higher GDP per capita and R&D investment had tended to converge to a club with higher carbon productivity (i.e. lower carbon intensity). Meanwhile, economies with higher energy intensity and foreign trade dependence had tended to converge to a club with a lower carbon productivity.

Brännlund, Lundgren, and Söderholm (2015) analysed the convergence of CO_2 emission intensities across fourteen Swedish manufacturing sectors in 1990–2008. They find conditional β-convergence with a speed of convergence that varies so that higher capital intensity is associated with a lower convergence rate towards different steady states.

Decreasing pollution and emissions on a purely voluntary basis is typically not efficient because the costs of the pollution are not covered by the polluter but by the community at large, and in the case of GHG emissions the whole planet. Consequently, policies and legislation – preferably at an international level – must be implemented to force pollution down to some desired level. The EU and the individual countries have implemented different systems, guidance, legislation, taxes, R&D subsidies, carbon pricing, etc. that have the aim of decreasing GHG emissions and accelerating convergence towards eventual zero net emissions in the member countries. We can assess the impact of some of these policies.

How can firms be directed towards using cleaner production technologies? According to Acemoglu et al. (2012, 2016), a combination of carbon taxes and research subsidies leads to the development and usage of new clean technologies. Taxes control and discourage current emissions, while R&D finds solutions for a low-carbon future. Aghion et al. (2020) find that pro-environmental attitudes and their interaction with competition both have a significantly positive effect on the probability for a firm to develop cleaner technologies.

European Emissions Trading System

The European Union first introduced ETS in 2005. Its purpose is to create a market and a price for carbon emissions. The size of the market (the volume of CO2 emissions allowed) decreases at a predetermined rate and thus emissions become ever costlier. This creates an incentive for firms to cut their emissions.

The first three years of ETS, its first phase, can be described as a learning period for all actors. The second phase started in 2008 and ended in 2012, and the third phase that followed ended in 2020. Our analysis that covers the years 2008–2020 is thus divided between phases 2 and 3. We use a dummy variable to assess the impact of the introduction of the third phase. Phase 2 coincided with the first commitment period of the Kyoto Protocol. The ETS countries then had concrete emission reduction targets to meet. Iceland, Liechtenstein, and Norway joined ETS at this time. Among other things, the proportion of free allocation fell to around 90 per cent, and firms were allowed to buy international credits totalling around 1.4 billion tonnes of CO2-equivalent emissions. Phase 3 (2013–2020) included: 1) an EU-wide cap on emissions instead of the earlier system of national caps; 2) auctioning, instead of free allocation, as the method for allocating allowances; 3) harmonised allocation rules applying to the allowances still given away for free; and 4) more sectors and gases than before.[1]

ETS carbon prices have been rising since only after mid-2017, preceded by many years of decline, and of course there were many free allocations and exceptions also. Nevertheless, Bayer and Aklin (2020) find that the ETS succeeded in reducing CO2 emissions despite low prices. They argue that low prices can be due to an oversupply of permits but also a signal that the demand for carbon permits will weaken. Also varying GDP growth developments affect carbon prices through changes in the demand for permits. It is worth noting that after the publishing of their analysis, ETS prices have risen considerably in the EU.

Consequently, a combination of costly carbon permits, R&D subsidies for greener production technologies, environmental taxes and regulation, and consumer and financial market pressure to reduce emissions will drive down carbon intensity in production and thus raise firms' carbon competitiveness. The global impact is strengthened with the EU Carbon Border Adjustment Mechanism which, despite technical and possibly legal challenges in its implementation, will probably put pressure on non-EU countries to take steps towards the same direction (see e.g. Kuusi et al., 2020). For example, Japan started a carbon-pricing scheme in stages in April 2023.

Model specification and the data

GHG emissions are produced as a by-product of economic activity, largely, but not exclusively, due to the burning of fossil fuels in various forms for energy production. Given the local production technology, emissions are therefore a function of the produced GDP or value added. Given overall technology Γ in country i, emissions E_i in year t are thus given by

$$E_{it} = \Gamma_{it} Y_{it}, \qquad (1)$$

where Y is GDP, or value added if we are analysing an industry or a specific firm. Rearranging this equation, we have the GHG intensity of the economy, $\Gamma_{it} = E_{it}/Y_{it}$. It shows how many tonnes of greenhouse gases are produced and emitted into the atmosphere per unit of GDP (value added or income). At the country level, one major factor affecting the aggregate outcome is how much of all electricity, heating and cooling is produced using fossil fuels. Increasingly in the future, also the share of electric cars, vans, and lorries will make a big difference between countries during the transition period.

The emission intensity varies over time and can evolve through changes in production structure and technology. As already seen above, according to several studies, technology change dominates this development over structural changes.

Our interest is to analyse the developments at the level of sectors that sum to total GDP at the national level. We thus have

$$E_{it} = \sum_j \Gamma_{ijt} Y_{ijt}, \qquad (2)$$

where j represents the industries in country i. In each country i and industry j the GHG-emission intensity Γ in year t is a function of the technology that firms use:

$$\Gamma_{ijt} = \Gamma_{ijt}(\pi, I, \tau, \eta), \qquad (3)$$

where π denotes productivity, I is investment (investment in general and/or investment into green technologies), τ is taxes and other costs on polluting, energy use etc., and η is a vector of other factors that may affect emission intensity in the industry. Productivity reflects the industry's distance from the technological frontier. If the distance is small, the level of know-how is high and the capability to develop, absorb and implement modern solutions is probably higher than when the distance is larger. On the other hand, if the industry uses outdated (carbon-intensive) technology, it has more potential for catching up with lower levels of GHG emissions. One of our interests is to see how the level of productivity is associated with the changes in intensity. Investments are included because they are a means for the industry to carry out a technological change or a change in production structure that will affect its emissions among other things.

We use both overall investment data at the level of industries and some data on environmental investments. The former most probably include (many of) the latter investments. Technology can change via investment into new production methods and equipment. Investment will then also change the capital stock and affect production volumes, ceteris paribus.

Of course, we cannot assume that all investments decrease GHG intensity. On the other hand, we can assume that new technology is typically more energy efficient than older technology, which is likely to mean that emission intensity tends to decrease even if fossil fuels are still used. There may also be an explicit intention to find production processes that decrease emissions (and pollution in general). This can arise from producers' own concern over the environment, as a response to environmental taxes, costs, and legislation, or it may be demand-based following changes in consumer attitudes. We do not possess data that could be used to control for shifts in attitudes or preferences. However, we do have data for environmental taxation, certain specific investment data, and EU ETS data that we can use to control some of these shifts. Taxation also reflects the society's preferences.

Among other things, we verify whether openness to trade as measured by the industry's goods exports (separately intra-EU exports and extra-EU exports) may affect the development of emission intensity. Exporting firms are on average more productive than non-exporting firms, and thus also probably use more efficient and modern technology than the latter. On the other hand, we also control for productivity levels.

We will analyse separately two 'independent' variables: the log of CO2-equivalent emissions' intensity of value added, and the log volume of CO2-equivalent emissions as measured in tonnes.

Based on the above, emission intensity in logs (in lower-case letters) in industry j is given by:

$$\gamma_{ijt} = e_{ijt} - y_{ijt} \qquad (4)$$

and consequently

$$\gamma_{ijt} = \gamma_{ijt}(\pi, I, \tau, \eta). \qquad (5)$$

We first control for the level of labour productivity. There remain considerable differences in intra-industry productivity and thus technological and know-how levels in Europe. These differences may contribute to the levels and development of GHG intensities. Our investment data include overall gross fixed capital formation in the industries. Here and in other investment and tax variables there are some gaps in the available data. All data are from Eurostat unless otherwise stated. Some of the independent variables are lagged by one year to decrease endogeneity problems. We run the model using xtreg in Stata.

We control data for environmental expenditure by environmental domains at the level of industries: overall investment in equipment and plant for pollution control, as well as its disaggregation into the protection of ambient air and climate (CEPA1), wastewater management (CEPA2), waste management (CEPA3), and other environmental protection activities (CEPA4–9).

These investments are expressed as ratios to the value of output. We further control for the total environmental protection activities investment in equipment and plant linked to cleaner technology ('integrated technology') relative to the value of gross output by industries. These data are also disaggregated by CEPA1–9 as above.

We also use environmental taxes by economic activity relative to the value of output and separately their disaggregation into energy taxes, pollution taxes, resource taxes, and transport taxes.

Additional data are a dummy for ETS3 from 2013 onwards, and an annual price for EU carbon permits. According to the third phase of the EU ETS, in force between 2013 and 2020, the total number of allowances issued was reduced annually by 1.74 per cent. The system was extended to power plants, many energy-intensive industrial sectors, and aircraft flying between airports in the EU, Norway, and Iceland. There are also annual national data for the total allocated allowances in ETS (all stationary installations) from Macrobond.

Some of the econometric analysis is performed using data for manufacturing industries, and electricity, gas, steam and air conditioning supply, i.e. industries C and D in the NACE Rev 2 classification, twenty industries in total. On the other hand, we also use data for the whole economy (59 industries). Most of the emissions are due to the energy and power industries, some manufacturing, agriculture, and transportation. The emission allowances affect manufacturing and energy, so we tested this partial dataset separately. Furthermore, emission intensity in agriculture and transportation did generally improve during the years we cover in the analysis. At least as concerns transportation technology will slowly start to change during the 2020s when heavy electric vehicles start to enter the markets. The change has already come to city buses. The data are mostly at the two-digit level of industries. The included industries are listed in Appendix A.

We tested the model specifications using the Hausman test to determine whether we need to use a fixed effects or a random effects model. Fixed effects with robust standard errors were used wherever Hausman test allowed.

Recent developments in GHG intensities

GHG-emission intensities vary a lot depending on which industry is analysed. Typically, the production of services emits much less GHGs than primary or secondary sectors, except for transportation. There are also huge differences between the manufacturing sectors. The main factor is how much fossil fuels are used in the production process. Additionally, some production processes in manufacturing emit considerable amounts of emissions, e.g., in the production of cement.

In this section we will review and discuss the GHG intensities in the EU27 on average, Denmark, Finland, Germany, and Sweden in 2020. Table 1 covers the primary and secondary sectors and Table 2 covers services.

We can see that average intensity (emissions/GDP in the first row) was broadly the same in the EU27 and the first three countries, but much lower in Sweden. One major difference in this respect is the supply of electricity, gas, steam, and air conditioning sector which is much less GHG intensive in Sweden.

Finland's primary production is on par with that in Sweden in terms of intensity, and much lower than in the average EU27 or in Denmark and Germany. However, crop and animal production (agriculture) in Finland is considerably weaker in this respect. Forestry and logging account for a much larger share of total value added in primary production in Finland. This pushes down the average emission intensity. Note that these data do not include the impact of primary production on land use, land-use change, and forestry (LULUCF) emissions or sinks.

GHG intensity of manufacturing production is lower in Denmark than it is in Sweden or Germany. The intensity is even higher in Finland and the EU27 on average. This is strongly affected by the production structure. The most GHG-intensive manufacturing industries are coke and refined petroleum products (C19), other non-metallic mineral products (C23), and basic metals (C24). Apart from the last industry, the other metal industries have very low intensities.

The production of electricity, and the supply of gas, steam and air conditioning has very different intensities depending largely on how important the use of fossil fuels is in power generation. Intensity was somewhat below the EU27 average in Finland and above it in Germany in 2020. On the other hand, intensity was very low in Sweden where the use of nuclear and hydropower is relatively more important. Intensity in this sector varied from 296 grams per euro in Iceland to over 14,000 grams per euro in Cyprus in 2020. As energy sources other that those based on the use of fossil fuels are constructed, this sector is the one that typically offers the largest potential for cuts in total emissions.

These data have been calculated vis-à-vis value added, and there are sectors where value added can be very vol-

Table 1 GHG intensities in primary and secondary production in selected countries in 2020, grams per euro of value added (current prices)

Codes	Sector	EU27	Denmark	Finland	Germany	Sweden
Total	**Total**	**227**	**260**	**211**	**188**	**92**
A	Agriculture, forestry and fishing	2,149	3,023	1,378	2,447	1,366
A01	Crop and animal production, hunting; related services	2,431	3,314	4,478	2,688	2,544
A02	Forestry and logging	180	260	95	231	252
A03	Fishing and aquaculture	1,089	1,307	1,139	211	812
B	Mining and quarrying	1,438	797	447	988	299
C	Manufacturing	384	136	317	290	216
C10–12	Food products; beverages and tobacco products	238	207	58	229	130
C13–15	Textiles, wearing apparel, leather products	104	34	21	84	42
C16	Wood and of products of wood and cork	110	39	33	65	128
C17	Paper and paper products	700	95	948	774	239
C18	Printing and reproduction of recorded media	101	22	12	111	23
C19	Coke and refined petroleum products	5,545	3,132	3,095	5,821	4,087
C20	Chemicals and chemical products	..	69	508	555	..
C21	Basic pharmaceutical products and preparations	..	5	1	46	..
C22	Rubber and plastic products	90	32	16	80	50
C23	Other non-metallic mineral products	2,504	1,936	1,176	1,900	1,714
C24	Basic metals	2,729	240	2,337	2,925	1,162
C25	Fabricated metal products	58	52	4	48	28
C26	Computer, electronic and optical products	..	5	2	26	4
C27	Electrical equipment	35	18	1	18	11
C28	Machinery and equipment n.e.c.	..	18	3	25	13
C29	Motor vehicles, trailers and semi-trailers	46	40	15	53	14
C30	Other transport equipment	..	20	33	41	9
C31–32	Furniture; other manufacturing	..	12	4	30	16
C33	Repair and installation of machinery and equipment	32	63	0	20	56
D	Electricity, gas, steam and air conditioning supply	2,683	1,716	2,497	2,968	576
E	Water supply; sewerage, waste management and remediation activities	1,243	1,188	1,162	480	426
E36	Water collection, treatment and supply	158	14	0	12	40
E37–39	Sewerage, waste management, remediation activities	1,611	1,491	1,564	576	507
F	Construction	76	104	101	56	60

Note: Greenhouse gases (CO2, N2O, CH4, HFC, PFC, SF6, and NF3, all in CO2 equivalent volumes) relative to current prices gross value added in grams per euro. Printing and reproduction of recorded media is 2019 for Finland. Coke and refined petroleum products is from 2019 for all countries.

Source: Eurostat.

Table 2 GHG intensities of service sectors in selected countries in 2020, grams per euro of value added (current prices)

Codes	Sector	EU27	Denmark	Finland	Germany	Sweden
Total	**Total – all NACE activities**	**227**	**260**	**211**	**188**	**92**
G	Wholesale and retail trade; repair of motor vehicles	69	27	21	51	33
G45	Wholesale and retail trade and repair of motor vehicles	73	77	9	33	84
G46	Wholesale trade, except of motor vehicles and motorcycles	73	22	2	46	24
G47	Retail trade, except of motor vehicles and motorcycles	62	17	49	66	21
H	Transportation and storage	621	2,647	933	542	244
H49	Land transport and transport via pipelines	547	909	808	315	183
H50	Water transport	4,356	5,344	3,850	5,981	2,823
H51	Air transport	4,064	5,082	4,719	4,432	4,597
H52	Warehousing and support activities for transportation	87	57	82	180	..
H53	Postal and courier activities	127	89	52	214	..
I	Accommodation and food service activities	64	39	59	81	14
J	Information and communication	12	6	1	9	3
J58	Publishing activities	10	3	1	23	1
J59–60	Motion picture, video, television programme production; programming and broadcasting activities	25	18	0	18	7
J61	Telecommunications	15	6	3	8	3
J62–63	Computer programming, consultancy, and information service activities	10	4	0	6	3
K	Financial and insurance activities	12	3	23	11	4
K64	Financial service activities	12	4	33	10	5
K65	Insurance, reinsurance and pension funding	10	3	7	15	1
K66	Activities auxiliary to financial services and insurance activities	15	2	21	10	4
L	Real estate activities	4	4	2	2	4
M	Professional, scientific and technical activities	19	9	2	20	10
M69–70	Legal and accounting activities; activities of head offices; management consultancy activities	16	9	1	20	15
M71	Architectural and engineering activities; technical testing and analysis	21	12	1	22	..
M72	Scientific research and development	19	2	6	9	..
M73	Advertising and market research	38	12	0	29	10
M74–75	Other professional, scientific and technical activities; veterinary activities	24	12	0	27	14
N	Administrative and support service activities	43	34	33	7	32
N77	Rental and leasing activities	74	23	12	6	84
N78	Employment activities	18	5	0	5	5
N79	Travel agency, tour operator and other reservation service and related activities	99	47	354	73	47
N80–82	Security and investigation, service and landscape, office administrative and support activities	35	58	49	7	26
O	Public administration and defence; compulsory social security	33	33	45	24	6
P	Education	19	8	7	21	4
Q	Human health and social work activities	28	7	8	24	8
Q86	Human health activities	26	7	8	19	7
Q87–88	Residential care activities and social work activities	33	7	9	36	9
R	Arts, entertainment and recreation	45	33	33	25	25
R90–92	Creative, arts and entertainment activities; cultural activities; gambling and betting activities	30	27	22	24	18
R93	Sports activities and amusement and recreation activities	66	46	42	27	34
S	Other service activities	56	17	25	67	17
S94	Activities of membership organisations	47	8	28	58	6
S95	Repair of computers and personal and household goods	76	50	0	113	59
S96	Other personal service activities	62	25	24	73	27

Note: Greenhouse gases (CO2, N2O, CH4, HFC, PFC, SF6, and NF3, all in CO2 equivalent volumes) relative to current prices gross value added in grams per euro. Air transport is from 2019 because the covid19 pandemic distorted the value-added data in 2020 for this sector.

Source: Eurostat.

atile. For example, we can see that the intensity in Sweden in the coke and refined petroleum products industry was very high in 2020. The figure in 2019 was just 4,087 g/€. There are also considerable differences in intensities between countries in water supply, sewerage, and waste management with Germany and Sweden having relatively low intensities. The differences seem to arise from sewerage, waste management, and remediation activities.

Table 2 shows the respective data for the service industries. Most service industries have very low carbon emission intensities. In terms of aggregate emissions, only the transport sector is really of significance. The differences between the presented countries in transport industries are relatively small in air transport., but larger than this in water and land transport.

Finally, Table 3 shows GHG intensities in Finland relative to the EU27 average (= 100) in 2020. The aggregate for all economic activities was 93.2 which is quite close to the EU27 average represented by 100. Primary production (agriculture, forestry, and fishing) has significantly lower intensity that the EU27 average, but this is due to forestry, whereas agriculture is clearly more intensive. Mining and quarrying industry is much less intensive that the EU27 average.

Manufacturing is somewhat less GHG intensive in Finland, but again there are very large differences between industries with some intensities that are only a fraction of the EU27 average. We lack data for six industries because the Eurostat had no data for the EU27. Out of the manufacturing industries we do have data for, only the Finnish manufacturing of paper and paper products had an intensity higher than the EU27 average. This industry is one of the major manufacturing emitters of GHGs in Finland. Other large emitters include coke and refined petroleum products, and basic metals. The latter was relatively close to the EU27 average in 2020. Also, the manufacturing of other non-metallic mineral products, and of chemicals and chemical products emit a lot of GHGs. Intensity in the former is about half of the EU27 average. We have no data for the latter. One factor that affects these results is the product structure of output. For example, if cement is a very important part of total production in other non-metallic mineral products, average GHG intensity in this industry is likely to be high. For this analysis we would need more disaggregated data than is available.

Energy and water management industries have a slightly lower intensity in Finland than the EU27 average, but intensity in the construction sector is one-third higher. Among the different service sectors, intensity is much lower in Finland than in the EU27 in trade, information and communication, professional, scientific and technical activities, administrative and support service activities (except travel agency activities, and security and investigation etc. activities), education, health and social work activities, arts, entertainment and recreation, and other service activities. The intensity is about the same in accommodation and food services, but higher in land and air transport, financial services and their auxiliary activities, and public administration and defence.

Appendix B shows how GHG intensities have developed since 2008 in 24 industries in the EU27 on average and eight separate EU countries, including Austria, Czechia, Denmark, Finland, France, Germany, the Netherlands, and Sweden. These countries often form a relatively tight bunch with a declining trend in intensities. We can also see that in some industries the differences in the levels of intensities are relatively large and persistent. One would perhaps have expected more convergence from the development. Czechia represents the 'new' EU countries and former transition countries. In many industries, its intensity is still much higher than in the other countries included in the graphs despite a lot of foreign direct investment which should drive down the emissions. We can also see that the covid19 pandemic distorted the data a little, as in some industries the intensities increased unexpectedly in 2020. For example, in accommodation and food service industries, value added often took a hit in the pandemic, but it does not seem to have affected the industry's emissions equivalently.

Table 3 GHG intensities in Finland in 2020 relative to EU27 average (=100)

Codes	Sector	Index	Codes	Sector	Index
Total	**Total**	**93.2**			
A	Agriculture, forestry, and fishing	64.1	H52	Warehousing and support activities	94.3
A01	Crop and animal production etc.	184.2	H53	Postal and courier activities	41.1
A02	Forestry and logging	52.8	I	Accommodation and food service activities	91.9
A03	Fishing and aquaculture	104.6	J	Information and communication	7.1
B	Mining and quarrying	31.1	J58	Publishing activities	6.9
C	Manufacturing	82.5	J59–60	Motion picture, video, TV programmes	0.5
C10–12	Food products; beverages; tobacco	24.5	J61	Telecommunications	22.9
C13–15	Textiles, wearing apparel, leather etc.	20.5	J62–63	Computer programming, consultancy, etc.	1.6
C16	Wood and of products of wood	30.0	K	Financial and insurance activities	188.1
C17	Paper and paper products	135.4	K64	Financial service activities	264.0
C18	Printing and recorded media	11.7	K65	Insurance, reinsurance, pension funding	68.0
C19	Coke and refined petroleum products	30.0	K66	Auxiliary activities	144.2
C20	Chemicals and chemical products	..	L	Real estate activities	37.3
C21	Pharmaceutical products	..	M	Professional, scientific and technical activities	8.5
C22	Rubber and plastic products	17.9	M69–70	Legal, accounting, head offices; consultancy	4.3
C23	Other non-metallic mineral products	47.0	M71	Architectural and engineering	6.2
C24	Basic metals	85.6	M72	Scientific research and development	32.0
C25	Fabricated metal products	6.9	M73	Advertising and market research	0.1
C26	Computer, electronic, optical products	..	M74–75	Other professional etc. activities	1.4
C27	Electrical equipment	1.6	N	Administrative and support service activities	76.5
C28	Machinery and equipment n.e.c.	..	N77	Rental and leasing activities	16.7
C29	Motor vehicles, trailers and semi-trailers	31.7	N78	Employment activities	0.6
C30	Other transport equipment	..	N79	Travel agency etc. activities	356.9
C31–32	Furniture; other manufacturing	..	N80–82	Security and investigation etc. activities	141.7
C33	Repair and installation of machinery	1.1	O	Public administration and defence	134.6
D	Electricity, gas, steam, A/C supply	93.1	P	Education	38.2
E	Water supply; waste management	93.5	Q	Human health and social work activities	29.9
F	Construction	132.9	Q86	Human health activities	31.6
G	Wholesale and retail trade	31.0	Q87–88	Residential care and social work activities	26.3
G45	Trade and repair of motor vehicles	12.3	R	Arts, entertainment and recreation	72.4
G46	Wholesale trade	3.2	R90–92	Creative, arts, entertainment etc. activities	71.4
G47	Retail trade	79.4	R93	Sports, amusement, recreation activities	64.5
H	Transportation and storage	150.1	S	Other service activities	44.0
H49	Land transport and pipelines	147.5	S94	Activities of membership organisations	58.7
H50	Water transport	88.4	S95	Repair of computers etc. goods	0.1
H51	Air transport	116.1	S96	Other personal service activities	38.6

Note: Greenhouse gases (CO2, N2O, CH4, HFC, PFC, SF6, and NF3, all in CO2 equivalent volumes) relative to current prices gross value added in grams per euro. Some manufacturing sectors did not have data for the EU27. Printing and recorded media (C18) and air transport (H51) are from 2019, because the 2020 figures were outliers.

Source: Eurostat.

Estimation results

Greenhouse gas emission intensities

We begin by analysing the log-changes of GHG intensities in the 20 manufacturing and energy producing sectors in Tables 4 and 5. We first control for the levels of labour productivity (value added divided by hours worked) because we expect that they may be associated with how intensities develop. We assume that a higher level of productivity is evidence of a more modern production technology. Other variables include the industry's investment rate (lagged by one year) and its openness to trade. Some of the independent variables have been lagged by one year to decrease possible endogeneity issues.

Openness to trade is measured as exports of products produced by the industry divided by the value of its output. We separate intra-EU and extra EU-exports. The logic is that exporting firms have, on average, higher productivity than other firms, and this may be visible also in the development of their emissions. In principle, intra-EU exports could be different from extra-EU exports. We can then see if openness to trade matters beyond the level of productivity that is also included. We also control for the log-change in the price of carbon in the EU Emissions Trading System (lagged by one year), and the introduction of the third phase of ETS in 2013 for manufacturing and power generating industries. The latter table 5 also includes data for environmental taxes and investment.

In Table 4 we use fixed effects where the Hausman test allows, but random effects otherwise. The first three specifications have fixed effects. They use either no fixed year

Table 4 Change in log GHG intensity, manufacturing (C) and power industries (D)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Labour productivity	-0.0529 *** (0.0112)	-0.0528 *** (0.0115)	-0.0577 *** (0.0123)	..	-0.0062 ** (0.0027)	-0.0049 *** (0.0017)	-0.0062 ** (0.0027)
Investment rate	-0.0000 * (0.0000)	-0.0000 * (0.0000)	-0.0000 * (0.0000)	..	-0.0000 (0.0000)	0.0000 (0.0000)	-0.0000 (0.0000)
ETS3 dummy	0.0056 (0.0072)	0.0041 (0.0135)	-0.1140 * (0.0657)	-0.0073 (0.0153)	-0.1084 (0.0891)	0.0777 (0.0788)	-0.1774 (0.1676)
Change in ETS price	-0.0140 * (0.0082)	-0.0148 (0.0100)	0.0600 (0.0395)	-0.0210 ** (0.0103)	0.0436 (0.0887)	-0.1513 * (0.0777)	0.1285 (0.1737)
Intra-EU exports	0.0000 * (0.0000)	0.0000 * (0.0000)	0.0000 * (0.0000)	..	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)
Extra-EU exports	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	..	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)
Year	..	0.0003 (0.0028)	..	0.0043 (0.0027)	..	..	..
Constant	0.3593 *** (0.0993)	-0.3085 (5.5674)	0.4399 *** (0.1189)	-8.5879 (5.4878)	0.2007 ** (0.0826)	-0.0559 (0.0712)	0.2411 ** (0.1088)
Observations	6,001	6,001	6,001	6,001	6,001	6,001	6,001
R-squared	0.0149	0.0149	0.0193				
Cross sections	584	584	584	584	584	584	584
Effects	Fixed	Fixed	Fixed	Random	Random	Random	Random
Year*Sector FE						Yes	
Year*Country FE					Yes		Yes
Year FE			Yes		Yes	Yes	

Note: Robust fixed effects. Fixed or random effects. *** p < 0.01, ** p < 0.05, * p < 0.1.

effects (1), a linear year trend (2), or fixed year effects (3). The R square values are quite low, but this may perhaps be expected when analysing annual changes in emission intensities.

First, labour productivity is statistically significant and negative implying that a larger and more negative change in emission intensities has been associated with higher levels of productivity. Consequently, emission intensities may decline at an increasing rate as industries develop. On the other hand, this may increase differences between the EU countries. We also found that the higher labour productivity was the lower was the level of emission intensity (result not shown in the tables), implying

Table 5 Change in log GHG intensity, manufacturing (C) and power industries (D)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Labour productivity	..	-0.1346 ***	-0.0531 ***	-0.1671 ***	-0.0534 ***	-0.1683 ***
	..	(0.0325)	(0.0116)	(0.0423)	(0.0116)	(0.0423)
Investment rate		-0.0000 **	-0.0000 **	-0.0000 **	-0.0000 **	-0.0000 **
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Total environmental taxes	-4.7689 ***	-2.0032	-5.1448 ***	-1.3191	..	..
	(1.2678)	(2.0035)	(1.2816)	(2.1558)		
Energy taxes	..	..	..	..	-4.9765 ***	0.2077
					(1.3063)	(1.9717)
Pollution taxes	..	..	..	..	14.2960 **	3.4313
					(6.2943)	(9.2913)
Transportation taxes	..	..	..	..	-25.5267 ***	-29.5983 ***
					(4.8019)	(5.1123)
Resource taxes	..	..	..	..	-20.3936	-59.2338 *
					(37.1569)	(33.9589)
Environmental investment	..	2.3311 *	..	1.3498	..	1.2488
		(1.2021)		(2.5148)		(2.5705)
Clean-tech investment	..	..	..	-0.2306	..	-0.3445
				(0.4723)		(0.4953)
ETS3 dummy	-0.0123	0.0028	0.0032	0.0046	0.0037	0.0040
	(0.0135)	(0.0150)	(0.0147)	(0.0154)	(0.0147)	(0.0154)
Change in ETS price	-0.0232 **	-0.0177 **	-0.0157	-0.0173 *	-0.0156	-0.0169 *
	(0.0102)	(0.0089)	(0.0101)	(0.0091)	(0.0101)	(0.0091)
Change in allowances	-0.0075	0.0177	0.0063	0.0324	0.0046	0.0294
	(0.0292)	(0.0266)	(0.0294)	(0.0278)	(0.0295)	(0.0278)
Intra-EU exports	..	0.0000	0.0000 **	0.0000	0.0000 *	0.0000
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Extra-EU exports	..	0.0000	0.0000	-0.0000	0.0000	-0.0000
		(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Year	0.0047 *	0.0015	0.0007	0.0020	0.0007	0.0017
	(0.0025)	(0.0028)	(0.0027)	(0.0029)	(0.0027)	(0.0029)
Constant	-9.5576 *	-2.0016	-0.9154	-2.5828	-0.9510	-1.9708
	(5.0083)	(5.6477)	(5.5658)	(5.8248)	(5.5674)	(5.8335)
Observations	5,586	4,164	5,586	3,966	5,575	3,966
R-squared	0.0056	0.0442	0.0214	0.0554	0.0244	0.0618
Cross sections	566	510	566	505	565	505

Note: Fixed effects. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

that more modern technology is associated with lower emission levels.

The investment rate is negative and statistically significant when robust fixed effects are used. This implies that higher investments are associated with lower emission intensities, albeit the coefficients are very low. This result is also in line with the previous reasoning concerning productivity. The exports-to-output ratios have positive coefficients in intra-EU trade when we use robust fixed effects. The introduction of the third phase of EU ETS shows one statistically significant negative coefficient when year-fixed effects are used. A lagged rise in the price of carbon is associated with a decline in emission intensities in around half of the specifications. When we use more complicated dummy structures, the Hausman tests fail and we use random effects instead of fixed.

We include environmental investment and taxation variables in Table 5 to broaden the picture. We now use a linear time trend in all specifications, and robust fixed effects. In the first specification we only include environmental taxes relative to the value of output and variables connected to ETS. Environmental taxes are negatively associated with a change in emissions intensity, as is the change in the price of ETS. These are logical results: A higher price on polluting decreases pollution.

The other specifications also include productivity, investment, and export data as variables that describe the sectors. The dummy variable for the third phase of EU ETS, and the change in the price of carbon are also included, this time further complemented with the change in carbon allowances.

The level of productivity and the investment rate have negative coefficients and are statistically significant as before. The dummy variable for the third phase of EU ETS is not significant. The change in the price of carbon mostly has a negative coefficient as before. The changes in the number of allowances were not statistically significant. On the other hand, they affect the price of carbon. The correlation between the two is strong in the latter half of the estimation period.

Environmental taxes relative to the value of output (lagged by one year) is statistically significant and has a negative coefficient when environmental expenditure is not present in the specifications. Disaggregating environmental taxes shows us that the results are due to taxes on energy, pollution, and transport. On the other hand, pollution taxes have a positive coefficient. Energy and transport often use fossil fuels and are therefore likely to be more connected to GHG emissions than overall pollution. Also, taxes on resources have a statistically significant negative coefficient in the last specification.

Investment in equipment and plant for pollution control, and total environmental protection activities relative to the value of output (lagged by one year) is positive but not statistically significant except once. A positive sign is not what we would expect, but one should remember that these investments include all sorts of environmental investments, not just GHG-emission related ones. Also, disaggregating them into the different CEPA classes did not yield statistically significant results, and the results are therefore not included in the table. The same happened with investment in equipment and plant linked to cleaner technology except that now the coefficients were negative, and statistically not significant.

We then use the same analytical construction to analyse the whole EU economy, i.e. with the primary and tertiary sectors, in Table 6, either with year-fixed effects or a linear trend. This expands our dataset considerably as we move from twenty to 59 industries. On the other hand, the increase in the number of sectors limits our choice of independent variables. The results for productivity, investment rate, and export openness are as before. Openness only concerns industry. Meanwhile, the ETS3 dummy for manufacturing and power industries, and carbon price lose their statistical significance, although they do retain the expected sign. Environmental taxes are statistically significant and have negative coefficients, thanks to taxes on energy as can be seen from specifications (2) and (4) where taxes have been disaggregated. Including data on environmental investment would drop services from the estimations.

Quantity of GHG emissions

As a complementary analysis we examine the log-volume of emissions and their change as the dependent variable. The approach is the same as above except that now we will include the log level of or change in value added on

Table 6 Change in log GHG intensity, total economy

Variables	(1)	(2)	(3)	(4)
Labour productivity	-0.0353 *** (0.0056)	-0.0358 *** (0.0056)	-0.0368 *** (0.0054)	-0.0372 *** (0.0054)
Investment rate	-0.0000 *** (0.0000)	-0.0000 *** (0.0000)	-0.0000 *** (0.0000)	-0.0000 *** (0.0000)
Total environmental taxes	-4.3549 *** (0.8543)	..	-4.2699 *** (0.8595)	..
Energy taxes	..	-4.9476 *** (0.9164)	..	-4.8691 *** (0.9285)
Pollution taxes	..	3.2544 (3.6863)	..	3.8564 (3.5761)
Transportation taxes	..	-2.8964 (2.8845)	..	-2.8071 (2.8625)
Resource taxes	..	-0.0734 (1.1255)	..	-0.1845 (1.1831)
ETS3 dummy	-0.0021 (0.0091)	-0.0011 (0.0090)	-0.0032 (0.0083)	-0.0022 (0.0083)
Change in ETS price	-0.0019 (0.0170)	-0.0003 (0.0170)	-0.0020 (0.0058)	-0.0025 (0.0058)
Change in allowances	0.0222 (0.0195)	0.0213 (0.0195)	0.0286 * (0.0146)	0.0276 * (0.0146)
Intra-EU exports	0.0000 * (0.0000)	0.0000 * (0.0000)	0.0000 * (0.0000)	0.0000 * (0.0000)
Extra-EU exports	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Year	.. ..	.. ..	0.0017 (0.0010)	0.0019 * (0.0010)
Constant	0.3282 *** (0.0483)	0.3302 *** (0.0485)	-3.0621 (2.1142)	-3.4344 (2.1084)
Observations	17,063	17,011	17,063	17,011
R-squared	0.0143	0.0148	0.0101	0.0106
Cross sections	1,708	1,704	1,708	1,704
Year FE	Yes	Yes	Trend	Trend

Note: Fixed effects. Robust standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

the right-hand side of the equation. Table 7 and 8 include data from manufacturing and power-generating industries, and Table 9 is the total economy again.

In the first specification in Table 7, we use emission levels and in the following ones their change. In the first case, the level of value added is the main independent scale variable, while in the other specifications it is of course the change in value added. The value-added variable is always positive and statistically significant as can be expected because higher or increasing output will increase emissions, ceteris paribus.

The lagged level of productivity has a negative, and in two specifications a statistically significant sign. This is a weaker result than above. In Tables 4–6 we used the pre-calculated emissions intensity data by the Eurostat, while here we have separate datasets for emissions and value added. We double-checked the above results by using GHG intensities calculated from these emission and value-added series, and the results did not change.

The investment rate had a negative sign above, but now it is positive. In both cases the coefficient is zero, however. Regardless, the results indicate that a rise in investment is associated with an increase in emissions after value added or its change has been controlled for. The introduction of the third phase of ETS is now negative in two specifications meaning that it is associated with a decrease in emissions. The same result applies to the ETS price of carbon. These results are as expected.

Table 8 shows the results when environmental taxation and investment data are included, as was done above. Now, with a linear time trend, the level of productivity is negative and statistically significant. This indicates again that a higher level of productivity is associated with a larger decrease in emissions when value added is controlled for.

Environmental taxes are associated with lower GHG emissions, and by disaggregating the taxes into four separate entities we find that this is due to taxes on transportation. This is a result we already got above. On the other hand, when environmental investment data are included, environmental taxes lose their statistical significance.

Table 7 Level or change in the log of aggregate GHG emissions, manufacturing (C) and power industries (D)

Variables	(1) Level	(2) Change	(3) Change	(4) Change	(5) Change	(6) Change	(7) Change	(8) Change
Value added	0.2527 *** (0.0752)	..	..	..	..	..	..	..
Change in value added	..	0.1023 *** (0.0370)	0.1023 *** (0.0370)	0.0902 ** (0.0360)	0.1030 *** (0.0377)	0.1052 *** (0.0157)	0.1016 *** (0.0158)	0.1052 *** (0.0157)
Labour productivity	0.0125 (0.0120)	-0.0072 (0.0059)	-0.0071 (0.0062)	-0.0146 ** (0.0069)	..	-0.0029 (0.0022)	-0.0039 *** (0.0014)	-0.0029 (0.0022)
Investment rate	0.0000 ** (0.0000)	0.0000 * (0.0000)	0.0000 * (0.0000)	0.0000 ** (0.0000)	..	0.0000 * (0.0000)	0.0000 *** (0.0000)	0.0000 * (0.0000)
ETS3 dummy	-0.0542 *** (0.0164)	0.0075 (0.0063)	0.0059 (0.0113)	-0.2222 *** (0.0548)	0.0049 (0.0104)	-0.1177 * (0.0708)	0.0225 (0.0629)	-0.1309 (0.1332)
Change in ETS price	-0.0038 (0.0058)	-0.0148 *** (0.0056)	-0.0157 ** (0.0071)	0.1168 *** (0.0340)	-0.0162 ** (0.0069)	-0.0366 (0.0705)	-0.1668 *** (0.0620)	-0.0495 (0.1381)
Intra-EU exports	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	-0.0000 (0.0000)	..	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Extra-EU exports	-0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	..	-0.0000 (0.0000)	0.0000 (0.0000)	-0.0000 (0.0000)
Year	-0.0100 ** (0.0043)	..	0.0004 (0.0022)	..	0.0010 (0.0020)	..	..	..
Constant	23.4102 *** (8.4484)	-0.0186 (0.0526)	-0.7482 (4.4044)	0.1467 * (0.0762)	-1.9387 (4.0234)	0.1051 (0.0657)	-0.0451 (0.0569)	0.0990 (0.0865)
Observations	6,045	6,030	6,030	6,030	6,030	6,030	6,030	6,030
R-squared	0.0727	0.0101	0.0101	0.0235	0.0086			
Cross sections	584	583	583	583	583	583	583	583
Effects	Fixed	Fixed	Fixed	Fixed	Fixed	Random	Random	Random
Year*Country FE						Yes		Yes
Year FE				Yes		Yes	Yes	
Year*Sector FE							Yes	

Note: Fixed or random effects. Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 8 Change in the log of aggregate GHG emissions, manufacturing (C) and power industries (D)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Change in value added	0.1044 *** (0.0382)	0.1210 ** (0.0518)	0.1223 ** (0.0527)	0.1304 ** (0.0562)	0.1325 ** (0.0568)	0.1302 ** (0.0638)
Labour productivity	-0.0083 (0.0060)	-0.0440 *** (0.0129)	-0.0390 *** (0.0137)	-0.0518 *** (0.0180)	-0.0530 *** (0.0179)	-0.0389 * (0.0209)
Investment rate	0.0000 (0.0000)	0.0000 * (0.0000)	0.0000 * (0.0000)	0.0000 (0.0000)	0.0000 * (0.0000)	0.0000 (0.0000)
Total environmental taxes	-1.6722 *** (0.5366)	..	..	1.0201 (2.0541)	..	2.4196 (2.2753)
Energy taxes	..	..	..	..	2.1371 (2.0668)	..
Pollution taxes	..	..	..	..	7.6767 (8.0419)	..
Transportation taxes	..	..	..	..	-21.7843 *** (6.3546)	..
Resource taxes	..	..	..	..	-48.9579 (50.0195)	..
Environmental investment	..	2.3327 ** (1.1391)	..	0.6474 (2.1139)	0.6139 (2.1806)	..
CEPA 1 investment	..	..	..	..	..	-0.0801 (0.3924)
CEPA 2 investment	..	..	..	..	..	1.7511 (1.2936)
CEPA 3 investment	..	..	..	..	..	0.7813 (2.2321)
CEPA 4–9 investment	..	..	..	..	..	7.2339 *** (2.5168)
Clean-tech investment	..	..	-0.5187 (0.4041)	-0.5015 (0.4176)	-0.6033 (0.4371)	-0.5021 (0.3389)
ETS3 dummy	0.0088 (0.0112)	-0.0052 (0.0127)	-0.0051 (0.0127)	-0.0037 (0.0133)	-0.0041 (0.0133)	-0.0005 (0.0154)
Change in ETS price	-0.0149 ** (0.0072)	-0.0251 *** (0.0065)	-0.0238 *** (0.0067)	-0.0221 *** (0.0066)	-0.0217 *** (0.0066)	-0.0215 *** (0.0073)
Change in allowances	0.0160 (0.0270)	0.0093 (0.0229)	0.0077 (0.0222)	0.0153 (0.0241)	0.0126 (0.0242)	0.0173 (0.0270)
Intra-EU exports	0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)
Extra-EU exports	0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)	-0.0000 (0.0000)
Year	-0.0002 (0.0019)	0.0050 ** (0.0021)	0.0053 ** (0.0021)	0.0046 ** (0.0022)	0.0044 * (0.0023)	0.0029 (0.0025)
Constant	0.3935 (3.8755)	-9.7783 ** (4.2070)	-10.3470 ** (4.2394)	-8.7715 * (4.4680)	-8.3225 * (4.5055)	-5.4482 (4.9311)
Observations	5,616	4,223	4,187	3,981	3,981	3,384
R-squared	0.0118	0.0214	0.0210	0.0247	0.0318	0.0241
Cross sections	565	510	511	505	505	452

Note: Fixed effects. Robust standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1. Here disaggregating clean-tech investments did not yield show statistically significant results.

This time, however, we also find a positive association between environmental investment, investment in equipment and plant for pollution control, and emissions when environmental taxes are not included. This seems counter to logic. We find that the connection is due to CEPA9, i.e. environmental protection activities other than protection of ambient air and climate, wastewater management, or waste management. These may have nothing to do with greenhouse gases. On the other hand, investment into equipment and plant linked to cleaner technology are associated with lower emissions, though the coefficients are not statistically significant. The price of carbon has a negative effect on emissions.

Table 9 shows the results for the change in GHG emissions at the level of the total economy. Environmental

Table 9 Change in the log of aggregate GHG emissions, total economy

Variables	(1)	(2)	(3)	(4)
Change in value added	0.1323 *** (0.0268)	0.1323 *** (0.0268)	0.1488 *** (0.0274)	0.1490 *** (0.0275)
Labour productivity	-0.0081 ** (0.0036)	-0.0085 ** (0.0036)	-0.0035 (0.0035)	-0.0037 (0.0035)
Investment rate	0.0000 ** (0.0000)	0.0000 ** (0.0000)	0.0000 ** (0.0000)	0.0000 ** (0.0000)
Total environmental taxes	-1.8621 *** (0.5221)	..	-1.8583 *** (0.5314)	..
Energy taxes	..	-2.1590 *** (0.6067)	..	-2.1969 *** (0.6206)
Pollution taxes	..	1.6675 (1.9831)	..	2.5394 (2.2461)
Transportation taxes	..	-1.1214 (1.4220)	..	-0.9117 (1.3719)
Resource taxes	..	-0.2229 (3.2299)	..	-0.6138 (3.5556)
ETS3 dummy	-0.0035 (0.0081)	-0.0034 (0.0081)	0.0037 (0.0067)	0.0042 (0.0067)
Change in ETS price	-0.0158 ** (0.0075)	-0.0152 ** (0.0075)	-0.0170 *** (0.0059)	-0.0169 *** (0.0059)
Change in allowances	0.0131 (0.0188)	0.0125 (0.0188)	0.0453 *** (0.0134)	0.0448 *** (0.0135)
Intra-EU exports	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Extra-EU exports	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Year	.. ..	.. ..	0.0015 ** (0.0006)	0.0016 *** (0.0006)
Constant	0.0754 ** (0.0319)	0.0759 ** (0.0323)	-2.9459 ** (1.2524)	-3.2023 ** (1.2457)
Observations	17,151	17,099	17,151	17,099
R-squared	0.0208	0.0210	0.0114	0.0116
Cross sections	1,708	1,704	1,708	1,704
Year FE	Yes	Yes	Trend	Trend

Note: Fixed effects. Robust standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1. If we include disaggregated environmental investment or clean-tech investment, services are omitted.

taxes are associated with lower emissions, and this is due to higher taxes on energy. The price of carbon has a statistically significant negative coefficient. Also, the change in allowances has a positive sign when a time trend is used. This means that the decrease in allowances is associated with a decrease in emissions beyond the price of carbon.

Conclusions

Greenhouse gas (GHG) emissions are produced as a by-product of economic activity including production in different industries, and households' transport, heating etc. emissions. The emissions are mostly due to the use of fossil fuels. Decreasing these emissions to combat the climate change calls for a variety of mechanisms, as has been discussed in literature, see e.g. Acemoglu et al. (2012, 2016). Ever stricter environmental regulation, R&D incentives to develop low-emission technology, pricing of CO2 emissions, and investment subsidies are among the main tools for the society to create incentives to decrease emissions. Consumer and financial market pressure complement these mechanisms.

We analysed the development of GHG emissions and the GHG-intensity of production in European countries in 2008–2020 at the level of industries (both twenty manufacturing and power industries, and 59 industries that also include the primary and tertiary sectors) using a panel data approach.

We find that labour productivity has a statistically significant and negative association with the change in GHG emission intensity. This implies that the change in emission intensity has on average been more negative when productivity is higher. Consequently, emission intensities may decline at an increasing rate as industries develop. Higher productivity is likely to mean that the industry is operating closer to the technological frontier and thus its know-how and ability to develop and absorb the newest, probably more energy-efficient and low-emission technology is higher than otherwise.

We also find that higher investments are typically associated with lower emission intensities, albeit the coefficients are very low. Our results further indicate that a lagged rise in the price of carbon is often associated with a decline in emission intensities. The EU's ETS has thus been working and been an incentive for firms to decrease their emissions. Finally, we find that environmental taxes are negatively associated with changes in emissions intensities. This is due to taxes on energy, resources, and transport.

Policies that promote productivity growth and financial incentives to decrease GHG emissions lead to lower emissions. One further step forward in this respect is to extend the ETS to include more industries. Productivity growth can be enhanced, among other things, by improving the working of national and EU internal markets, and targeting green-technology R&D.

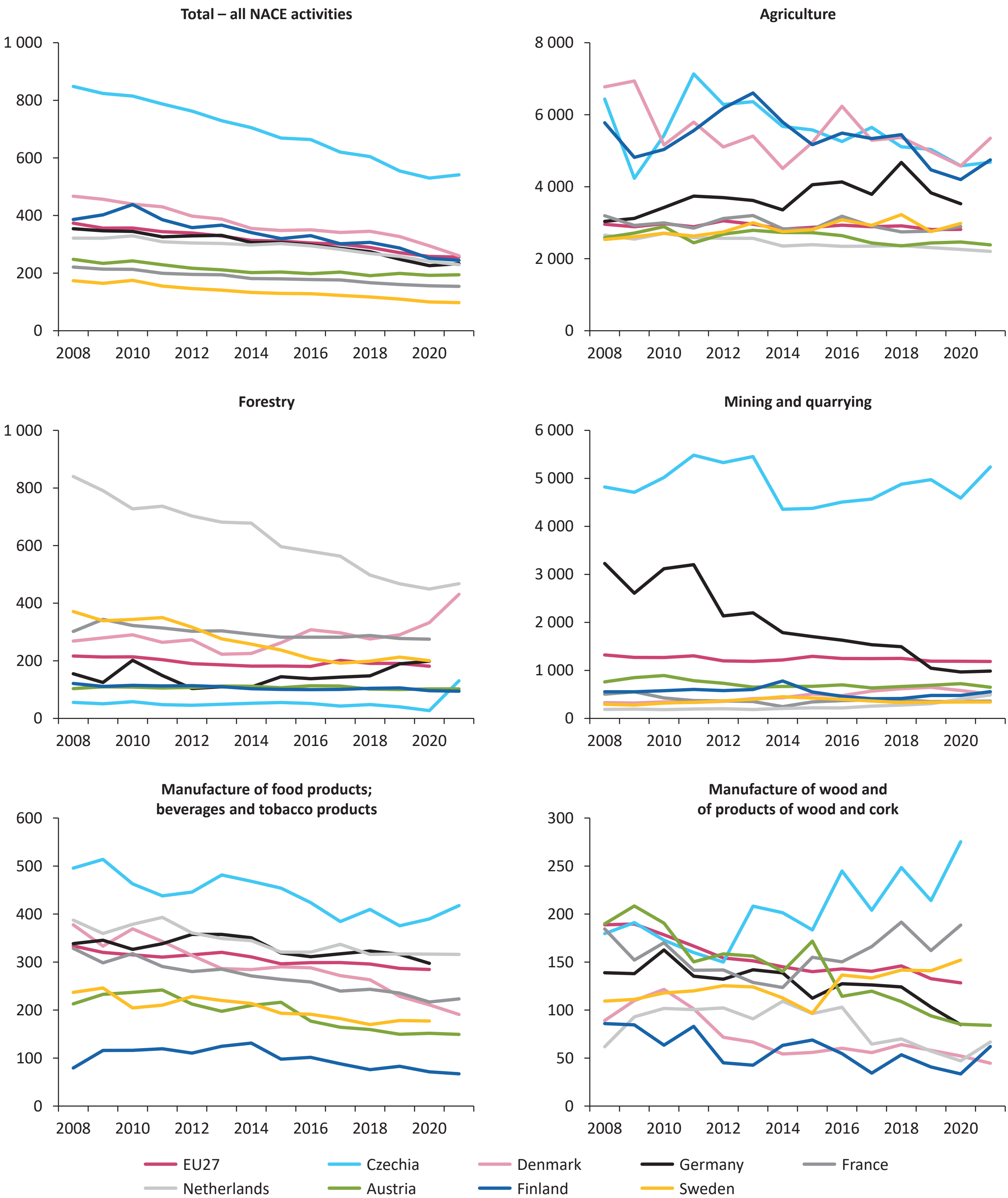
Appendix A

List of included NACE Rev. 2 industries

A	Agriculture, forestry and fishing
B	Mining and quarrying
C10–C12	Manufacture of food products; beverages and tobacco products
C13–C15	Manufacture of textiles, wearing apparel, leather and related products
C16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
C17	Manufacture of paper and paper products
C18	Printing and reproduction of recorded media
C19	Manufacture of coke and refined petroleum products
C20	Manufacture of chemicals and chemical products
C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
C22	Manufacture of rubber and plastic products
C23	Manufacture of other non-metallic mineral products
C24	Manufacture of basic metals
C25	Manufacture of fabricated metal products, except machinery and equipment
C26	Manufacture of computer, electronic and optical products
C27	Manufacture of electrical equipment
C28	Manufacture of machinery and equipment n.e.c.
C29	Manufacture of motor vehicles, trailers and semi-trailers
C30	Manufacture of other transport equipment
C31–C32	Manufacture of furniture; other manufacturing
C33	Repair and installation of machinery and equipment
D	Electricity, gas, steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities
F	Construction
G45	Wholesale and retail trade and repair of motor vehicles and motorcycles
G46	Wholesale trade, except of motor vehicles and motorcycles
G47	Retail trade, except of motor vehicles and motorcycles
H49	Land transport and transport via pipelines
H50	Water transport
H51	Air transport
H52	Warehousing and support activities for transportation
H53	Postal and courier activities
I	Accommodation and food service activities
J58	Publishing activities
J59–J60	Motion picture, video, television programme production; programming and broadcasting activities
J61	Telecommunications
J62–J63	Computer programming, consultancy, and information service activities
K64	Financial service activities, except insurance and pension funding
K65	Insurance, reinsurance and pension funding, except compulsory social security
K66	Activities auxiliary to financial services and insurance activities
L	Real estate activities
M69–M70	Legal and accounting activities; activities of head offices; management consultancy activities
M71	Architectural and engineering activities; technical testing and analysis
M72	Scientific research and development
M73	Advertising and market research
M74–M75	Other professional, scientific and technical activities; veterinary activities
N77	Rental and leasing activities
N78	Employment activities
N79	Travel agency, tour operator and other reservation service and related activities
N80–N82	Security and investigation, service and landscape, office administrative and support activities
O	Public administration and defence; compulsory social security
P	Education
Q86	Human health activities
Q87–Q88	Residential care activities and social work activities without accommodation
R90–R92	Creative, arts and entertainment activities; libraries, archives, museums and other cultural activities; gambling and betting activities
R93	Sports activities and amusement and recreation activities
S94	Activities of membership organisations
S95	Repair of computers and personal and household goods
S96	Other personal service activities

Appendix B

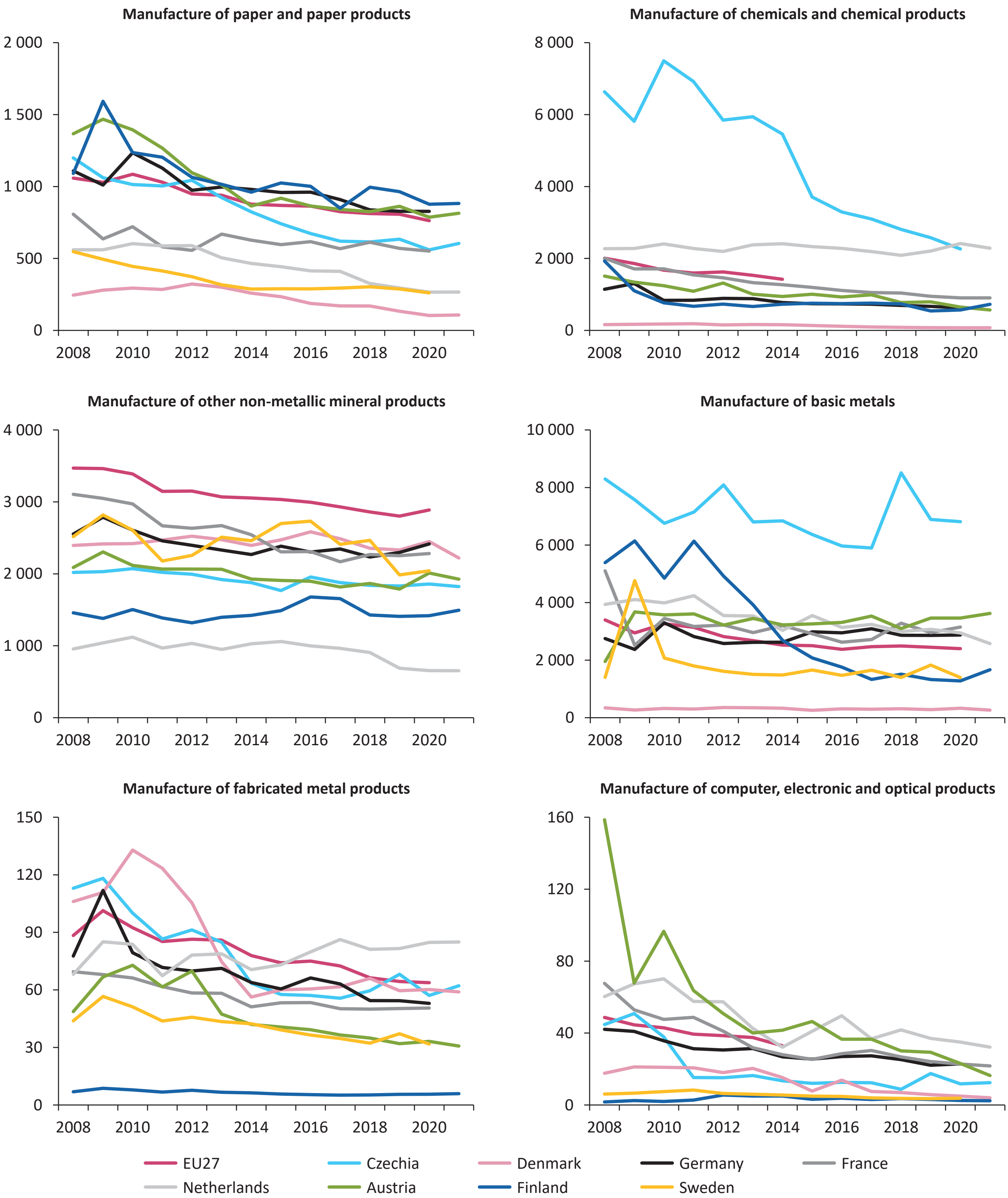
GHG intensities in selected countries and industries 2008–2021



Note: Grams (CO2 equiv.) per euro of value added, chain linked volumes (2010).

Source: Eurostat.

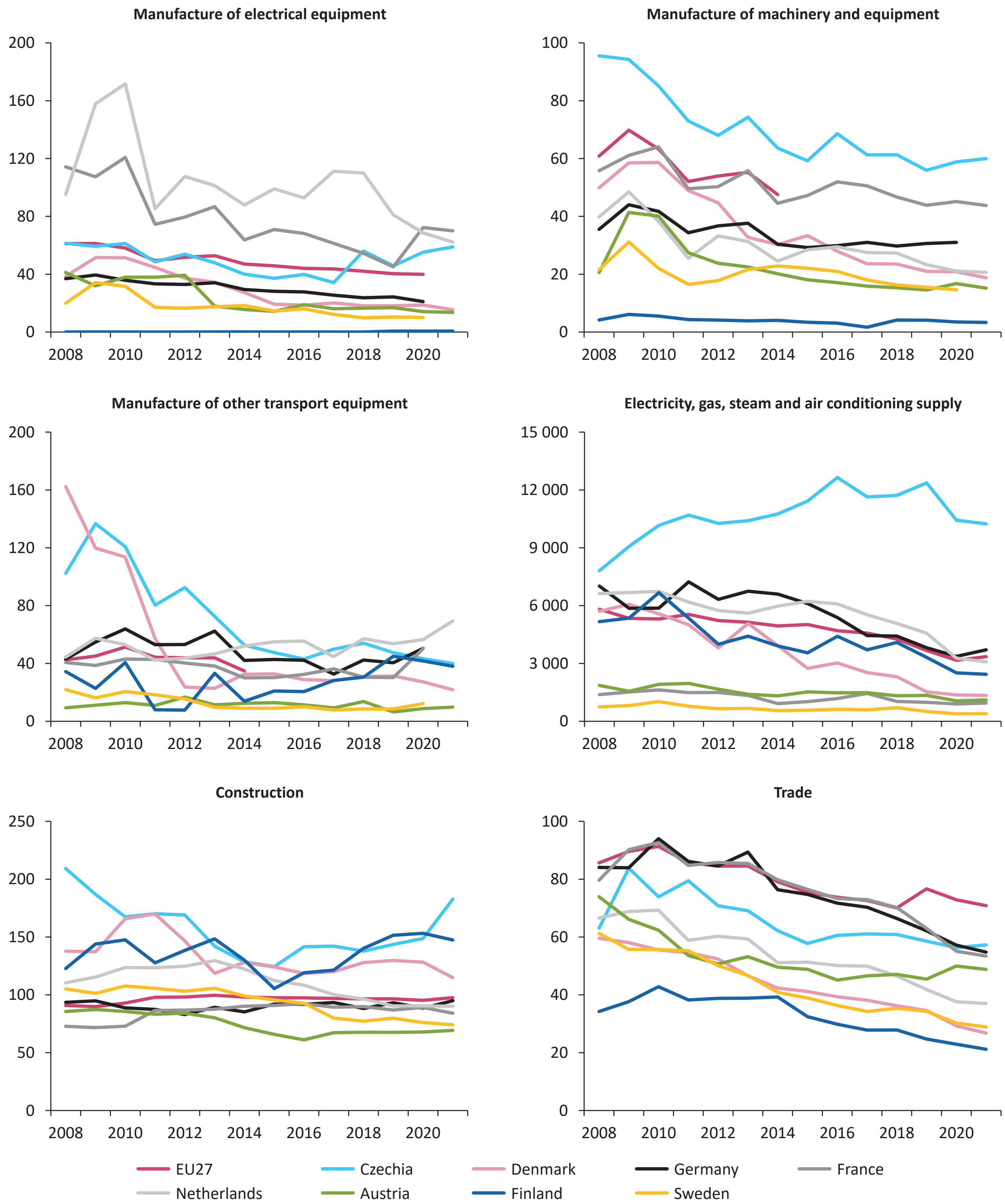
GHG intensities in selected countries and industries 2008–2021



Note: Grams (CO2 equiv.) per euro of value added, chain linked volumes (2010).

Source: Eurostat.

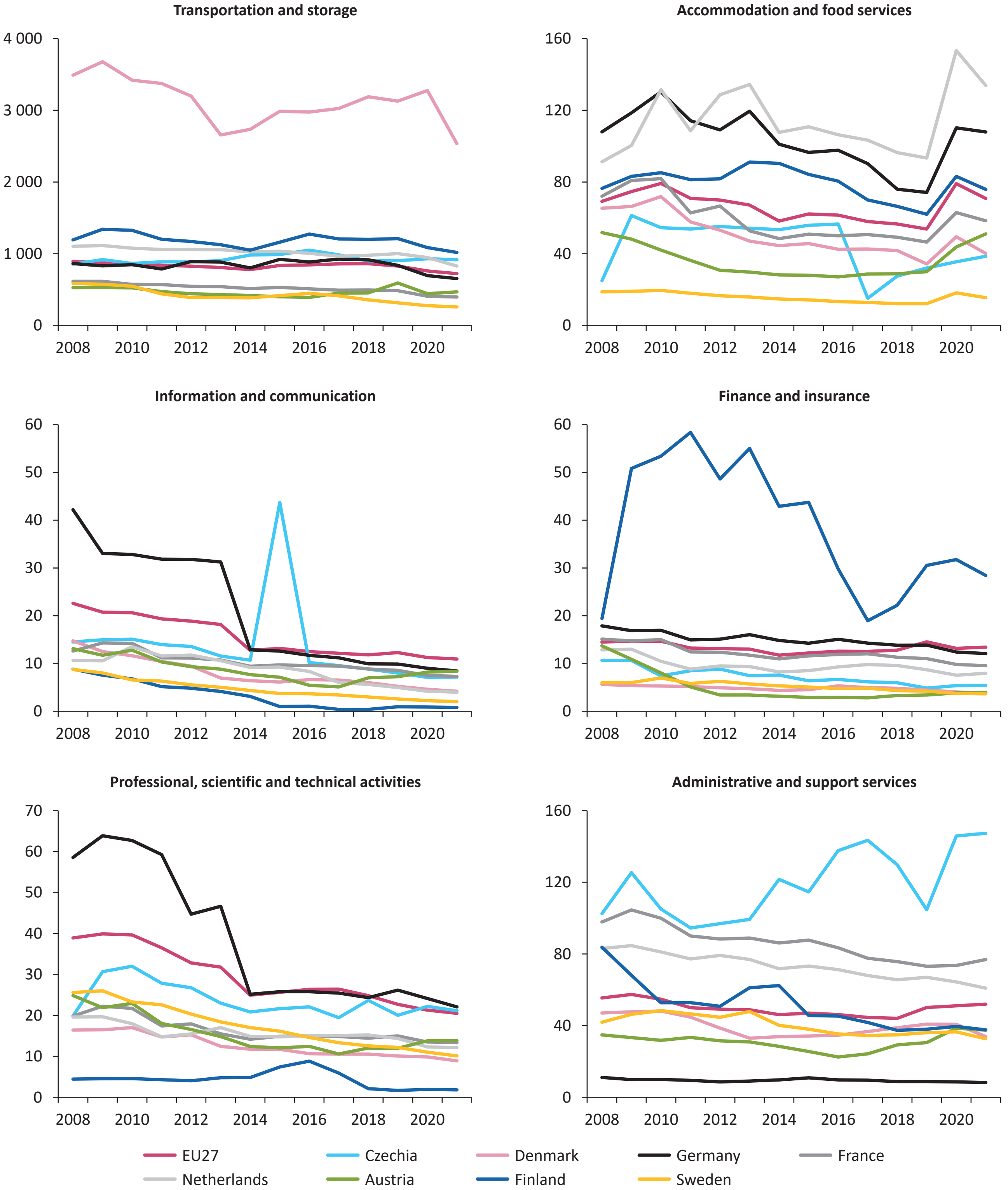
GHG intensities in selected countries and industries 2008–2021



Note: Grams (CO2 equiv.) per euro of value added, chain linked volumes (2010).

Source: Eurostat.

GHG intensities in selected countries and industries 2008–2021



Note: Grams (CO2 equiv.) per euro of value added, chain linked volumes (2010).

Source: Eurostat.

Endnote

[1] See https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/development-eu-ets-2005-2020_en.

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