



# Trends of the EU's territorial and consumption-based emissions from 1990 to 2016

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## Abstract

Emissions of CO<sub>2</sub> from the EU can be estimated using different system boundaries, depending on the policy question. We analyze and compare the trends in territorial emissions (1990–2016) and consumption-based emissions and emissions embodied in trade (1990–2014). We find the Global Financial Crisis (GFC) in 2008 was an important turning point. Territorial emissions were roughly stable in the years before the GFC but have since declined. Consumption-based emissions rose from 2000 to the GFC but then declined in concert with territorial emissions. A Kaya identity decomposition suggests that the main factor pushing the EU's territorial emissions up before the GFC was a growth in GDP, balanced by constant improvements in energy and carbon intensity. The large increase in consumption-based emissions up to the GFC was mainly due to emissions from the production of imported manufactured goods, particularly from China. After the GFC, the Kaya identity decomposition suggests that lower GDP growth facilitated a sustained decrease in territorial emissions. The decline in consumption-based emissions since the GFC was partly due to decreasing territorial emissions but accelerated due to a decrease in the emissions from the production of imported products from China. Preliminary data indicates that EU CO<sub>2</sub> emissions have increased from 2014 to 2017, with the Kaya identity decomposition suggesting the increase is due to a return to stronger GDP growth.

## 1 Introduction

The Paris Agreement entered into force in 2016, where most parties have ratified the accord (UNFCCC 2017). The EU, being one of the Parties, has pledged to reduce greenhouse gas (GHG) emissions by at least 40% by 2030 relative to 1990 levels (European Commission 2015). Additionally, the EU has previously committed to reduce emissions by 20% by 2020, and further by more than 80% by 2050 (European Commission 2011). European GHG emissions, according to the EU's nationally determined contribution (NDC), were already at 19% below 1990 levels in 2012, and based on the most recent data are 24% below 1990 levels

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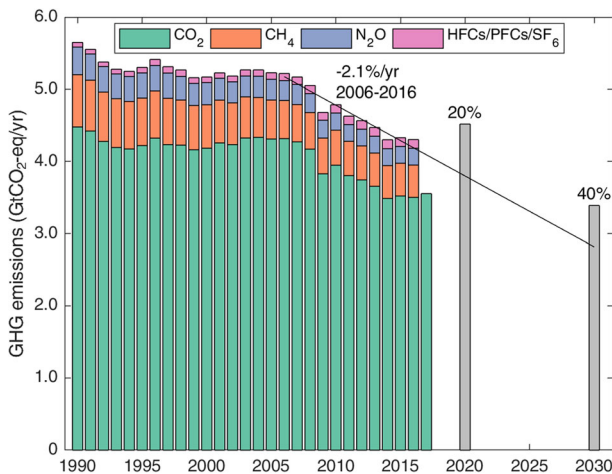
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in 2016 (European Environment Agency 2018). This indicates that the EU has already exceeded its 2020 target (20% reduction). The emission reduction for CO<sub>2</sub> over the same time period is 22%. In recent years, the rate of decline of CO<sub>2</sub> emissions has slowed (Jackson et al. 2017), a concerning trend that warrants deeper analysis. If new policies ensure current trends continue (2.1% per year over 2005–2015), then the 2030 target (40% reduction) is within reach (Fig. 1).

The effort of curbing emissions and global warming can be seen as a global effort. In this view, one could argue that nations should not undermine their commitments by causing emissions to grow in countries not regulated by emission reductions (Peters et al. 2011b). Studies have shown that consumption-based emissions in developed countries are generally larger, and are increasing faster, than territorial emissions due to increasing emissions embodied in imports (Kanemoto et al. 2014; Peters et al. 2011b). The EU's consumption-based emissions have consistently been larger than its territorial emissions, as the emissions generated during production of imported commodities have always been larger than the emissions embodied in exports (Kanemoto et al. 2014; Peters et al. 2011b). Though, recent studies have indicated that the gap has been less pronounced since the global financial crisis (Pan et al. 2017; Mi et al. 2017), and EU consumption-based emissions may have already peaked and started declining.

To understand the EU's opportunities for further emission reductions, policy makers should understand recent trends and drivers in territorial emissions, consumption-based emissions, and emissions embodied in trade. This study investigates why the EU's emissions have changed since 1990 by looking at the immediate drivers of emissions and how those have evolved over time (Blanco et al. 2014). We focus on the immediate drivers of economic activity, energy intensity, and carbon intensity, and the underlying driver of international trade (Blanco et al. 2014). We focus particularly on how the immediate and underlying drivers have changed since the global financial crisis in 2008.



**Fig. 1** Reported EU GHG emissions from 1990 to 2016 (European Environment Agency 2018), excluding emissions from land use, land-use change, and forestry (LULUCF). The 2017 estimate for CO<sub>2</sub> is based on an IEA estimate (International Energy Agency 2018). The targets are shown in 2020, 20% below 1990, and for 2030, 40% below 1990. The black line shows the extrapolation of the emission reductions in the last 10 years through to 2030

## 2 Methods

The EU's emissions can be estimated based on territorial, production, or consumption-based principles, among others (Kander et al. 2015). Since our analysis is based on a variety of different approaches, we restrict our analysis to carbon dioxide emissions which are consistently available in all datasets. In this section, we discuss the definitions, data sources, and methods used in the paper.

### 2.1 Definitions

Territorial emissions are allocated to the country and sector, where the emissions physically are released into the atmosphere, and this principle is used for emission inventories officially reported to the UNFCCC (IPCC 2006; European Environment Agency 2018).

Production-based emissions are allocated to the country where the emitter is resident, a subtle variation of the territorial emissions. In Europe, they are commonly called the “National Accounting Matrix with Environmental Extensions” (NAMEA). The production-based emissions are consistent with the definitions used in the System of National Accounts (SNA; United Nations et al. (1993)). The territorial and production-based emissions are often similar in magnitude, but differ in the allocation of activities associated with international transport and resident versus non-resident economic activity (Pedersen and Haan 2006; de Haan and Keuning 1996). The latest data from Eurostat for 2014 shows a 7% difference for EU emissions, with the production-based emissions being higher, due to production and consumption activities abroad by residents (Eurostat 2015). We do not perform analysis on the production-based emissions in this paper, but they are used as input into consumption-based emissions.

Consumption-based emissions are allocated to where final consumption of goods and services occurs. They should be derived from production-based emissions (Peters 2008), but are often compared to territorial emissions. For a country, consumption-based emissions are effectively calculated by adding emissions embodied in imports to the production-based emissions and subtracting emissions embodied in exports. This compensates for imports and exports through international trade in both intermediate and final goods, allocating emissions to the demanding regions and sectors (Peters 2008). Consumption-based emission accounts were developed in response to concerns that growth and structural changes in international trade may undermine climate policy (Munksgaard and Pedersen 2001).

### 2.2 Data

We used different datasets to compare the EU's emissions from different perspectives (territorial and consumption), allowing us to perform different types of analysis for different time periods. This data inconsistency is somewhat unavoidable due to the underlying datasets and methodological approaches, but we do not see that this would alter our conclusions given the consistency between different datasets (Peters et al. 2012; Andres et al. 2012). The alternative, aiming for consistent datasets, would greatly limit the temporal and sectoral resolution of our analysis and substantially reduce potential insights.

For territorial emissions, we use official UNFCCC national emission reports (European Environment Agency 2018), excluding land-use, land-use change, and forestry (LULUCF) emissions (Fig. 1). Energy data is from Eurostat (2018) and GDP data is from the United Nations (2015).

For consumption-based emissions, we use two different datasets, each of which has distinct advantages and disadvantages. The primary dataset is a time series based on the GTAP database (Aguiar et al. 2016) extended over time (Peters et al. 2011b) and updated annually from 1990 to 2014 (Le Quéré et al. 2016). We use territorial emissions from UNFCCC for the EU countries, and data from the Global Carbon Project covering the rest of the world (Le Quéré et al. 2016). We further use the annual OECD input-output data and emissions to give reliable estimates when comparing production and consumption-based emissions on a sector level, but it only covers the period 1995 to 2011 (Wiebe and Yamano 2016).

## 2.3 Methods

To analyze changes in EU's territorial emissions, we use a Kaya identity decomposition (Peters et al. 2017; Raupach et al. 2007; Nakicenovic and Swart 2000). The Kaya identity is used to decompose the overall change in emissions into underlying factors, including changes to economic activity, energy intensity, and carbon intensity, which together represent the annual changes of CO<sub>2</sub> emissions. We follow the terminology of the IPCC Fifth Assessment Report call these factors “immediate drivers” (Blanco et al. 2014). We consider three immediate drivers. First, the GDP represents the aggregated level of economic activity. Second, the energy intensity of the economy (energy/GDP) indicates how much energy is used for a given increment in GDP, indicating structural changes to the sectors that generate GDP or indicating technological advancements. Third, the carbon intensity of energy (CO<sub>2</sub>/energy) indicates a shift in energy carriers or technological improvements. Following Peters et al. (2017), we do a first-order decomposition with a “cross” term representing the very small interactions between the terms, representing the residual when summing the first-order decompositions and comparing with the total change in CO<sub>2</sub> emissions.

We additionally consider two important “underlying drivers” (Blanco et al. 2014), consumption and international trade. Consumption-based emissions are generally estimated using a Multi-Regional Input-Output (MRIO), the methods of which have been discussed extensively elsewhere (Tukker and Dietzenbacher 2013). The methods we use to convert the GTAP database into an MRIO and further estimate the consumption based emissions have been discussed elsewhere (Andrew and Peters 2013). We have developed two methods, the Emissions Embodied in Bilateral Trade (EEBT) method considers all intermediate and final consumption but only bilateral trade, while the MRIO method includes all tiers of the supply-chain between all regions (Peters 2008; Peters et al. 2011a). Our time series analysis using the GTAP database uses the EEBT method (Peters et al. 2011b), which is ideal for analysis of trade flows but not for consumption patterns. To analyze consumption patterns over time, we use the OECD MRIO model linking directly to final consumption in the EU (Wiebe and Yamano 2016). Ideally, we would use one database, but we chose to use the GTAP-based trade analysis for the extended period from 1990 to 2014, and the OECD-based consumption analysis for the shorter 1995 to 2011 period. In both datasets, we perform the calculations on a detailed sector level, before aggregating to ten sectors for presentation.

Although the datasets used in this study have been used elsewhere, a thorough analysis on the uncertainties of the data and methods is missing. Karstensen et al. (2015) found that uncertainties in the economic MRIO datasets generally resulted in lower uncertainties in MRIO results than uncertainties in territorial emissions. Cancellation effects reduce uncertainties in data on national and EU-level, and while absolute emissions may be somewhat uncertain, trends over time can be considered more certain.

### 3 Trends and drivers of emissions

We first present an overview of trends in CO<sub>2</sub> emissions in the different perspectives at the EU level, before investigating the immediate drivers of change in the EU's territorial emissions, emissions embodied in trade, and, finally, changes in consumption-based emissions. Since we cover different perspectives and datasets, we focus on CO<sub>2</sub> emissions from fossil fuels and industry.

#### 3.1 Overview of emission trends

We divide our analysis of changes in the EU's emissions into two periods, from 1990 to the start of the Global Financial Crisis (GFC) in 2008, and from 2008 to the latest data in each dataset. While emissions trends may have changed in 2007 in some sectors or regions, the change from 2008 to 2009 is clearly the largest (Fig. 1). The global financial crisis coincided with a series of changes in the EU and globally and represents an important turning point in emission trends in many countries (Le Quéré et al. 2016). While the EU's territorial emissions hovered above 4 GtCO<sub>2</sub>/year before the global financial crisis, this dropped below 4 GtCO<sub>2</sub> after the global financial crisis and has continued to decline (Fig. 1a). The average annual growth rate of territorial emissions indicates a slow decline in the first period (−0.1%/year, 1990–2008) and a more rapid decline in the second period (−1.8%/year, 2009–2016).

The territorial emissions consist of domestic emissions emitted to produce domestic goods (“domestic” line in Fig. 1a, about 87% of the total in 2014) and emissions caused by production of goods destined for other regions (“exports,” about 13% in 2014). The emissions from the production of exports have grown gradually, with average annual growth of 1.8%/year, while the domestic emissions have caused most of the decline in territorial emissions in recent years.

Consumption-based emissions have been consistently higher than territorial emissions, on average 790 MtCO<sub>2</sub> (19%) above the territorial emissions from 1990 to 2014. However, consumption-based emissions, and the difference between territorial and consumption, have dropped since the global financial crisis (Pan et al. 2017). The net trade (shown as consumption less territorial) has decreased most since 2011 due to the decline in imported emissions. The emissions embodied in net trade relative to territorial emissions have increased from 1996 to a peak of 27% in 2011, as imports have increased and exports slightly increased, while domestic emissions have decreased. Imported emissions have seen a large increase of 67% from 1990 to the peak in 2006, which has been mostly caused by imports from non-Annex B countries (Fig. 1b), with China dominant. Imports from Annex B countries have declined, although there have been large annual variations. Exports to both Annex B and non-Annex B countries have slightly increased since 1990, and the EU has exported more to non-Annex B countries since 2008.

#### 3.2 Trends and immediate drivers of territorial emissions

Over the period 1990 to 2008, the EU's territorial emissions were relatively flat (−0.1%/year, 1990–2008), but since the financial crisis in 2008, the rate of decline has increased to −1.8%/year (2009–2016). These changes have occurred in different countries and sectors.

At the sector level (Fig. 3a), the EU's territorial emissions have been dominated by electricity and heat production (31% of total emissions over entire period), transport (22%), fuel combustion in households, commercial buildings, and agriculture (18%), and emissions from manufacturing and construction (16%). Emissions have decreased in most large sectors:

electricity and heat has had the most significant decreases (−29% from 1990 to 2016, and −3.0%/year since 2008), followed by households and buildings (−21%), manufacturing and construction (−44%), and industrial processes (−26%). The big exception was transport, with a 19% rise from 1990 to 2016.

At the country level (Fig. 3b), the declines have been more wide-spread, but the five largest emitters (Germany, the UK, Italy, France, and Poland, covering 63% of emissions) generally explain most of the aggregated changes. About two thirds of the EU's emission reductions of 978 MtCO<sub>2</sub> from 1990 to 2016 was due to these five countries. From 1990 to 2016, emission declines were 24% in Germany, 34% in the UK, 20% in Italy, 14% in France, and 14% in Poland. For the UK and Italy, in particular, the declines were most rapid after the global financial crisis. The 20 EU countries with the lowest emissions (similar in aggregated size to Germany) had reductions of 29%, with a strong acceleration after 2008; this group consists of countries with both rising and declining emissions.

The Kaya identity decomposition of immediate drivers reveals that the EU's territorial emissions have had upwards pressure from increases in GDP and downward pressure from energy/GDP and CO<sub>2</sub>/energy, with the intensity terms generally dominating, leading to decreasing emissions (Fig. 4). The EU economy saw an average annual growth rate of 2.4%/year between 1990 and 2008 putting upwards pressure on emissions, but the declines in energy intensity of 1.7%/year and carbon intensity of 0.7%/year led to a slight emission decline of 0.1%/year. After the global financial crisis (2009–2016), the economy has grown much slower at 1.1%/yr., while strong declines continued for energy intensity at 2.1%/year and carbon intensity at 0.8%/year, leading to a reduction in emissions of 1.8%/year. The lower economic growth rate is therefore the dominant immediate driver in the faster decline in emissions since 2008.

While the EU's GDP has seen a 50% increase from 1990 to 2016, absolute energy use has declined 1.0% below 1990 levels, with most reductions since the global financial crisis. The continual improvements in the energy use per unit GDP have put downward pressure on energy use and therefore emissions, but GDP remains a dominant immediate driver in the lower energy use. The CO<sub>2</sub> per unit energy use has been the second-largest immediate driver helping to push emissions down. This has primarily been driven by large increases in renewable energy (Peters et al. 2017), but recently offset by slowing improvements in the CO<sub>2</sub> emissions from fossil fuels. Strong energy and climate policies are needed to ensure that efficiency improvements more than compensate for economic growth, ensuring emission declines continue.

The official UNFCCC data used in this section finishes in 2016 (European Environment Agency 2018), but more recent analysis based on non-official data (International Energy Agency 2018) suggests that EU CO<sub>2</sub> emissions increased 1.5% in 2017 and have not declined from 2014 to 2017 (Fig. 1). Preliminary analysis (International Energy Agency 2018) suggests that this is because the rapid declines in coal consumption across most of Europe has not been sufficient to offset a return to stronger growth in oil and gas consumption. Indeed, economic growth in the last few years has picked up and is now at similar levels as before the global financial crisis. This may indicate that the declines seen in the EU in the last decade based on lower economic growth may not continue in the future without stronger energy and climate policies.

### 3.3 Trends in emissions embodied in bilateral trade

The EU is one of the largest trading blocs in the world, being responsible for around 15% of global imports (extra-EU trade) and 15% of global exports in monetary terms in 2014 (Eurostat

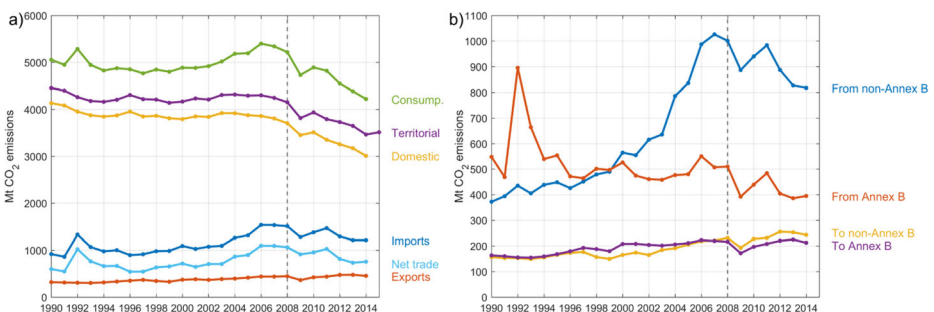
2016). This has implications for global emissions, as large amounts of emissions are from the production of traded products (Peters et al. 2011b). Emissions outside of the EU from the production of imports in 1990 were almost three times larger than the emissions inside the EU to produce exports (Fig. 2).

From a sectoral perspective, imported emissions have been dominated by energy-intensive manufacturing and non-energy-intensive manufacturing, which have been responsible for the large increase before the global financial crisis and for the decline after the global financial crisis (Fig. 5a). The increase in imported emissions from the energy-intensive manufacturing sector from 2002 to 2007 was primarily due to chemical, rubber, and plastic products being imported from China. Imported emissions from the non-energy-intensive manufacturing sector had a growth rate of 6.5%/year from 1990 to the peak in 2007. The growth occurred mainly in machinery and equipment and electronic equipment.

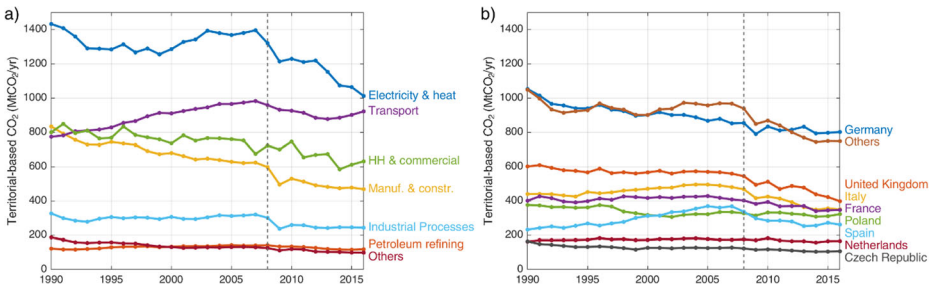
Imported emissions from the non-energy-intensive manufacturing sector surpassed those from the energy-intensive manufacturing sector in 2004, and it has stayed the largest sector ever since. Both these sectors experienced substantial drops from 2007 to 2009 during the global financial crisis, at  $-26\%$  and  $-17\%$  respectively, and neither has fully recovered despite a small rebound towards 2011. Most of the decrease in emissions embodied in trade since 2011 happened in imports of electronic equipment and metals. Large changes have also been seen in the import of emissions from mining activities, which have doubled from 1990 to 2014, where most is oil from Russia and Kazakhstan.

The emissions from the production of exported products has also been dominated by energy-intensive manufacturing and non-energy-intensive manufacturing, although the emissions are much smaller than for imports. Exports of transport services have increased substantially (5%/year), especially air transport from Germany and the UK.

At the country level, significant changes occurred for most of the important EU trading partners (Fig. 5b). Imported emissions from Russia and the USA were the largest in 1990, with 28 and 15%, respectively, before imports from China started to grow rapidly from 2002 following the accession of China to the World Trade Organization. The growth rate of Chinese imports into the EU in the high growth period (from 2001 to 2007) was 26%/year, but this declined to  $-5.6\%$ /year from 2007 to 2014 (Pan et al. 2017). Total imported emissions in 2014 were down 21% from the peak in 2007, and in 2014 came primarily from China, Russia, and



**Fig. 2** **a** Territorial and consumption-based emissions for the EU with domestic and trade components, **b** emissions embodied in trade to and from the EU, broken down by flows with Annex B countries of the Kyoto Protocol as a proxy for development level (Le Quéré et al. 2016; own calculations). The domestic component of territorial emissions only shows emissions to produce goods and services destined for domestic consumption. The exports and imports do not include intra-EU trade. The peak in emissions imported from Annex B countries in 1992 is an artifact resulting from poor data during the collapse of the former Soviet Union (see Fig. 4)



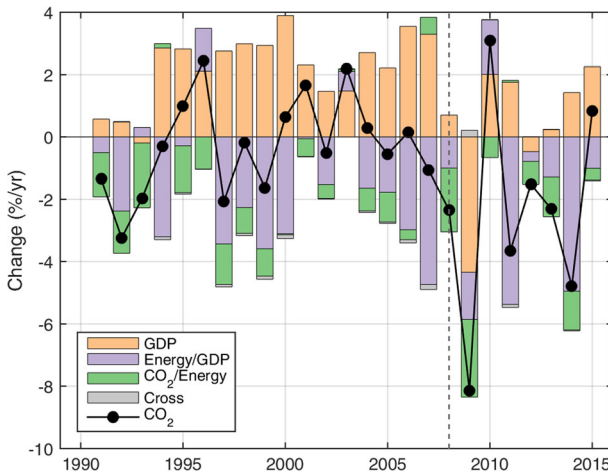
**Fig. 3** Territorial CO<sub>2</sub> emissions in the EU at the **a** sector and **b** country level (European Environment Agency 2018). The figures are based on the UNFCCC emission inventories, with the top source sectors and countries selected in each case. The sector “HH and commercial” covers fuel combustion in households, commercial buildings, and agriculture

the USA. Imports from India have increased more than five times from 1990 to 2014, and grew steadily at 6.5%/year over the whole period.

On the export side, emissions increased by 42% from 1990 to 2014. The largest emission export partners for the EU were the USA, Switzerland, China, Russia, and Japan. Exported emissions to the USA peaked in 2000 and declined slightly towards 2014. The other top nations except for Japan have seen continuous growth over the entire period included the largest contribution from the rest of the world.

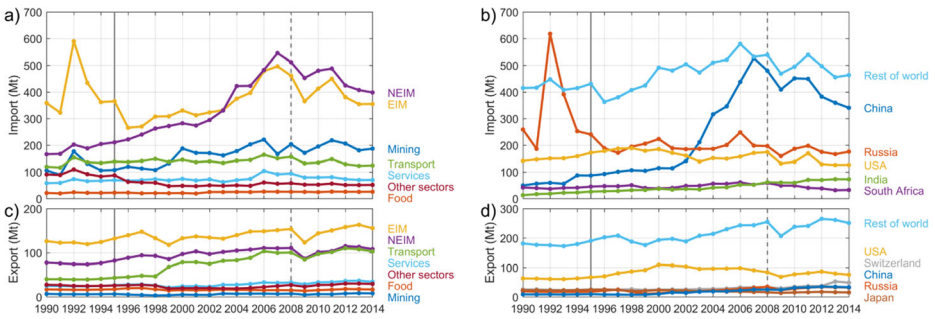
### 3.4 Trends in consumption-based emissions

To analyze regional and sectoral consumption-based emissions, we shift to the results from the OECD database which has a more detailed dataset but over a shorter time period and performs a full MRIO analysis by reallocating intermediate trade to final consumers (Peters 2008). The sectors represent economic sectors (and therefore, for example, transport represents the sector providing transportation services), in contrast to the UNFCCC sector definitions which



**Fig. 4** Kaya identity decomposition of key factors affecting the annual changes in territorial emissions: Gross Domestic Product (GDP), energy intensity (Energy/GDP), and carbon intensity (CO<sub>2</sub>/Energy). The cross term represents a small interaction effect between the different terms. Data sources: European Environment Agency (2018), Peters et al. (2017), own calculations

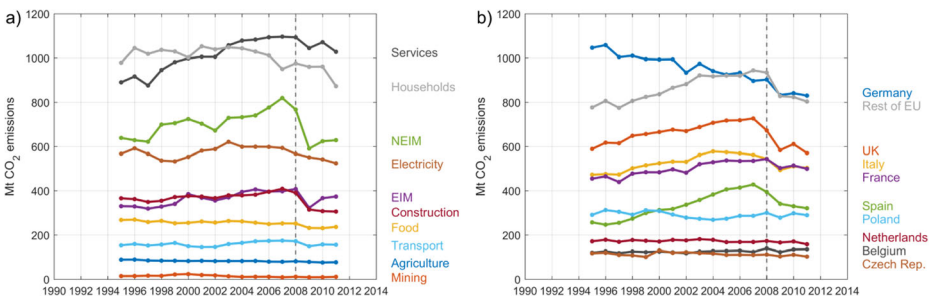




**Fig. 5** **a, c** Sectoral and **b, d** regional emissions embodied in the EU trade, not including intra-EU trade (Le Quéré et al. 2016; own calculations). Imports (**a, b**) and exports (**c, d**) are split into separate figures. EIM, intensive manufacturing sectors; NEIM, non-energy intensive manufacturing sectors, and Other sectors represent construction, agriculture, and electricity. The vertical solid gray line in 1995 represents the split between uncertain data before 1995 and more certain data after, primarily due to poor data during the collapse of the former Soviet Union and extrapolation of trade data from 1995 back to 1990. The dotted line in 2008 indicates the GFC

represent activities (and therefore all transport activities will be in the transport sector, regardless of who undertakes the activity).

At the sector level, the consumption-based emissions (Fig. 6b) are mainly allocated to services (22%, average over entire period), direct emissions from households (22%), direct use of electricity, gas, and water by final consumers (13%), non-energy intensive manufacturing (NEIM; 15%), construction sectors (8%), and energy intensive manufacturing (EIM; 8%; Fig. 5a). From 1995 to 2008, most sectors saw increasing emissions. The largest sectoral changes occurred in energy-intensive manufacturing (2%/year), services (1.8%/year), and non-energy-intensive manufacturing (1.7%/year). For services, this was driven by wholesale and retail trade, particularly in Italy, Germany, and the UK. The energy-intensive manufacturing sector was dominated by growth in petroleum products, mainly allocated to Germany, France, and Italy. The non-energy-intensive manufacturing sector was dominated by motor vehicles and textiles. After the global financial crisis, however, a large drop in emissions occurred in non-energy-intensive manufacturing (23% drop from 2008 to 2009), energy-intensive manufacturing (21%), and construction (19%), while the total emissions dropped by –9.9%, consistent with the results in Fig. 1.



**Fig. 6** The EU's consumption-based emissions by **a** sectors and **b** regions (Wiebe and Yamano 2016; own calculations). Sectors are aggregated from the 34 OECD sectors to ten sectors for clarity. EIM, energy intensive manufacturing sectors; NEIM, non-energy intensive manufacturing sectors; Electricity, electricity, gas, and water supply

At the country level, the trends in consumption-based emissions (Fig. 6b) have a few notable differences to the trends in territorial emissions (Fig. 3b). The most significant difference is that before the global financial crisis consumption-based emissions were diverging from the territorial emissions, but the gap stabilized after the global financial crisis (Pan et al. 2017). This implies that the net imports increased in the first period and declined in the second (Fig. 2). In total, consumption-based emissions have reduced by 17% from 1990 to 2014, while territorial emissions fell 22% over the same period. Germany has had the largest and continual reductions in emissions over the entire period. The next largest nations (the UK, Italy, France, and Spain) had increasing consumption-based emissions before the financial crisis (particularly manufactured products and services), but decreasing emissions after the global financial crisis (particularly manufactured products, electricity, and services). Since the OECD dataset finishes in 2011, we do not have sufficient understanding of changes more distant from the immediate effect of the global financial crisis.

## 4 Conclusions

The EU's territorial CO<sub>2</sub> emissions were 22% lower in 2016 than in 1990 (GHG emissions 24% lower), while consumption-based emissions were 17% lower (in 2014). Territorial CO<sub>2</sub> emissions in the EU were stable from 1990 to the global financial crisis in 2008 and have decreased since then. Since 2014, and up to and including 2017 using preliminary estimates, EU emissions have been flat or rising, potentially due to stronger economic growth pushing up oil and gas consumption, despite declines in coal consumption. The EU's consumption-based emissions have been much larger than territorial emissions, but the gap between them has been declining since the global financial crisis. A Kaya identity decomposition analysis suggests that the dominant immediate factor for the declines in territorial CO<sub>2</sub> emissions since the global financial crisis was lower GDP growth, given relatively constant improvements in energy and carbon intensity over the entire period. The closing gap between territorial and consumption-based emissions partly reflects a softening of growth in global trade (Pan et al. 2017).

The EU has been reducing territorial and consumption-based emissions, but some of this is arguably good fortune. A Kaya identity decomposition suggests that weaker EU economy is the dominant immediate factor for the reductions since 2008, and the Kaya identity decomposition also suggests that a return to stronger economic growth since 2014 has helped push emissions back up again. This suggests that if economic growth remains strong in the years ahead, then it will continue to put upward pressure on emissions, requiring stronger energy and climate policies to ensure the EU climate policy objectives are met.

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