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Abstract

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JEL Classification: F18, F64, O13, O44, Q40, Q54, Q56

Keywords: N/A

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Energy footprints and the international trade network: A new dataset. Is the European Union doing it better?[*]

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Abstract

Understanding the developments of energy efficiency in the context of the global energy network is key to advance energy regulation and fight climate change. We develop a global panel dataset on energy usage accounts based on territorial production, final production and consumption over 1997–2014. We apply structural decomposition analysis to isolate energy efficiency changes and study the effectiveness of the European Union Energy Services Directive [2006/32/EC] on energy efficiency. The effectiveness of the Directive is mixed. The different dynamics found among the European Union members result from differences in the ambition of national energy policies and from the structure of their supply chains. The observed trends towards energy efficiency gains and increases in renewable energy shares are not specific to the European Union, but are common among high income countries. Energy policies in high-income countries are less effective for energy footprints. Our findings are indicative of energy leakage. Energy regulation should account for global supply chains.

Keywords: Energy usage, energy efficiency, energy footprints, renewable energy, MRIO analysis, Structural Decomposition Analysis, EU Energy Services Directive.

JEL-codes: F18, F64, O13, O44, Q40, Q54, Q56.

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1 Introduction

Projections of increasing global energy demand, mostly covered by fossil fuels, contrast with the goal of greenhouse gas (GHG) emission abatement set in the Paris Agreement (2015). This calls for a change of environmental policies, in particular energy policies. Improving energy efficiency is a way to reduce energy usage and GHG emissions without compromising economic growth. Many countries target energy efficiency in their nationally determined contributions (NDCs) to the Paris Agreement, and the United Nations emphasizes energy efficiency in the Sustainable Development Goals.

Energy policies focus primarily on energy usage of production activities within the territory and do not address energy embodied in final production and consumption (see e.g. Nieto et al., 2018; Iyer et al., 2017). In a globalized world where international trade is characterized by vertical specialization and global supply chains (e.g. Koopman et al., 2014; Johnson and Noguera, 2012), energy usage of a country's territorial production can differ substantially from the energy required for final production and consumption. Energy policies aimed at territorial production fail to account for energy embodied in imported intermediates and final goods and fall short for improving the energy footprint of nations (see also Hertwich, 2020; Chen et al., 2019). Moreover, energy policies targeting territorial production may change relative costs of production and goods prices and induce the relocation of energy-intensive production processes towards countries with relatively lax energy policies. Policy-induced relocations of energy-intensive production underlie carbon leakage.[1]

Energy policies targeting energy efficiency should anticipate potential outsourcing of energy-intensive production and rebound (general-equilibrium) effects to ensure that the policy instruments deployed are sufficient to decrease energy usage. We analyze the effectiveness of the EU's Energy Services Directive to enhance energy efficiency, considering the effects of global supply chains. For that purpose, we develop a dataset of energy accounts and propose the sectoral energy intensity factor from a structural decomposition analysis (SDA) as an improved measure of energy efficiency, which we use in an econometric analysis. The contributions of this paper are threefold.

First, this paper introduces a dataset of energy usage accounts for a global panel of 66 countries and 12 composite regions, disaggregated to seven energy commodities and 57 economic sectors (plus private households), for six years between 1997 and 2014. We

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[1] Carbon leakage occurs when firms relocate their production from a country with stringent environmental policies to a country with lax environmental policies, leading to an increase in GHG emissions (see e.g. Babiker, 2005; Copeland and Taylor, 2005; Aichele and Felbermayr, 2015). Carbon dioxide (CO_2) emissions from fossil fuel combustion are the most important source of increased atmospheric concentration of CO_2 since the pre-industrial period (Solomon et al., 2007). Accordingly, policy-induced relocations of energy-intensive production, energy leakage, may account for the bulk of carbon leakage.

construct energy usage accounts based on territorial production and, using multi-regional input-output (MRIO) techniques, calculate two energy footprint accounts. These two footprint accounts, associated with final production and consumption, factor in the energy used in the production of intermediates and final goods, respectively, traded along global supply chains. Energy embodied in final production and consumption differs from the definition of final energy consumption commonly used.[2] Embodied-energy footprints refer to the energy used along all production stages in the supply chain of a final product that is assembled (final production) or consumed (final consumption) in a country, regardless of where this energy usage takes place. Thus, our dataset provides relevant information on the responsibility for energy usage from a footprint perspective. It also supplements other existing datasets on energy accounts and extends them in one or several dimensions.[3]

Second, this paper puts forward a proxy for energy efficiency derived from a SDA and uses it in an econometric analysis. We apply multiplicative Logarithmic Mean Divisia Index decomposition to energy usage and to the ratio of energy usage per unit of value added derived from the three accounts calculated. We decompose changes in energy usage and intensity over 1997–2014 into seven factors reflecting changes in the scale of economic activity, changes in the composition of production and consumption, and changes in the energy-production technology, covering the scale, composition and technology effects used in the pollution–growth literature (Antweiler et al., 2001; Copeland and Taylor, 2005). The energy intensity factor derived from the SDA is shown to be a better proxy for energy efficiency than the ratio of energy usage per value added, the measure of energy intensity typically used in the literature. Energy per value added is not only affected by changes in sectoral energy efficiency but also by changes in national and international supply chain relations, international trade patterns, and economic growth, among others. By contrast, the SDA disentangles energy efficiency changes from other factors that affect energy per value added, and the intensity factor is weakly correlated with energy per value added. Accordingly, the contribution of improvements in energy efficiency to observed changes in energy usage and intensity across countries can be correctly measured by the intensity factor (which we name efficiency factor).

Finally, this paper analyzes whether the developments of energy usage in the EU from 1997–2014 are related to the EU Energy Services Directive [2006/32/EC] and whether these developments differ from those of other countries and regions. The Energy Services Directive, issued in 2006, aims at stronger energy efficiency improvements and introduces

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[2] The term energy consumption is used to refer to energy usage based on territorial production e.g. in decomposition analyses (Voigt et al., 2014; Löschel et al., 2015; Forin et al., 2018), in convergence analyses (Berk et al., 2020), and in the literature on the relationship between energy usage and economic growth (Chica-Olmo et al., 2020; Huang et al., 2008; Inglesi-Lotz, 2016; Dogan et al., 2020).

[3] Our dataset, comprising the three energy accounts, is available upon request.

specific targets as compared to previous regulation (i.e. Council Directive [1993/76/EEC] to limit carbon dioxide (CO_2) emissions by improving energy efficiency). The Energy Services Directive specifies an overall national indicative, not legally enforceable, energy savings target of 9%, to be achieved from 2008–2016 through energy services and other energy efficiency improvements. It also specifies the need to promote the production of renewable energy, although it does not lay out specific targets on renewable energy shares. The Directive requires the EU member states to bring into force national policies by May 2008 and to progressively update Energy Efficiency Action Plans outlining national measures taken. Yet, the implementation and achievements following the Directive differ across the EU member states. Follow-up regulation strengthens the targets for energy usage and renewable energy (e.g. the Energy Efficiency Directive [2012/27/EU] and the Directive on Energy Efficiency [2018/2002]), and specifies mandatory targets for renewable energy (e.g. the Renewable Energy Directive [2009/28/EC] and the Renewable Energy Directive [2018/2001/EU]).

Our energy accounts dataset allows us to study whether the EU Energy Services Directive, the first EU policy with an explicit target for energy savings to be achieved through efficiency gains, is effective at improving energy efficiency associated with territorial-based energy and energy footprints. Through a set of regressions, we compare changes in the energy efficiency factor derived from the SDA in EU countries before and after the implementation of the Directive with changes observed in other countries over the same periods. Using the efficiency factor, instead of the ratio of energy per value added, reduces potential endogeneity that arises if the implementation of the Directive depends on trends in trade patterns or prospects of economic growth. We also analyze changes in the shares of seven energy commodities in the energy mix before and after the implementation of the Directive. The analysis is conducted for the three energy accounts calculated—territorial production-, final production-, and consumption-based energy usage. To the best of our knowledge, such an analysis is novel in the literature.

The following section reviews the related literature. Section 3 briefly describes the construction of the dataset containing the three energy accounts and the methods applied. In Section 4, we discuss the results of the SDA of energy usage and intensity and study the effects of the EU Energy Services Directive on energy efficiency. Section 5 concludes.

2 Related literature

Our research relates to four strands of literature. First, the production-based accounts in our dataset supplement existing datasets on energy accounts—such as Eora (Lenzen et al., 2012, 2013), Exiobase (Stadler et al., 2018a), Global Trade Analysis Project (GTAP;

Aguiar et al., 2019; McDougall and Lee, 2006) and WIOD (Timmer et al., 2015, 2016; Genty et al., 2012)—and extend them in one or several dimensions (sectoral disaggregation, country and time coverage, and energy usage concept and energy commodity disaggregation). The sectoral coverage of our dataset is similar to WIOD and larger than that publicly available in Eora. Exiobase and GTAP offer a larger sectoral disaggregation but GTAP has a shorter time coverage. WIOD, Exiobase and Eora provide few more recent years, but most of these years in Exiobase and Eora are projected. Although we present a country aggregation that keeps consistency with the available disaggregation of 1997 (GTAP 5), the country coverage is similar to GTAP and larger than that in WIOD and Exiobase. Only Eora provides a larger number of countries.

With respect to the energy usage concept, existing MRIO-based datasets offer energy extensions benchmarked to different definitions of energy usage (see Usubiaga-Liaño et al., 2021, for an overview). Eora provides gross and net energy usage, while WIOD and Exiobase offer gross- and emission-relevant energy use. Exiobase also provides net energy use and distinguishes between primary and secondary energy use. GTAP provides energy volume for the usage of fossil fuels and electricity only, although the electricity sector has been recently disaggregated to identify electricity produced from nuclear and several renewable energy sources by Peters (2016) and Chepeliev (2020). Our dataset includes gross and primary energy usage, and groups 62 energy commodities into seven energy source groups, which is beyond or at the level of detail offered by existing databases. All in all, our dataset provides a good compromise between these dimensions. Moreover, in contrast to the existing datasets, we provide energy footprint accounts for the same sector, country, time and energy coverage as for the production-based accounts.[4]

Second, our analysis relates to previous research performing index decomposition analysis (IDA-) and SDA-based decompositions of energy usage and intensity across countries.[5] This previous research concludes that factors capturing economic activity and population are the most important drivers of increasing energy usage, whereas the energy intensity factor, although contributing to decreasing energy usage, does not offset the effect of economic activity (Lan et al., 2016; Kaltenegger et al., 2017; Zhong, 2018; Kulionis and

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[4] Although users can download consumption-based energy accounts based on these existing MRIO-databases from the Industrial Ecology Programme of the Norwegian Institute of Science and Technology, the availability and benchmarks of these footprints varies by source and is restricted to total energy and to a reduced number of countries and sectors.

[5] Henriques and Kander (2010), Voigt et al. (2014), Löschel et al. (2015), and Forin et al. (2018) use IDA decompositions of production-based energy usage and intensity. Decompositions of consumption-based energy footprints using SDA for a broad set of countries can be found in Lan et al. (2016), Kaltenegger et al. (2017), and Kulionis and Wood (2020). Zhong (2018) and Croner and Frankovic (2018) implement decompositions for production- and consumption-based accounts. Alcántara and Duarte (2004) apply a cross-sectional decomposition on consumption-based energy intensity for a set of European countries, and Guevara et al. (2021) do so for energy intensities benchmarked to production- and consumption-based accounts.

Wood, 2020). Factors capturing the structure of the economy seem to play a minor role in Zhong (2018), while Kaltenegger et al. (2017) highlight the contribution of the factor capturing global supply chains for consumption-based energy footprints, being the second largest contributor after economic activity. Changes in global supply chains increase energy footprints over 1995–2009.

The results from the analyses on energy intensities are consistent with the picture for energy usage. Decreases in energy intensity are mostly driven by efficiency gains captured by the intensity factor, whereas sectoral composition effects captured by the structure factor are less important (Mulder and de Groot, 2012; Fernández González et al., 2013; Croner and Frankovic, 2018). Also differences across European countries are largely driven by the intensity factor (Alcántara and Duarte, 2004; Guevara et al., 2021) and by the composition of final energy demand (Guevara et al., 2021), while the structure factor is less important (Alcántara and Duarte, 2004; Guevara et al., 2021). Croner and Frankovic (2018) find that the intensity factor shows a similar pattern for production- and consumption-based accounts, whereas the effects of the structure factor are larger for production- than for consumption-based accounts. International trade leads to an increase of global energy intensity for both accounts.

Third, our analysis adds to the literature on the measurement of energy efficiency improvements that can be attributed to energy efficiency policies. We propose to use the efficiency factor resulting from an SDA, instead of energy per value added, to measure energy efficiency, and use it in an econometric framework to quantify the effect of energy efficiency policies. Energy intensity, defined as energy usage by GDP, is commonly used to set energy and climate targets in the nationally determined contributions of the Paris Agreement, to inform climate change policies, and for cross-country comparisons (see Chang, 2014; Goh and Ang, 2020). Yet, many socio-economic, technological and environmental elements affect energy intensity. Energy efficiency factors derived from decomposition analyses isolate the effect of sector-specific energy intensity and are thus better suited to quantify policy-induced changes in energy efficiency. Some studies emphasize the use of decomposition-based factors to measure energy efficiency (Goh and Ang 2020; for IDA-based analyses see e.g. Ang et al. 2010, Román-Collado and Economidou 2021 and for SDA-based analyses Guevara et al. 2021), but factors resulting from IDA- and SDA-based decompositions cannot isolate policy-impacts without further analysis. This problem affects many of the studies cited above (see Bertoldi and Mosconi, 2020; Trotta, 2020; Román-Collado and Economidou, 2021, for a discussion). Nevertheless, efficiency factors from decompositions are not used in econometric applications to our knowledge (see also Wang et al., 2017).

Finally, our article relates to the literature on the effectiveness of the EU's energy policy. The findings of this literature suggest that the EU's energy policy could be the cause of lower energy usage over time,[6] and that most member states show strong progress in increasing the share of renewable electricity sources (Andreas et al., 2017; Reuter et al., 2017). Yet, the findings of this literature are usually not contrasted to developments outside the EU. The progress achieved varies considerably across EU member states, potentially on account of differences in the translation of EU directives into national legislation (see e.g. Horowitz and Bertoldi, 2015; Rosenow et al., 2016; Nabitz and Hirzel, 2019) and the presence and success of voluntary energy agreements (Cornelis, 2019). Additionally, differences in national legislation may result from heterogeneous energy-related positions (Szulecki et al., 2016), diverse stringency in energy targets (Reuter et al., 2017, 2019), and differences in initial conditions for improvement across countries (Cornillie and Frankhauser, 2004; Chan, 2014; Vehmas et al., 2018), which often reflect a divide between the old EU15 and the new Eastern European Union (EEU) member states.

Research that evaluates the impacts of the EU's Energy Services Directive [2006/32/EC] is scarce and emphasizes the challenge to measure policy-induced energy savings. In order to identify the effect of the Energy Services Directive, Horowitz and Bertoldi (2015) regress national-level energy usage on bottom-up energy-efficiency indexes and a set of situational (economic, socio-demographic and physical) factors for the period before and after the Directive enters into force. The authors find that situational factors account for a large part of national energy savings and that the savings resulting from energy policies increase in the period after the Directive applies. The authors conclude that the larger policy-induced savings stem from the household but not from the manufacturing sector.

3 Data construction and methods

This section summarizes the construction of the energy accounts and outlines the methodology used in the empirical analysis. We first describe the construction of the production-based energy accounts and the derivation of the two energy footprint (final production- and consumption-based) accounts. After that, we briefly describe the SDA of the three energy accounts including the extraction of the efficiency factor, and the regression analysis applied. Further details are provided in Appendix B.

3.1 Construction of the energy accounts

Production-based energy accounts

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[6] See Horowitz and Bertoldi (2015); Reuter et al. (2017); Román-Collado and Colinet (2018); Reuter et al. (2019); Bertoldi and Mosconi (2020); Román-Collado and Economidou (2021).

The construction of production-based energy accounts relies on raw data from the World Energy Balances database (2018 edition) of the IEA, which provides information on the territorial usage of 62 imported and domestically produced energy commodities by 98 economic activities (flows, in IEA terms) in the territories of 171 countries and several regional aggregates (see IEA, 2018). Tables (A.2) and (A.3) in Appendix A provide an overview of these energy flows. The raw IEA data are processed in four steps to link them to the monetary MRIO and trade data sourced from GTAP and used to calculate the footprints. Our methodology to construct the production-based accounts is based on the methods developed by Stadler et al. (2018a), Genty et al. (2012) and McDougall and Lee (2006), who compile energy satellite data for Exiobase, WIOD, and GTAP, respectively. First, we map the regional aggregation used in the IEA data to the regional aggregation of the MRIO data used, which comprises 66 single countries and 12 composite regions.[7]

Second, we allocate the 98 IEA energy flows to the 57 economic sectors and private households present in our database, following the International Standard Industrial Classification (ISIC) of the United Nations (UN, 2008). Most IEA flows are directly matched to a specific economic sector. These directly matched flows cover 91.5% of total energy usage covered by the database. In cases where the sectoral structure in the MRIO tables includes more disaggregated sectors than the economic activities in the IEA data, we split the flows of these activities according to purchases of intermediates from sectors that predominantly produce the energy commodities in the IEA data.

Third, we correct the IEA energy balances, which follow a strict territorial system boundary (IEA, 2018), for the residential principle used in the system of national accounts (SNA) that underlies the MRIO data. While the territorial principle assigns energy usage to geographic national boundaries, the residential principle assigns economic activities to the residents of a country (World Bank, 2009). This correction is especially relevant for international road, air, and sea transport (see Peters, 2008; Peters and Hertwich, 2008a; Usubiaga and Acosta-Fernández, 2015; Usubiaga-Liaño et al., 2021). Completing this step results in a database on the gross energy use of 62 energy commodities by 57 economic sectors and private households in 66 countries and 12 composite regions.

Fourth, for our empirical application, we aggregate the subset of primary energy commodities in our data to seven groups (see Table A.1 in Appendix A for the aggregation, and Appendix B.1 for further details). The seven groups comprise four renewable (hydro, wind, solar, and other renewable) and three non-renewable (fossil, nuclear, and other non-renewable) primary energy products. We aggregate all primary fossil fuels to the cat-

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[7] The aggregation is determined by the detail of the IO tables for 1997 sourced from GTAP and used to calculate our energy footprint measures. For consistency, we keep the same aggregation across years. A larger disaggregation is possible for the years after 1997.

egory *fossil fuels.* We keep *nuclear energy* as a specific category and assign the remaining non-renewable energy sources, such as non-renewable waste from industry and municipalities, to the category *other non-renewable energy.* For renewable primary energy, we keep separate categories for *hydro*, *solar* and *wind energy*, and assign biofuels from biomass, geothermal and tide energy to the category *other renewable energy.*

The resulting dataset comprises territorial-based usage of seven primary energy commodities disaggregated to 57 economic sectors (plus private households) in 78 regions (66 single countries and 12 composite regions) for the years 1997, 2001, 2004, 2007, 2011 and 2014. The restriction to the definition of energy usage as primary energy consumption (PEC) within the MRIO framework in our empirical application presents three advantages. First, it avoids double counting of energy. The presence of secondary fuels would lead to double counting as they are derived from primary energy products. Usubiaga-Liaño et al. (2021) find that double counting is an issue in many studies on MRIO-based energy footprints. Second, primary energy data includes losses that occur in their transformation to secondary energy. This allows us to capture energy savings from improvements in energy transformation. Third, energy extensions of MRIO datasets which are based on energy usage are better suited to assess efficiency developments at the level of industries and households compared to supply-based extensions such as extraction-based energy supply (see Owen et al., 2017; Wieland et al., 2019).

Footprint energy accounts

Based on the production-based energy data, we calculate two footprint-based (final production and consumption) energy accounts. These accounts measure the total energy content of final goods by accounting for energy used in their production along their whole (national and international) supply chains, using MRIO techniques (see e.g. Peters, 2008; Davis and Caldeira, 2010; Fernández-Amador et al., 2016, 2020), such that the responsibility for energy usage is assigned to the assembler and consumer of final goods, respectively.

We construct the energy footprints for each of the seven primary energy commodities and each year in our dataset as follows. First, we combine national input-output tables for the regions considered and a rest of World aggregate to global MRIO tables (see Peters et al., 2011b), which we use to derive the global intermediate requirements matrix A. This matrix collects the direct input requirements sourced from all other sectors to produce one unit of output in each sector in each region. To minimize the problem of aggregation bias, which arises in input-output data from the aggregation of the economic activities of firms to a broad set of sectors (see Miller and Blair, 2009), we keep the sector and country aggregation in our dataset constant over time. For this, we aggregate all tables to the sectors and countries present in the earliest year of our dataset, 1997, with $s = 57$ sectors and $n = 78$ regions.[8]

Second, the matrix A allows us to express gross output produced by each sector, collected in a vector x, as the sum of intermediates sold to other sectors, Ax, and sales of final goods, collected in a vector y, i.e. $x = Ax + y$. We can solve for the vector of gross output as $x = (I - A)^{-1}y$, I being the identity matrix. $(I - A)^{-1}$ is the Leontief-inverse matrix, which captures direct and indirect input requirements to produce one unit of output in each sector in each region.

Third, to trace embodied flows of each primary energy commodity through global supply chains, we transform the linkages among the sectors to value added, using the matrix of sector value-added intensities, V, and re-scale the Leontief-inverse matrix with sectoral energy intensities, E^q, for each energy commodity, q, sourced from the production-based energy account, i.e. $E^qV(I - A)^{-1}$. To derive the national energy footprint accounts, we allocate these flows to the country where the final good is assembled (final production account) and consumed (consumption account) by multiplying the re-scaled Leontief-inverse matrix with matrices of final production, Y^o, and consumption, Y^c, respectively. This results in the national commodity-specific energy footprint accounts $\psi^{o,q}$ for final production and $\psi^{c,q}$ for consumption

$$\begin{aligned} \psi^{o,q} &= \iota' \left[E^q V(I - A)^{-1} Y^o\right] \\ \psi^{c,q} &= \iota' \left[E^q V(I - A)^{-1} Y^c\right] \end{aligned} \tag{1}$$

with ι' being a column vector of ones.

As a last step, we add the direct usage of the seven primary energy commodities by private households, captured by the vectors ψ^q_{ehh} to the national energy accounts, i.e. $\tilde{\psi}^{o,q} = \psi^{o,q} + \psi^q_{ehh}$ and $\tilde{\psi}^{c,q} = \psi^{c,q} + \psi^q_{ehh}$. These two vectors complement similar vectors for the production-based energy accounts, $\tilde{\psi}^{\upsilon,q}$. We obtain the accounts for total energy usage by summing over all energy commodities q, and extract from these vectors the energy usage for each region r. We refer to Appendix B.2 for details.

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[8] Aggregation bias can be especially problematic when MRIO tables are combined with physical activities, such as energy usage, if those activities are the result of a subset of firms in a sector only (see Wyckoff and Roop, 1994; Bouwmeester and Oosterhaven, 2013; Steen-Olsen et al., 2014; de Koning et al., 2015; Piñero et al., 2015; Schoer et al., 2021). Since our empirical application focuses on changes in energy efficiency over time, aggregation bias that stays constant over time does not affect our results.

3.2 Structural decomposition analysis of national energy usage

Let $\tilde{\psi}^{\omega,r}$ denote the energy usage of region r benchmarked to account ω—alternatively, production, final production, and consumption. Accounts for value added, $\phi^{\omega,r}$, are obtained through a similar procedure, after all monetary values in the MRIO tables are expressed in real terms with 1997 as base year (see Appendix B.2). Accordingly, we derive consistent measures for energy intensity as the ratio of energy usage per value added, $\tilde{\theta}^{\omega,r} = \tilde{\psi}^{\omega,r}/\phi^{\omega,r}$, and calculate indices of the relative change of regional energy usage and intensity within a given period as $\underline{\Delta}\tilde{\psi}^{\omega,r}$ and $\underline{\Delta}\tilde{\theta}^{\omega,r}$, respectively, such that for years 0 and t, the first and the last year of any given period, $\underline{\Delta}\tilde{\psi}^{\omega,r} = \tilde{\psi}^{\omega,r,t}/\tilde{\psi}^{\omega,r,0}$ and $\underline{\Delta}\tilde{\theta}^{\omega,r} = \tilde{\theta}^{\omega,r,t}/\tilde{\theta}^{\omega,r,0}$.

Energy usage and intensity, and their associated relative-change indices, are determined by economic scale, structural composition, and technology (and the changes thereof). We calculate the contribution of different factors to these changes by applying SDA to the MRIO tables underlying the construction of the energy accounts (see e.g. Miller and Blair, 2009; Xu and Dietzenbacher, 2014). In particular, we apply the multiplicative Logarithmic Mean Divisia Index decomposition method I (LMDI-I; see Ang and Liu, 2001; Ang, 2004, 2015) to derive the contributions of seven factors to changes in energy usage and intensity of a region. The seven factors comprise changes in the energy mix to produce final goods and intermediates (*mix*), in sectoral energy intensity (*int*), in the sourcing pattern of foreign and local intermediates (*sup*), in the sectoral composition of final goods produced and consumed (*str*), in the geographic composition of trading partners of final goods (*trd*), in the volume of production and consumption of final goods (*act*) and in direct primary energy usage by private households (*ehh*). From these seven factors, one refers to the scale of economic activity (*act*), two to energy-production technology (*mix* and *int*), three to the composition of production or consumption (*sup*, *str*, *trd*) and one to energy usage by private households (*ehh*).

We decompose the index of the change in region r's energy usage of account ω, $\underline{\Delta}\tilde{\psi}^{\omega,r}$, as $\underline{\Delta}\tilde{\psi}^{\omega,r} = \prod_a \underline{\Delta}\psi_a^{\omega,r}$, and the index of the change in region r's energy intensity of account ω, $\underline{\Delta}\tilde{\theta}^{\omega,r}$, as $\underline{\Delta}\tilde{\theta}^{\omega,r} = \prod_a \underline{\Delta}\theta_a^{\omega,r}$, where $a = \{act, mix, int, sup, str, trd, ehh\}$. The seven sub-indices $\underline{\Delta}\psi_a^{\omega,r}$ and $\underline{\Delta}\theta_a^{\omega,r}$ report the contribution of each of these seven factors to changes in the energy index decomposed—i.e. energy usage ($\underline{\Delta}\tilde{\psi}^{\omega,r}$) and intensity ($\underline{\Delta}\tilde{\theta}^{\omega,r}$) for each of the three energy accounts ω—when holding all other factors constant. Like $\underline{\Delta}\tilde{\psi}^{\omega,r}$ and $\underline{\Delta}\tilde{\theta}^{\omega,r}$, the contributions are expressed as relative-change indices. A sub-index $\underline{\Delta}\psi_a^{\omega,r}$ and $\underline{\Delta}\theta_a^{\omega,r}$ can be smaller (larger) than one, indicating that the underlying factor contributes to a decrease (increase) in the aggregate energy indicator over the time period considered, while a sub-index equal to one indicates that this factor has no influence on the relative change of energy use or intensity. Appendix B.3 offers a detailed explanation of the derivation of $\underline{\Delta}\tilde{\psi}^{\omega,r}$, $\underline{\Delta}\tilde{\theta}^{\omega,r}$, and their sub-indices, from the underlying MRIO tables.[9]

From the decomposition of $\underline{\Delta}\tilde{\psi}^{\omega,r}$ and $\underline{\Delta}\tilde{\theta}^{\omega,r}$ it is apparent that energy usage and intensity are affected by (i) economic scale; (ii) sectoral composition and geographical sourcing of goods and services; and (iii) the energy technology used in the production of goods and services, both through the mix of energy commodities used and the sectoral energy intensity associated with each input of production. Technological change is thus defined by the change in the mix of energy commodities and the change in sectoral energy intensities. The change in the mix of commodities refers to the mix of energy sources that feed production, which is typically determined by the technology of production of the energy sector. The change in sectoral energy intensities is related to the energy required to produce goods and services provided by a sector. Therefore, the factor $\underline{\Delta}\theta^{\omega,r}_{int}$ isolates these intensity changes on the sector level from all other factors including the energy mix. It is thus a better proxy for changes in energy efficiency than the most commonly used ratio of energy per value added, energy intensity ($\underline{\Delta}\tilde{\theta}^{\omega,r}$), which is affected by other factors related to economic scale and composition. We name the sectoral intensity factor as efficiency factor, accordingly.

The efficiency factor has the form

$$\underline{\Delta}\theta^{\omega,r}_{int} = \frac{\underline{\Delta}\psi^{\omega,r}_{int}}{\underline{\Delta}\phi^{\omega,r}_{int}} = \underline{\Delta}\psi^{\omega,r}_{int}, \tag{2}$$

where the last equality results from the fact that $\underline{\Delta}\phi^{\omega,r}_{int} = 1$ because the intensity factor does not exist in the decomposition of value added (i.e. $\Delta\phi^{\omega,r}_{int} = 0$ where the sub-indicator $\Delta\phi^{\omega,r}_{int}$ denotes the absolute change in region r's energy usage due to changes in sector energy intensity; see details and Table B.2 in Appendix B.3).

We calculate the efficiency factor, $\underline{\Delta}\psi^{\omega,r}_{int}$, at the most disaggregated level available in our MRIO framework and then aggregate across regions, sectors, and energy commodities to keep aggregation bias as small as possible. For this, we express region r's efficiency factor as a function of changes in energy intensities of all energy commodities, sectors and partner regions along the supply chain, which are weighted by expressions that reflect changes in region r's energy usage and bilateral flows of embodied energy between trading partners. We proceed in three steps.

First, we express region r's efficiency factor for account ω, $\underline{\Delta}\psi^{\omega,r}_{int}$, as the product of efficiency factors across all sectors ($k \in [1, s]$) and across all partner regions (p). Let u and

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[9] The geographic composition of trading partners of final goods (trd) can only be derived for territorial production and consumption accounts, as from a final production perspective there is no trade in final goods. For the final production account, $\underline{\Delta}\psi^{\omega,r}_{trd} = \underline{\Delta}\theta^{\omega,r}_{trd} = 1$ by definition.

m define, respectively, destination and origin regions ($u, m \in [1, n]$ where n is the total number of regions). For the production-based energy account, the partner regions, denoted by p, are destination regions ($p = u$) where production of the origin region m ($r = m$) is consumed, while for the final production- and consumption-based energy accounts the partner regions are the origin regions ($p = m$) of production used for final production or consumption in the destination region ($r = u$; see Table 1).

energy account	origin region (m)	destination region (u)
production	r	p
final production & consumption	p	r

Table 1: Origin and destination regions for the derivation of energy accounts

Thus,

$$\underline{\Delta}\psi_{int}^{\omega,r} = \prod_{p}^{n}\prod_{k}^{s}\underline{\Delta}\psi_{int,k}^{\omega,mu}\,, \tag{3}$$

where $r = m$ and $p = u$ in production accounts, and $r = u$ and $p = m$ in final production and consumption accounts.

Second, we derive $\underline{\Delta}\psi_{int,k}^{\omega,mu}$, the efficiency factor for account ω in region r specific to partner p and sector k, as a function of the change in bilateral embodied energy ($\Delta\psi_{int,k}^{\omega,mu}$), scaled by a weighting function, i.e.

$$\underline{\Delta}\psi_{int,k}^{\omega,mu} = \exp\left[\frac{\Delta\psi_{int,k}^{\omega,mu}}{L(\tilde{\psi}^{\omega,r,t}, \tilde{\psi}^{\omega,r,0})}\right]\,, \tag{4}$$

where again $r = m$ and $p = u$ in production accounts, and $r = u$ and $p = m$ in final production and consumption accounts. The weighting function in the denominator, $L(\cdot)$ denotes the logarithmic mean, which is defined as $L(x, y) = (x - y)/ln(x/y)$ and $L(x, x) = x$ for positive numbers, and $\tilde{\psi}^{\omega,r,t}$ and $\tilde{\psi}^{\omega,r,0}$ refer to the national energy usage of region r for account ω in periods t and 0. Thus, the weighting function in the denominator is the logarithmic mean of the change in national energy usage of account ω in region r.

Finally, we express $\Delta\psi_{int,k}^{\omega,mu}$, the change in bilateral embodied energy, as a weighted function of changes in energy intensities, $ln(e_k^{m,t}/e_k^{m,0})$, across all sectors k and partner regions m between periods t and 0 (see Table B.2 and Equation (B.17) in Appendix B.3).

$$\Delta\psi_{int,k}^{\omega,mu} = \sum_{g}^{n}\sum_{j}^{s}\sum_{q}^{f} W_{\psi,kj}^{\omega,mgu,q}\ln\left(\frac{e_k^{m,t}}{e_k^{m,0}}\right)\,, \tag{5}$$

where g refers to regions and j to sectors along the supply chain between origin region m and destination region u. The weights multiplying the change in energy intensities are represented by $W^{\omega,mgu,q}_{\psi,kj} = L(v^{\omega,mgu,q,t}_{\psi,kj}, v^{\omega,mgu,q,0}_{\psi,kj})$, where $v^{\omega,mgu,q,t}_{\psi,kj}$ and $v^{\omega,mgu,q,0}_{\psi,kj}$ are bilateral flows of embodied energy commodity q from the sector-region of origin (k, m) via the intermediate sector-region (j, g) to the region of destination (u) in periods t and 0, respectively. In this way, we derive the efficiency factor, $\underline{\Delta}\psi^{\omega,r}_{int}$, from the most disaggregated level available in the MRIO framework. We refer to Appendix B.3 for further details.

3.3 Regression analysis

We carry out a set of regressions in the spirit of difference-in-difference analysis to investigate whether the EU countries experience significantly stronger energy efficiency improvements after the implementation of the EU Energy Services Directive and relative to other countries. For that purpose, we distinguish two sub-periods, 1997–2007 and 2007–2014.[10] The econometric analysis aims at identifying policy-induced changes in the SDA-based efficiency factor. The inclusion of control groups allows to identify the EU specific dynamics. The dependent variable is the average annual growth rate of the efficiency factor of region i in period t and energy account ω derived from the SDA, which we denote as $\overline{\underline{\Delta}}\psi^{\omega}_{int,it}$ such that we account for the different lengths of the two sub-periods. We implement the analysis using our data disaggregated at the level of 77 countries and regions.[11]

$$\overline{\underline{\Delta}}\psi^{\omega}_{int,it} = \alpha + \beta P_2 + \sum \gamma_g D_g + \sum \delta_g P_2 D_g + u_{it} \tag{6}$$

where P_2 is a dummy for the second period of analysis (2007–2014), D_g are dummies for the groups specified in different specifications—namely EU28, EU15, the Eastern European Union (EEU), and rest of OECD—and $P_2 D_g$ are interactions of both.[12] The intercept α stands for the base group in the first period of analysis (1997–2007). The base group is regression specific, the countries in the base group change depending on the specific group dummies included in the regressions.

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[10] Difference-in-difference analysis relies on the assumption that in the absence of treatment, differences in the outcome between the treatment and the control group remain constant over time (parallel trends assumption). In our analysis, we only have one time period before and one time period after the treatment. Thus, it is not possible to assess the parallel trends assumption by visual inspection.

[11] It is not possible to further isolate individual countries forming part of composite regions in the underlying IO tables that form the basis of the SDA (see Table A.4 for the countries and regions included). Malta reports zero energy usage in 1997 but a positive value thereafter, resulting in infinite growth rates of energy usage. Accordingly, Malta is excluded from the analysis.

[12] The United Kingdom is included in the group of EU28 and EU15 countries, although at the date of writing, it is not part of the EU any more.

Additionally, we run similar regressions to study whether the EU's switch from fossil fuels towards renewable energy was particularly rapid relative to other regions after the implementation of the Directive. In these regressions, the dependent variable is the average annual change in the share of each of the seven energy commodities in the energy mix.

4 The EU's Energy Services Directive

The Energy Services Directive [2006/32/EC], issued in 2006, specifies an overall national indicative energy savings target of 9%, to be achieved from 2008–2016 through energy services and other energy efficiency improvements, and refers to the need to promote the production of renewable energy. It aims at stronger energy efficiency improvements as compared to previous regulation, and introduces specific targets for energy savings. Already the 1993 Council Directive [93/76/EEC] aims at limiting CO_2 emissions by improving energy efficiency but it does not specify quantifiable efficiency targets. Following the Directive, EU member states must start implementing national policies by May 2008 and must prepare and periodically update Energy Efficiency Action Plans (EEAP), outlining which national measures are taken to achieve the 9% target. However, the national target is not legally enforceable and the implementation and achievements following the Directive differ across the EU member states.[13]

The Energy Services Directive does not set specific targets for the share of renewable energy in energy consumption, which is addressed in subsequent regulation. The Renewable Energy Directive [2009/28/EC], issued in 2009, introduces mandatory national targets from 2011 up to 2020, amounting to a share of 20% of energy consumption from renewable sources for the EU in aggregate by 2020. It also specifies a target share of renewable energy in transport of 10% to be reached by 2020. The Renewable Energy Directive [2018/2001/EU] of 2018 updates the Directive of 2009 and increases the renewable energy targets for the EU to 32%, and to 14% in transport, by 2030.[14]

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[13] Follow-up regulation strengthens the targets for energy usage. The Energy Efficiency Directive [2012/27/EU], which repeals the Energy Services Directive, formulates an energy target of a 20% reduction in primary energy usage as compared to projections until 2020 and supplements it with targets for CO_2 emissions and renewable energy, while the Directive on Energy Efficiency [2018/2002], amending the previous Energy Efficiency Directive, increases the target to a 32.5% reduction in energy usage as compared to projections until 2030. Nevertheless, because of the typical lag required to start their implementation and to produce effects, our sample, covering 1997–2014, is free from the effects of these other directives.

[14] The Renewable Energy Directive [2009/28/EC] repeals Directive [2001/77/EC] on the promotion of electricity produced from renewable energy sources in the internal electricity market, and Directive [2003/30/EC] on the promotion of the use of biofuels or other renewable fuels for transport, which propose reference values for national indicative targets on the shares sourced from renewable energy sources. In contrast to the Renewable Energy Directives [2009/28/EC] and [2018/2001/EU], these previous directives do not cover energy used for heating or cooling.

Theoretically, energy savings may be reached through different channels. Energy savings may result from a contraction of economic activity. Energy savings may also result from improved energy efficiency, because of technological change that reduces the energy intensity of production or because of production structures change towards production in less energy intensive sectors. The incentives to promote technological progress to improve energy efficiency vary across the EU countries depending on the expectations about the level of future economic activity and structural re-locations. Yet, only technological progress that increases energy efficiency leads to sustainable reductions in energy usage in the long run, since declines in economic activity merely lead to transitional reductions in energy usage and the relocation of energy-intensive production processes to other countries does not reduce energy usage at a global scale. Thus, to assess whether the Energy Services Directive implies sustainable energy efficiency gains, it is necessary to isolate the influence of other factors that contribute to the energy savings targeted by the Directive.

To isolate changes in sectoral energy intensity from other factors, we apply the SDA to energy usage and to the ratio of energy usage per unit of value added (energy intensity) in Section 4.1, and analyze their factor compositions. As we show below, the efficiency factor from the SDA is a better measure of energy efficiency developments than energy per value added and is only weakly correlated with the latter. In Section 4.2 we estimate the effects of the EU Energy Services Directive on the efficiency factor.

4.1 Changes in energy usage and intensity

Decomposition of energy usage

We decompose the change of energy usage to isolate the contribution of changes in sectoral energy intensity (*int*) from changes in other factors that contribute to overall energy usage over time, such as economic activity (*act*), sourcing patterns of intermediates (*sup*), sectoral composition (*str*) and trading partners (*trd*) of final goods, energy mix applied (*mix*), and energy usage by households (*ehh*). Figure 1 presents the results of the decomposition for all three energy accounts for the EU28, its two sub-groups the EU15 and the EEU, the rest of OECD (R.o.OECD), and the rest of the world (R.o.World), which is composed of low and middle-income countries, between 1997 and 2014. The change in overall energy usage, $\underline{\Delta}\tilde{\psi}^{\omega,r}$, is represented as percentage change by the black dots, while the colored bars represent the contribution of the seven factors, $\underline{\Delta}\psi_a^{\omega,r}$, where $a = \{act, int, sup, str, trd, mix, ehh\}$, to the overall change, also in percentages. The height of a given bar reflects the percentage change in $\underline{\Delta}\tilde{\psi}^{\omega,r}$ when fixing all other factors over the period considered.[15] Four main outcomes can be highlighted from Figure 1.

First, energy usage associated with all three accounts increases between 1997 and 2014 in all regions, with the exception of production-based energy usage in the EU28 and its two sub-groups. In the EEU, the reductions of production-based energy usage are marginally larger than in the EU15 (in line with Vehmas et al., 2018). The largest increase in energy usage occurs in the R.o.World group (see also Kaltenegger et al., 2017).[16]

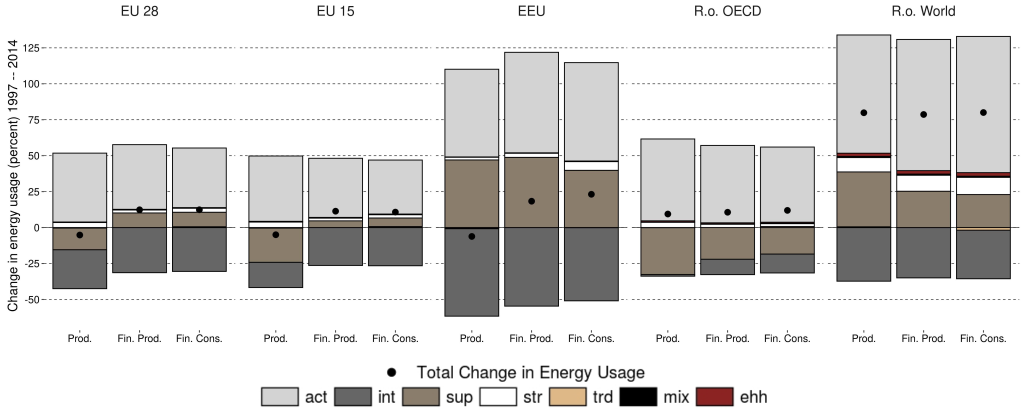

Figure 1: Decomposition of changes in energy usage, 1997–2014.
Note: Prod. stands for production-based energy usage, Fin. Prod. and Fin. Cons. for energy embodied in final production and consumption, respectively. *act* stands for economic activity, *int* for sectoral energy intensity, *sup* for the structure of supply chains for intermediates, *str* for the sectoral composition of final goods trade, *trd* for the geographic composition of final goods trade, *mix* for the energy mix, and *ehh* for the energy usage by households. The black dots denote the change of energy usage over the period considered in percent. The stacked bars summarize the contribution of the seven factors considered to the overall change in energy usage, holding all the other factors fixed. They are constructed by transforming the sub-indices obtained from the multiplicative LMDI-I decomposition, as described in Appendix B.3.2, to percentage changes. As such, they do not add up to the percentage changes of total energy, but indicate which factors contributed to higher, and which factors to lower energy usage as well as their relative importance. The figure is based on the numerical results presented in Table C.1 in Appendix C.1.

Second, the development of energy usage is primarily determined by changes in economic activity (*act*), changes in sectoral energy intensity (*int*), and changes in the structure of supply chains for intermediates (*sup*). The effects of changes in the remaining factors are negligible.[17] Increasing economic activity (*act*) is the main factor contributing to higher

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[15] The product of the seven factors equals $\underline{\Delta}\tilde{\psi}^{\omega,r}$. In Figure 1, the heights of the bars do not add up to the black dot because of the conversion of the factors to percentage changes. Table C.1 in Appendix C.1 reports the values of the untransformed factors, such that their product equals $\underline{\Delta}\tilde{\psi}^{\omega,r}$.

[16] Lan et al. (2016) find a similar pattern as for the *R.o.World* for consumption-based energy accounts in China and Russia between 1990 and 2010, reflecting the importance of these countries in that group.

[17] Related to the small contribution of our energy mix factor (*mix*) to changes in energy usage, Dietzenbacher et al. (2020) show in the context of renewable energy that the energy transition factor, which is related to the share of renewable energy in total energy usage, has a small effect on global production-based usage of renewable energy.

energy usage in all regions and accounts, with the exception of production-based accounts in the EEU, where the influence of energy intensity improvements (*int*) is larger. In general, the patterns found for the EU28 closely resemble those of the EU15 because of its larger economic and demographic mass compared to the EEU.[18]

Third, energy intensity improvements (negative *int* term) reduce energy usage across all accounts and regions shown, partially counteracting the effect of increasing economic activity. The most sizable improvements are observed in the EEU, pointing to a catch-up process due to the modernization and restructuring of the former planned economies. The second largest improvements occur in the R.o.World, reflecting the stronger importance of energy intensity improvements in lower income countries (see also Zhong, 2018).

Fourth, whether reorganizations in supply-chain linkages (*sup*) contribute to higher or lower energy usage depends on the energy account and country group considered. This varying contribution is also found by Lan et al. (2016), Kaltenegger et al. (2017), and Kulionis and Wood (2020) for consumption-based accounts. For production-based energy, a decreasing effect (negative *sup* term), indicating that production of intermediates decreased or shifted towards sectors with lower energy usage, is apparent in all regions but in the EEU and the R.o.World. In the EEU countries, this may result from the process of economic restructuring and their integration into the European supply chain network (see Baldwin and Lopez-Gonzalez, 2015). For the footprint-based accounts, the increasing effect (positive *sup* term) suggests a shift in the sourcing of intermediates towards sectors and/or countries with higher energy usage in all regions but the R.o.OECD.

The pattern observed for the sourcing of intermediates (*sup*) in the aggregate EU28 and the EU15 suggests outsourcing of energy-intensive intermediates to other countries. There, the production of intermediates declines and/or shifts towards sectors with lower energy usage, while the energy content of imported intermediates increases. For the production-based energy usage, this reduction in the energy content of domestically produced intermediates, together with improvements in energy-intensity, is strong enough to counterweight the influence of economic activity. Without the observed restructuring of its intermediate supply chains, the efficiency improvements in the EU28 and the EU15 alone are not strong enough to reduce energy usage for production. Bertoldi and Mosconi (2020) argue that the implementation of energy policies in the EU28 and Norway reduces energy usage by 12% in 2013. This finding may be reflecting such supply-chain effects, however. For the footprint-based energy accounts, the higher energy content of imported intermediates observed in our data contributes to the increase in energy footprints. The targets for outsourcing are

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[18] Individual countries may deviate from the region-specific patterns. For example, Lan et al. (2016) and Kulionis and Wood (2020) show that in some high-income countries, large energy intensity improvements outweigh the effect economic affluence.

the EEU and the R.o.World region, where the *sup* factor contributes to an increase in production-based energy usage.

Decomposition of energy intensity

As we argued above, energy intensity, defined as the ratio of energy usage per unit of value added, can itself be affected by the same of factors as energy usage. Figure 2 displays the results of the decomposition of energy intensity. The change in energy intensity, $\underline{\Delta}\tilde{\theta}^{\omega,r}$, is represented as percentage change by the black dots, while the colored bars represent the percentage change in energy intensity arising from a specific factor, $\underline{\Delta}\theta_a^{\omega,r}$, where $a = \{act, int, sup, str, trd, mix, ehh\}$. As explained in Section 3.2, the efficiency factor (int) affects only the numerator of energy intensity (i.e. energy usage), such that changes in energy intensity and usage caused by this factor are numerically identical ($\underline{\Delta}\theta_{int}^{\omega,r} = \underline{\Delta}\psi_{int}^{\omega,r}$).

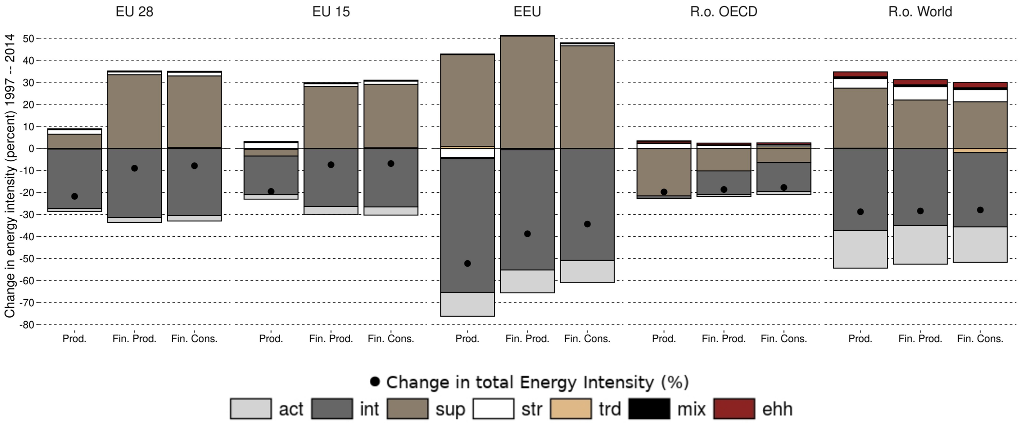

Figure 2: Decomposition of changes in energy intensity, 1997–2014.
Note: Energy intensity is defined as energy usage divided by value added. The figure is based on the numerical results presented in Table C.2 in Appendix C.1. Other notes as in Figure 1.

From Figure 2, it is apparent that energy intensity decreases in all regions and accounts. The main factors affecting changes in energy intensity are changes in the energy efficiency factor (*int*; in line with Mulder and de Groot 2012; Fernández González et al. 2013; Croner and Frankovic 2018) and in the structure of supply chains for intermediates (*sup*). Unlike for energy usage, economic growth (*act*) reduces energy intensity in all regions and accounts but the production-based accounts in the R.o.OECD. The effects of the four other factors are much smaller.

The efficiency factor (*int*) is not always the largest contributor to energy intensity, being surpassed by the sourcing patterns of intermediates (*sup*) in some cases. Improvements in the efficiency factor (*int*) are larger than reductions in energy intensity in most cases, except for the R.o.OECD and the production-based account in the EU15. This is driven primarily by changes in the production or sourcing patterns of intermediates, which shift towards sectors with higher energy intensity (positive *sup* term) in all regions and accounts shown but the R.o.OECD and the production-based account in the EU15. Since changes in other factors also affect energy intensity, the magnitude of energy intensity improvements and the efficiency factor (*int*) can differ substantially (see e.g. the R.o.OECD), and the sample correlation between energy intensity and the efficiency factor is 0.27. Therefore, using changes of energy intensity as a proxy for efficiency gains may lead to invalid conclusions about efficiency development, and the efficiency factor from the SDA is a better proxy for energy efficiency and to address the effectiveness of energy intensity policies to achieve their targets.[19]

In Figure 3, we present the decomposition of energy intensity for the periods before and after the implementation of the EU Energy Services Directive (1997–2007 and 2007–2014). After 2007, the contribution of the efficiency factor is much larger than the contribution of changes in supply chains for intermediates in all regions except the R.o.World, suggesting that the correlation between energy intensity and the efficiency factor is not constant over time and increases after 2007. In the EU28, production-based efficiency gains are stronger after 2007. This is driven by the developments in the EU15, while efficiency gains in the EEU decrease after 2007. Efficiency gains in the footprint-accounts decelerate after 2007 in both EU regions. In the R.o.World, the energy efficiency factor deteriorates after 2007.[20]

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[19] The efficiency factor should also be isolated from the major part of the rebound effects. Thomas and Rosenow (2020) distinguish direct and indirect rebound effects resulting from cost decreases of energy induced by efficiency improvements. These cost reductions may result in higher consumption of energy services (direct rebound effect) and higher demand for other goods and services (indirect rebound effect). These rebound effects should be mostly captured by SDA-factors relating to the level of activity, the composition of global supply chains and final goods, and households energy usage. In this regard, it should be noted that a policy targeting energy efficiency could be effective in meeting its target but not so effective with respect to diminishing energy usage because of the existence of rebound effects.

[20] See also Table C.5 in Appendix C.2, which reports average annual growth rates of energy intensity and the efficiency factor. The results for similar decompositions at the level of individual EU countries are reported in Appendix C.3, and data on average annual growth rates of efficiency factor of production for individual countries is available in Appendix C.4.

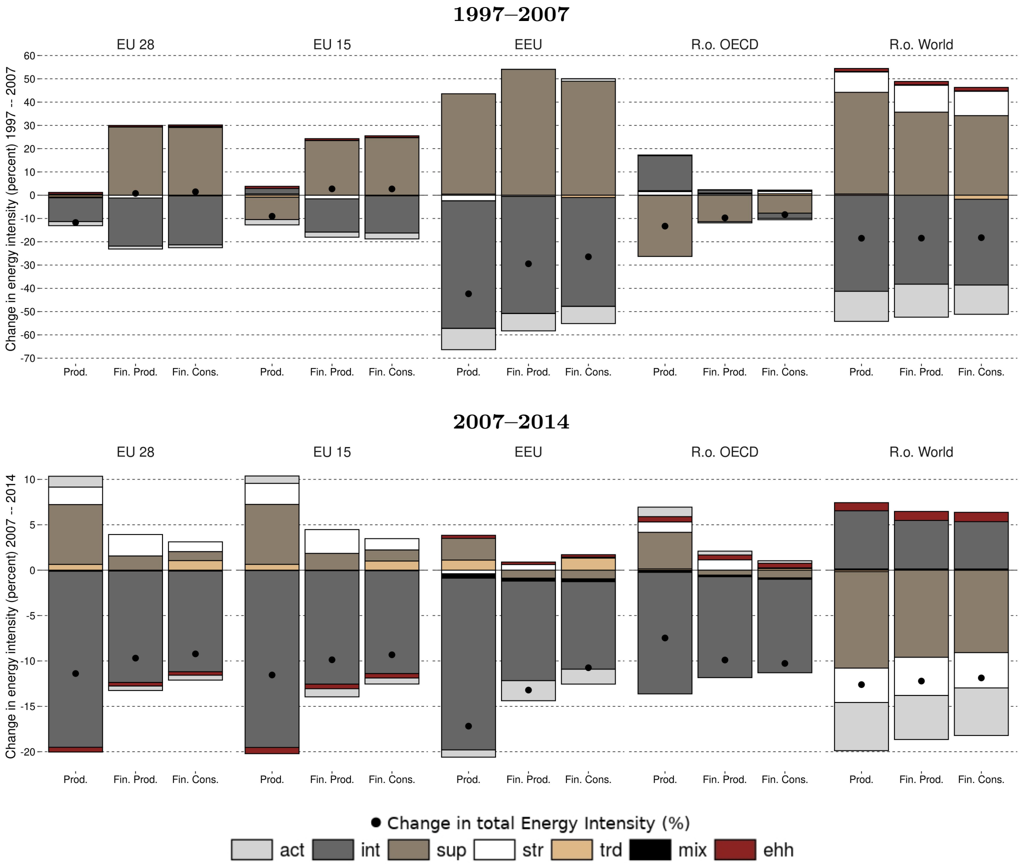

Figure 3: Decomposition of changes in energy intensity, sub-periods.
Note: Decompositions of changes in energy intensity between 1997–2007 (upper graph) and between 2007–2014 (lower graph). The figure is based on the numerical results presented in Tables C.3 and C.4 in Appendix C.1. Other notes as in Figure 1 and Figure 2.

4.2 Regression analysis

We test whether the EU countries show significantly stronger energy efficiency improvements after the implementation of the EU Energy Services Directive and relative to other countries. For that purpose, we use average annual growth rates of the efficiency factor from the SDA from the three energy accounts as dependent variable disaggregated at the level of 77 individual countries and regions, for the sub-periods 1997–2007 and 2007–2014.

Energy intensity in production-based accounts

The EU Energy Services Directive targets energy intensity improvements within the territorial boundaries of the EU. Table 2 presents the regressions for the production-based energy account in five columns. In each regression, the performance of specific country groups is contrasted against each other and against a base group before and after the implementation of the Directive. The base group is regression specific, it includes countries and regions that are not part of the country groups that enter as dummies.

The first column presents the simplest specification, separating EU countries from all other countries (the base group). We regress the average annual growth rate of the efficiency factor on dummy variables for the period 2007–2014, for EU countries, and their interaction. Subsequently, in columns 2 and 3 we split EU countries and distinguish specific effects for EU15 and EEU countries, including their interactions with the 2007–2014 dummy. In columns 4 and 5, the model distinguishes the EU15, EEU, and the rest of OECD countries from all remaining countries (the base group). This specification adds a dummy for the group of OECD countries that do not form part of the EU and its interaction with the 2007–2014 dummy to test if the developments of the EU15 and EEU countries are different from those of other OECD countries. In columns 3 and 5, we exclude Switzerland, which is an outlier.[21] The top panel in Table 2 reports the main output of the regressions. To facilitate the reading of the regression results, the middle panel shows the average annual growth rate of the efficiency factor of the corresponding country groups for 1997–2007 (P1) and 2007–2014 (P2). The bottom panel displays a series of Wald tests for differences in the average annual growth rates of the efficiency factors across country groups and/or periods. Had the EU Energy Services Directive an effect on the efficiency factor in EU countries that is not observed in non-EU countries, we would notice an accelerated reduction of the efficiency factor in the EU after 2007 above and beyond that of other countries—this would result in a statistically significant and negative coefficient of the EU–period interaction. If similar accelerations took place in other OECD countries, the difference between the EU–period and the OECD–period interactions would not be statistically significant.

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[21] In Switzerland, the increase in the energy efficiency factor is exceptionally large between 2007 and 2014 due to the large influence of the electricity sector, which experiences a sharp decline in value added over this period. We ran several specifications. We included sector energy intensity and GDP per capita (ppp-adjusted) at the beginning of the period as control variables in the regressions, but both are statistically insignificant (see Table (C.10) in Appendix C.5). We also interacted GDP per capita with the period-dummy, but this interaction was also insignificant at conventional levels. Thus, we report the regressions without additional controls.

	Average annual growth rate of the energy efficiency factor for production				
	(1)	(2)	(3)	(4)	(5)
Constant	-1.828***	-1.828***	-1.778***	-2.360***	-2.360***
2007–2014	2.566***	2.566***	2.084***	3.196***	3.196***
EU	-0.668				
EU · (2007–2014)	-2.162*				
EU15		0.888	0.838	1.419	1.419
EU15 · (2007–2014)		-3.806**	-3.324**	-4.435***	-4.435***
EEU		-2.613**	-2.664**	-2.082*	-2.082*
EEU · (2007–2014)		-0.107	0.375	-0.736	-0.736
R.o.OECD				2.415*	2.852**
R.o.OECD · (2007–2014)				-2.860	-5.445***
N	154	154	152	154	152
R^2	0.109	0.142	0.140	0.163	0.200
P1: base	-1.828	-1.828	-1.778	-2.360	-2.360
P1: EU	-2.497				
P1: EU15		-0.940	-0.940	-0.940	-0.940
P1: EEU		-4.442	-4.442	-4.442	-4.442
P1: R.o. OECD				0.055	0.492
P2: base	0.738	0.738	0.307	0.836	0.836
P2: EU	-2.092				
P2: EU15		-2.180	-2.180	-2.180	-2.180
P2: EEU		-1.983	-1.983	-1.983	-1.983
P2: R.o. OECD				0.391	-1.757
p-value: P1 EU15 – EEU		**	**	**	**
p-value: P1 EU15 – OECD				·	·
p-value: P1 EEU – OECD				***	***
p-value: P2 base – EU	***				
p-value: P2 base – EU15		***	***	***	***
p-value: P2 base – EEU		***	***	***	***
p-value: P2 base – OECD				·	***
p-value: P2 EU15 – EEU		·	·	·	·
p-value: P2 EU15 – OECD				·	·
p-value: P2 EEU – OECD				·	·
p-value: P1-P2 base	***	***	***	***	***
p-value: P1-P2 EU	·				
p-value: P1-P2 EU15		·	·	·	·
p-value: P1-P2 EEU		**	**	**	**
p-value: P1-P2 OECD				·	·
p-value: DID EU15 – EEU		**	**	**	**
p-value: DID EU15 – OECD				·	·
p-value: DID EEU – OECD				·	**

Table 2: Regression results: energy efficiency factor—production
Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable measures the average annual percentage change in the energy efficiency factor from the SDA for production-based energy usage. R.o.OECD stands for the rest of the OECD aggregate. The panel below the R^2 reports the average annual percentage change in the energy efficiency factor for each of the country-groups and periods. *P1* refers to the period 1997–2007, *P2* to the period 2007–2014. *base* stands for the base-group (i.e. non-EU countries in regressions (1)–(3), non-EU non-OECD countries in regressions (4) and (5)). The bottom panel reports a series of Wald-tests for differences across country-groups and/or periods. · stands for not statistically significant at the 10% level. *DID* stands for difference-in-differences and tests for differences in the interaction-terms (i.e. differences in changes from P1 to P2 across country-groups). Regressions (3) and (5) exclude Switzerland in both periods.

The results in column 1 point to a better performance of the EU relative to the base group (non-EU countries) after 2007. The efficiency factor decreases in EU countries before and after 2007, whereas in the base group it decreases before 2007 but increases afterward. Energy efficiency improvements do not significantly differ across the two periods in the EU.[22] The difference between the annual reductions in the EU countries (-2.50%) and the base group (-1.83%) is not statistically significant in the first period (1997–2007), but because of the different evolution of the efficiency factors between 2007 and 2014, with annual growth rates of -2.09% in the EU countries and 0.74% in the base group, the differential increases to 2.83% and becomes statistically significant (p-value P2 base-EU).[23] Therefore, the difference in the growth rates of the efficiency factor between EU and the non-EU countries increases from the first to the second period, as also indicated by the EU–period interaction, which is statistically significant at the 10% level.

The patterns found for the EU mainly concern the old EU15 members (see column 2) and indicate that the Directive may contribute to larger efficiency gains in the EU15 members but not in the EEU. Prior to 2007, the reductions in the efficiency factor in the EU15 are not significantly different from the base group of non-EU countries. These reductions in the EU15 accelerate after 2007, however, from -0.94% to -2.18%, such that the difference becomes significant in the second period (p-value P2 base-EU15). The EU15–period interaction is statistically significant, suggesting that the large efficiency gains in the EU15 across the two periods are not accompanied by similar developments in the base group. By contrast, in the EEU, the reductions in the efficiency factor are significantly stronger (-4.44%) than those in the base group before 2007. These reductions in the EEU slow down to -1.98% annually after 2007, but the differential to the base group remain statistically significant (p-value P2 base-EEU). The comparison between EU15 and EEU countries shows that improvements in energy efficiency are significantly larger in the EEU before 2007 (p-value P1 EU15-EEU) but are not statistically different across the groups after 2007 (p-value P2 EU15-EEU). This contrasts with the larger potential for improvement in many EEU countries found by Chan (2014) in an efficiency frontier analysis of energy intensities in the EU in the period 2006–2010.[24] Additionally, this

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[22] Horowitz and Bertoldi (2015) find larger reductions in energy use from the household sector but not the manufacturing sector after the implementation of the Energy Services Directive. In our regression analysis, the effect from household demand has been isolated by separating the household factor. The decomposition in Figure 3 shows that the household factor decreased energy intensity in the EU15 over 2007–2014.

[23] The average annual growth rate in the second period for non-EU countries (the base group) is the sum of the constant and the coefficient of the period dummy. For EU-countries, the growth rate is calculated by adding to this the coefficients of the EU- and the EU–period dummy. These values are reported in the middle panel of Table 2. The p-value for the difference between the growth rates is based on a Wald test reported in the lower panel.

[24] Related to the larger room for improvement in EEU countries, Cornillie and Frankhauser (2004) and Vehmas et al. (2018) show that energy intensity in these countries tends to be above the EU average.

suggests that voluntary agreements on industrial energy efficiency, which existed in the EU15 already since the 1990s but emerged in the EEU only after 2009 (see Cornelis, 2019), are not enough to induce large energy efficiency improvements. These results are robust to the exclusion of Switzerland from the regression (column 3).

The different dynamics of the EU15 and the EEU detected finds its underpinning in the different implementation of the Directive by the member states (see European Commission, 2014, for an overview of the national policies implemented). Of the national Energy Efficiency Action Plans (EEAPs) submitted for the first reporting period of Directive in 2007, the European Commission considers only eight of them as being ambitious, and only one of these ambitious EEAPs belongs to an EEU country, Slovenia. The rest of EEAPs are considered as business-as-usual scenarios. From the second reporting round in 2011, the Commission adds Poland and Cyprus to the group of ambitious EEAPs, while ten of the EU15 countries are included in that group.

The larger rates of decrease of the efficiency factor in the EU15 after 2007 can reflect a general trend of high-income countries, e.g. from CO_2 emission reduction programs implemented in the first commitment period of the Kyoto Protocol. All EU countries and most OECD countries, as part of Annex B to the Kyoto Protocol, face binding CO_2 emission targets. Improving energy efficiency may be a strategy to reach these targets common to these countries. Thus, we test whether the developments in the EU15 are different from developments in other OECD countries (column 4). We segregate the remaining OECD countries from the countries in the base group. The new base group shows the same patterns as in the previous regressions: the efficiency factor decreases before 2007 but increases afterward. However, the group of other OECD countries presents a different pattern. It experiences an increase in the efficiency factor in both periods (0.06% and 0.39%). Yet, the differential between the OECD and the EU15 is not statistically significant for any of the periods (p-values P1 EU15-OECD and P2 EU15-OECD). From 1997–2007, the differences between the EEU and these two groups are significant (p-values P1 EU15-EEU and P1 EEU-OECD), whereas from 2007–2014 they are not (p-values P2 EU15-EEU, and P2 EEU-OECD). Also, the differential between the EU15 or the EEU and the other OECD countries remain statistically similar across the two periods (p-values DID EU15-OECD and DID EEU-OECD).

This similarity in the developments in EU15 and other OECD countries is robust to the exclusion of Switzerland (column 5). However, some patterns change for the OECD group. The stronger decrease of the efficiency factors of both the OECD and the EU15 after 2007 compared to the period before is significantly different from the developments in the EEU (p-value DID EEU-OECD and DID EU15-EEU) and the base group (significant group–

period interactions). The difference between the EU15 and other OECD countries is not significant, similar to before (p-value DID EU15-OECD).

Energy intensity in footprint-based accounts

Although the EU Energy Services Directive does not target footprint-based energy measures, it can have two indirect effects on the energy intensity of suppliers of intermediates, which affect the energy footprint of EU countries. First, the Directive may induce a re-direction of domestic production towards sectors with lower energy usage and increase the demand for imports of energy-intensive products or from energy-intensive countries, increasing the energy intensity of final production and consumption relative to territorial production. Second, potential technological improvements in domestic production processes in EU countries as a result of the EU Directive may spill over to suppliers of intermediates (see Mandel et al., 2020, on the contribution of technological diffusion to climate change mitigation). In this case, the energy intensity of final production and consumption would decrease. The net outcome of these two effects is ambiguous, however. Besides, the difference between the results for footprint-based energy intensity and for production-based energy intensity may be relatively small, because a large part of domestic production ends up in domestic consumption (see e.g. Fernández-Amador et al., 2016), and because a large share of trade occurs between the EU members, all affected by the Directive. Accordingly, we compare the results of regressions for production- and footprint-based accounts. Table 3 reports the main results for the country groups and the two periods considered. We highlight the following findings.

First, the estimates for the footprint accounts reflect the different sourcing patterns of intermediates. The differences in the efficiency factor across country-groups are less pronounced for the footprint accounts than for the production-based account. This may indicate that energy-efficient countries, EU15 and other OECD countries, source energy-intensive intermediates from less efficient countries, EEU and the base group (non-EU non-OECD countries). The dynamics observed are consistent with this reading. Before 2007, the EU15 and the group of other OECD countries show larger efficiency gains in footprint-based than in production-based accounts, because of their large shares of energy embodied in intermediates from the EEU and the base group (non-EU non-OECD countries), which present stronger improvements in production-based energy efficiency. Although the footprint-based efficiency factor decreases in the other OECD countries, their production-based efficiency factor increases, such that the energy-efficiency improvements of suppliers of embodied intermediates are the source of the observed footprint-efficiency gains. After 2007, the gains in production-based efficiency slow down in EEU countries and reverse in the base group, while they accelerate in EU15 and other OECD countries.

	P1 (1997–2007)	P2 (2007–2014)	Difference (P2−P1)
	Production-based energy efficiency factor		
Base	-2.360	0.836	3.196
EEU	-4.442	-1.983	2.459
EU15	-0.940	-2.180	-1.240
R.o.OECD	0.492	-1.757	-2.249
	Final production-based energy efficiency factor		
Base	-2.585	0.608	3.193
EEU	-4.464	-1.296	3.168
EU15	-2.110	-1.641	0.469
R.o.OECD	-1.221	-1.529	-0.308
	Consumption-based energy efficiency factor		
Base	-2.518	0.577	3.095
EEU	-4.171	-1.153	3.018
EU15	-2.155	-1.465	0.690
R.o.OECD	-1.312	-1.413	-0.101

Table 3: Comparison of production- and footprint-based results

Note: Results from the regressions analyzing the average annual percentage change in the efficiency factor from the SDA for the respective energy account (production, final production or consumption). The numbers show the average annual percentage change in the energy efficiency factor for each of the country-groups, periods, and energy accounts. *Base* stands for the base-group of non-EU non-OECD countries, *R.o.OECD* stands for the rest of the OECD aggregate. The detailed regression results including Wald-tests for significant differences across country-groups and periods are reported in Tables 2, C.11, and C.12 for production, final production, and consumption-based energy intensity, respectively. The numbers reported here refer to the model specification in column (5) of the regression tables: The regressions exclude Switzerland in both periods.

In this period, the energy-efficiency of footprints in EU15 and other OECD countries improves less than production-based energy efficiency.

Second, the comparison of the efficiency gains between footprint- and production-based accounts suggests that the EU15 relies more heavily on imports of energy-intensive embodied intermediates than the rest of OECD after 2007. This is apparent from the larger difference between production-based and footprint-based efficiency gains in the EU15 relative to the OECD in that period. While the reductions in the efficiency factor in the EU15 and the OECD (excluding Switzerland) are larger after 2007 for production-based accounts, for footprint accounts this is the case only in the OECD (see difference P2–P1). Nevertheless, the differences between EU15 and other OECD countries are not statistically significant in any period.

Third, EEU countries show faster improvements in the footprint-based efficiency factor than EU15 and OECD countries before 2007 (see Tables C.11 and C.12 for details). However, after 2007, the footprint-based efficiency gains are slightly larger in the EU15 than in the EEU and the rest of the OECD (the difference being statistically insignificant).

All in all, EU15 and OECD countries experience stronger efficiency gains in production-based energy accounts after 2007 as compared to before. Yet, the estimated dynamics of production- and footprint-based estimates are indicative of a shift of energy-intensive production from EU15 and OECD countries towards countries in the EEU and non-EU, non-OECD countries. This is in line with findings supporting the existence of carbon leakage provided by e.g. Aichele and Felbermayr (2015) and Fernández-Amador et al. (2016). Given the analogous dynamics estimated for EU15 and OECD countries, it is unlikely that the EU Energy Services Directive constitute an idiosynchratic pattern but rather is part of a common trend of increasing energy efficiency in high-income countries which may be related to the Kyoto Protocol implementation. Finally, the energy leakage that our results indicate may offset the potential of energy intensity policies in high-income countries to contribute to a reduction of consumption-based energy usage. In this case, the trend towards more energy efficiency does not translate into lower energy footprints in high-income countries.

Changes in the energy mix

From the dataset elaborated, it can be observed that the EU's switch from fossil fuels towards wind and solar energy is faster than in other regions over 1997–2014 (see also Dietzenbacher et al., 2020). Although the Energy Services Directive does not formulate specific targets on renewable energy, faster improvements in the shares of renewable energy in EU countries over 2007–2014 may result from the mandatory renewable energy targets for 2011–2020 specified in the Renewable Energy Directive [2009/28/EC]. To test for this observation, we run regressions using the average annual change in the share of the seven energy commodities in the energy mix as dependent variables.[25] Table 4 reports the results for production-based accounts. From these results, we conclude that although there is a transition from fossil fuels to renewable energy sources, the EU regulation does not imply a differential between the EU and the rest of the OECD concerning the switch from fossil fuels to renewable resources. Two findings support our conclusion.

First, in both the EU15 and the EEU, the reduction in the share of fossil fuels and the increase in the shares of the renewable energy categories are larger after 2007. The reduction in the share of fossil fuels in the EU15 is significantly different from the reduction in the rest of OECD countries for the same period (p-value P2 EU15-OECD). The shares of hydro-, wind-, and solar energy also increase faster after 2007 in other OECD countries (see p-values P1-P2). However, wind- and solar energy expand significantly stronger in the EU15 compared to the EEU and the rest of OECD countries in both time-periods. This

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[25] An outlier, Cyprus, is excluded from the regressions: Cyprus reports an energy usage from fossil fuels of about 1.1 mtoe in 1997, which drops to 0.03 mtoe in 2007. The usage of renewable energy increases over that period. This results in a huge increase in the share of renewable energy in the energy mix. may report the EU's average instead of their actual final energy consumption in air transport.

	non-renewable			**renewable**			
	fossil	nuclear	other n-ren	hydro	wind	solar	other ren
Constant	0.213**	-0.008	0.003*	0.031	0.002**	0.003	-0.243**
2007–2014	-0.065	0.016	0.000	-0.039	0.016**	0.005	0.065
EU15	-0.458***	-0.050	0.028***	-0.070	0.068***	0.004	0.479***
EU15 · (2007–2014)	-0.501**	0.053	0.016	0.142*	0.089*	0.076***	0.125
EEU	-0.406**	0.085	-0.006	-0.054	0.003*	-0.002	0.380***
EEU · (2007–2014)	-0.668	-0.133	0.076**	0.234*	0.050**	0.032***	0.410**
R.o.OECD	-0.219	0.029	0.012	-0.111*	0.009**	0.001	0.279**
R.o.OECD · (2007–2014)	-0.053	-0.240	-0.002	0.121	0.026*	0.021**	0.126
N	152	152	152	152	152	152	152
R^2	0.243	0.025	0.290	0.044	0.415	0.391	0.218
P1: base	0.213	-0.008	0.003	0.031	0.002	0.003	-0.243
P1: EU15	-0.245	-0.059	0.031	-0.039	0.069	0.006	0.236
P1: EEU	-0.193	0.077	-0.002	-0.024	0.005	0.000	0.137
P1: R.o.OECD	-0.007	0.021	0.015	-0.080	0.011	0.003	0.036
P2: base	0.148	0.008	0.003	-0.008	0.018	0.007	-0.177
P2: EU15	-0.811	0.011	0.047	0.065	0.175	0.087	0.426
P2: EEU	-0.926	-0.040	0.074	0.171	0.071	0.038	0.612
P2: R.o.OECD	-0.124	-0.203	0.014	0.002	0.053	0.029	0.228
p-value: P1: EU15–EEU	·	·	**	·	***	***	·
p-value: P1: EU15–OECD	*	·	·	·	***	·	**
p-value: P1: EEU–OECD	·	·	·	·	·	·	·
p-value: P2: base–EU15	***	·	***	·	***	***	***
p-value: P2: base–EEU	**	·	**	·	**	**	***
p-value: P2: base–OECD	·	·	·	·	***	***	**
p-value: P2: EU15–EEU	·	·	·	·	**	*	·
p-value: P2: EU15–OECD	***	·	**	·	***	**	·
p-value: P2: EEU–OECD	*	·	**	·	·	·	**
p-value: P1–P2 base	·	·	·	·	**	·	·
p-value: P1–P2 EU15	***	·	·	***	**	***	**
p-value: P1–P2 EEU	*	·	**	*	***	***	***
p-value: P1–P2 OECD	·	·	·	*	***	***	·
p-value: DID EU15–EEU	·	·	*	·	·	*	*
p-value: DID EU15–OECD	·	·	·	·	·	**	·
p-value: DID EEU–OECD	·	·	**	·	·	·	·

Table 4: Regression results: energy mix of production
Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. *other n-ren* and *other ren* stand for the group of other non-renewable energy commodities, and other renewable energy commodities, respectively. The dependent variables measure the average annual change in the share (expressed in percent) of the respective energy commodity in the total energy mix. The panel below the R^2 reports the average annual change in the share of the energy commodity for each of the country-groups and periods. *P1* refers to the period 1997–2007, *P2* to the period 2007–2014. *base* stands for the base-group of non-EU non-OECD countries. The bottom panel reports a series of Wald-tests for differences across country-groups and/or periods. · stands for not statistically significant at the 10% level. *DID* stands for difference-in-differences and tests for differences in the interaction-terms (i.e. differences in changes from P1 to P2 across country-groups). Cyprus is excluded from the regressions.

contrasts to the non-significant difference between wealthy and less wealthy EU countries in the transition to renewable energy after 2008 documented by Andreas et al. (2017). Since Andreas et al. do not distinguish between renewable energy sources, their finding may be explained by the stronger increase in hydro- and other non-renewable energy in the EEU compared to the EU15 after 2007, although these differences between EU15 and EEU are statistically insignificant in our case.

Second, the change in the expansion rates across periods in most energy sources differs between EU countries and the base group (non-EU non-OECD countries) but is not significantly different from that taken place in the other OECD countries. The shares of many renewable commodities increase significantly stronger in the EU after 2007 when compared to the base group (significant interactions). However, when compared to OECD countries the increase in renewables is significantly stronger only in the EU15 for solar energy (p-value DID EU15-OECD). The faster reduction in the share of fossil fuels in the EU15 after 2007 is similar to the rest of the OECD (the differential is marginally insignificant; p-value DID EU15-OECD). The EEU increase the share of other non-renewable energy after 2007 faster than the OECD (p-value DID EEU-OECD). For the energy mix of footprint accounts, our findings are qualitatively similar to the ones described for the production-based energy mix (see Tables C.13 and C.14 in Appendix C).

5 Conclusion

Energy usage in the EU shows some peculiarities which are not present in other high-income regions. The EU's energy usage for production declines between 1997 and 2014, while energy footprints from final production and consumption increase. Also, the EU experiences a strong reduction in fossil energy and a rapid expansion of wind and solar energy used for production.

In this paper, we study the effects of the EU Energy Services Directive [2006/32/EC] on energy efficiency of production, final production and consumption to account for the effects of global supply chains on the effectiveness of the Directive. We construct a dataset of national energy accounts and propose the sector energy efficiency factor from an SDA as an improved measure of energy efficiency. The energy efficiency factor is used in a regression analysis, where we compare changes in energy efficiency in EU countries with changes observed in other countries over the periods before and after 2007 for the three energy accounts calculated, and analyze changes in the energy source mix over the same periods.

Our results indicate that the EU Energy Services Directive may have triggered policies that lead to stronger energy efficiency gains in production in the EU15 after 2007, as targeted by the Directive, but not in final production and consumption. The effectiveness of the Directive is mixed. It differs between EU15 and EEU member states. EU15 countries show accelerated efficiency improvements in production after 2007, whereas the newer EEU members realize important energy efficiency gains before 2007 but only limited gains afterward. The different ambition between the national EEAPs of the EU15 and EEU countries and some complementarity in supply chains seem to underlie the different dynamics of energy efficiency found between EU15 and EEU member states.

The developments of energy efficiency and changes in the energy mix observed in other OECD countries are similar to those of the EU15. The efficiency of production-based energy usage of EU15 and OECD countries relative to non-high-income countries increases after 2007. Also, the shift towards renewable energy sources for production- and footprint-based energy inventories seen in the EU15 and the EEU after 2007 is shared by other OECD countries, although to a smaller extent for solar energy. Overall, gains in energy efficiency and changes the mix of energy sources are common to high-income countries and not a specific trend of EU members. The EU energy policy does not determine a specific EU trend but rather seems part of a trend common to other high-income countries.

Our results are consistent with the existence of energy leakage. The EU15 and other OECD countries experience a shift toward more energy-intensive imports from non-high-income countries after 2007, and their better efficiency for production-based energy usage, relative to non-high-income countries, does not extend to footprint inventories. EU15 members reduce their energy usage for production from 1997–2014, because improvements in energy efficiency are coupled with compositional changes towards the production of less energy intensive intermediates and/or a reduction of the volume of intermediates produced. However, despite the gains in energy efficiency, changes supply chains contribute to larger footprints of energy embodied in final production and consumption. These supply chain changes point to a larger reliance on relatively energy-intensive imports and reduce the efficiency improvements of energy footprints in the EU15 after 2007.

Although energy regulation, which usually targets production-based energy, has the potential to reduce domestic energy usage for territorial production, it is less effective in reducing energy footprints, which account for the energy used in the production of imports accruing final production and consumption. Energy regulation should account for global supply chains to ensure that energy efficiency gains imply reducing energy footprints. The identification of the existence and the degree of energy leakage and the evaluation of alternatives to make energy policy robust to it deserve further research. Furthermore, the design of energy efficiency policies should also account for potential rebound effects. In this regard, a general-equilibrium approach can identify and incorporate the role of global supply chains and rebound effects into ex-ante policy assessments.

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A Data appendix

IEA Commodity	IEA Code	Energy Type
Anthracite	ANTCOAL	Primary Fossil Fuels
Coking Coal	COKCOAL	
Other Bituminous Coal	BITCOAL	
Sub-Bituminous Coal	SUBCOAL	
Lignite	LIGNITE	
Peat	PEAT	
Oil Shale and Oil Sands	OILSHALE	
Natural Gas	NATGAS	
Crude, nat. gas liquids and feedstocks	CRNGFEED	
Crude Oil	CRUDEOIL	
Natural Gas Liquids	NGL	
Patent Fuel	PATFUEL	Processed Fossil Fuels
Brown Coal Briquettes	BKB	
Peat Products	PEATPROD	
Refinery Feedstocks	REFFEEDS	
Additives and Blending Components	ADDITIVE	
Other Hydrocarbons	NONCRUDE	
Coke Oven Coke	OVENCOKE	
Gas Coke	GASCOKE	
Coal Tar	COALTAR	
Coke Oven Gas	COKEOVGS	
Gas Works Gas	GASWKSGS	
Blast Furnace Gas	BLFURGS	
Other Recovered Gases	OGASES	
Refinery Gas	REFINGAS	
Ethane	ETHANE	
Liquefied Petroleum Gases	LPG	
Motor Gasolines excl. Biofuels	NONBIOGASOL	
Aviation Gasoline	AVGAS	
Gasoline Type Jet Fuel	JETGAS	
Kerosene Type Jet Fuel excl. Biofuels	NONBIOJETK	
Other Kerosene	OTHKERO	
Gas Diesel Oil excl. Biofuels	NONBIODIES	
Fuel Oil	RESFUEL	
Naphtha	NAPHTA	
White Spirit	WHITESP	
Lubricants	LUBRIC	
Bitumen	BITUMEN	
Paraffin Waxes	PARWAX	
Petroleum Coke	PETCOKE	
Other Oil Products	ONONSPEC	
Elec/Heat Output from non-Specified Manufactured Gases	MANGAS	

Table A.1: IEA energy commodities matched to broad energy types. The table denotes all of the 62 energy commodities included in the 2018 edition of the IEA extended energy balances and their allocation to the final energy commodities of our database.

IEA Commodity	**IEA Code**	**Energy Type**
Nuclear	NUCLEAR	Nuclear Energy
Hydro	HYDRO	Hydro Energy
Solar Photovoltaics	SOLARPV	Solar Energy
Solar Thermal	SOLARTH	
Wind	WIND	Wind Energy
Biogasoline	BIOGASOL	Other Renewable Energy
Biodiesels	BIODIESEL	
Bio Jet Kerosene	BIOJETKERO	
Other Liquid Biofuels	OBIOLIQ	
Municipal Waste Renewable	MUNWASTER	
Primary Solid Biofuels	PRIMSBIO	
Biogases	BIOGASES	
Geothermal	GEOTHERM	
Tide Wave and Ocean	TIDE	
Charcoal	CHARCOAL	
Industrial Waste	INDWASTE	Other non-Renewable Energy
Municipal Waste non-Renewable	MUNWASTEN	
Other Resources	OTHER	
Gross Electricity Production	ELECTR	Heat and Electricity
Heat	HEAT	

Table A.1: – continued.

IEA Flow	**IEA Code**	**Sector Name**	**Sector Code**
IEA flows associated with transformation to electricity:			
Main activity producer electricity plants	MAINELEC	Electricity	ely
Autoproducer electricity plants	AUTOELEC[a]		
Main activity producer CHP plants	MAINCHP		
Autoproducer CHP plants	AUTOCHP[a]		
Main activity producer heat plants	MAINHEAT		
Autoproducer heat plants	AUTOHEAT[a]		
Heat pumps	HEAT		
Electric boilers	BOILER		
Chemical heat for electricity production	ELE		
IEA flows associated to transformation activities not related to electricity:			
Gas works	TGASWKS	Gas Distribution	gdt
For blended natural gas	BLENDGAS		
Charcoal production plants	TCHARCOAL	Electricity	ely
Patent fuel plants	TPATFUEL		
BKB/peat briquette plants	BKB		
Oil refineries	TREFINER		
Coal liquefaction plants	TCOALLIQ		
Gas-to-liquids (GTL) plants	TGTL		
Blast furnaces	TBLASTFUR[b]	Iron & Steel	i_s
Coke ovens	TCOKEOVS[b]		
Petrochemical plants	TPETCHEM	Chemical Rubber Products	crp
IEA flows associated to energy usage by the energy sector itself:			
Coal mines	MINES	Coal	coa
Gas works	GASWKS	Gas Distribution	gdt
Liquefaction (LNG) / regasification plants	LNG		
Pumped storage plants	PUMPST	Electricity	ely
Charcoal production plants	CHARCOAL		
Gasification plants for biogases	BIOGAS	Other Ser. (Government)	osg
Blast furnaces	BLASTFUR	Iron & Steel	i_s
Coke ovens	COKEOVS		
Patent fuel plants	PATFUEL	Petroleum & Coke	p_c
BKB/peat briquette plants	BKB		
Oil refineries	REFINER		
Coal liquefaction plants	COALLIQ		
Gas-to-liquids (GTL) plants	GTL		
Own use in electricity, CHP and heat plants	POWERPLT		
Nuclear industry	NUC		

Table A.2: Energy flows from the IEA Extended World Energy Balances matched to a single sector.

IEA Flow	**IEA Code**	**Sector Name**	**Sector Code**
IEA flows associated to industrial activities matched to a single economic sector:			
Iron and steel	IRONSTL	Iron & Steel	i_s
Chemical and petrochemical	CHEMICAL	Chemical Rubber Products	crp
Non-ferrous metals	NONFERR	Non-Ferrous Metals	nfm
Non-metallic minerals	NONMET	Non-Metallic Minerals	nmm
Transport equipment	TRANSEQ	Motor Motor vehicles and parts	mvh
Transport equipment	TRANSEQ	Other Transport Equipment	otn
Machinery	MACHINE	Other Machinery & Equipment	ome
Mining and quarrying	MINING	Other Mining	omn
Paper, pulp and print	PAPERPRO	Paper & Paper Products	ppp
Wood and wood products	WOODPRO	Lumber	lum
Construction	CONSTRUC	Construction	cns
Other IEA flows that can be matched to a single economic sector:			
Transfers	TRANSFER	Petroleum & Coke	p_c
Fishing	FISHING	Fishing	fsh
Residential	RESIDENT	Private Households	HH
IEA flows associated to transport activities:			
Domestic aviation	DOMESAIR	Air transport	atp
World aviation bunkers	WORLDAV		
Rail	RAIL	Other Transport	otp
Pipeline transport	PIPELINE		
Non-specified (transport)	TRNONSPE		
World marine bunkers	WORLDMAR	Water Transport	wtp
Domestic navigation	DOMESNAV		

Table A.2: – continued.

IEA Flow	**IEA Code**	**Sector Name**	**Sector Code**
IEA flows releated to industrial activities matched to several economic sectors:			
Oil and gas extraction	OILGASEX	Oil	oil
		Gas	gas
Agriculture and forestry	AGRICULT	Paddy Rice	pdr
		Wheat	wht
		Other Grains	gro
		Vegetables and Fruits	v_f
		Oil Seeds	osd
		Cane and Beet	c_b
		Plant Fibres	pfb
		Other Crops	ocr
		Cattle	ctl
		Other Animal Products	oap
		Raw Milk	rmk
		Wool	wol
		Forestry	frs
Food and tobacco	FOODPRO	Cattle Meat	cmt
		Other Meat	omt
		Vegetable Oils	vol
		Milk Products	mil
		Processed Rice	pcr
		Sugar	sgr
		Other Food	ofd
		Beverages and Tobacco products	b_t
Textile and leather	TEXTILES	Textiles	tex
		Wearing Apparel	wap
		Leather	lea
Machinery	MACHINE	Other Machinery & Equipment	ome
		Fabricated Metal Products	fmp
		Electronic Equipment	ele
Transport Equipment	TRANSEQ	Motor Vehicles and Parts	mvh
		Other Transport Equipment	otn
Non-specified industry	INONSPEC	Other Machinery & Equipment	ome
		Other Manufacturing	omf
		Electronic Equipment	ele
Commercial and public services	COMMPUB	Communications	cmn
		Other Financial Intermediation	ofi
		Insurance	isr
		Other Business Services	obs
		Recreation & Other Services	ros
		Other Ser. (Government)	osg
		Dwellings	dwe
Road	ROAD	Other Transport	otp
		Private Households[a]	HH

Table A.3: Energy flows from the IEA data that have to be matched to more than one economic sector. Note: [a] The ROAD activity includes also the usage of gasoline and diesel, including their renewable derivatives. Some of them is used by non-residents such that this flow item had to be bridged from the territorial to he residency principle as discussed in the main text.

Aggregate	**Countries and regions included**
	Single Countries and Regions:
The 66 single countries and regions	Albania, Argentina, Australia, Austria, Belgium, Bangladesh, Bulgaria, Brazil, Botswana, Canada, Chile, China, Colombia, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Malawi, Malaysia, Malta, Mexico, Morocco, Mozambique, Netherlands, New Zealand, Peru, Philippines, Poland, Portugal,Romania, Russia, Singapore, Slovakia, Slovenia, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Tanzania, Thailand, Turkey, Uganda, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Zambia and Zimbabwe.
	The 12 Composite Regions:
Rest of Andean Pact	Bolivia and Ecuador
Central America, Caribbean	Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Montserrat, Netherl. Antilles, Nicaragua, Panama, Puerto Rico, Saint Helena, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, Turks and Caicos Islands, British Virgin Islands, US Virgin Islands.
Rest of EFTA	Iceland, Liechtenstein and Norway.
Rest of Former Soviet Union	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.
Middle East	Bahrain, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates and Yemen.
Rest of North Africa	Algeria, Egypt, Libya and Tunisia.
Other Southern Africa	Angola and Congo (DPR).
Rest of South African Customs Union	Lesotho, Namibia, South Africa and Swaziland.
Rest of South America	Guyana, Paraguay and Suriname.
Rest of South Asia	Bhutan, Maldives, Nepal and Pakistan.
Rest of Sub-Saharan Africa	Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Mali, Mauritania, Mauritius, Mayotte, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, Sudan and Togo.
Rest of World	Antarctica, Afghanistan, American Samoa, Andorra, British Indian Ocean territory, Bosnia and Herzegovina, Bouvet Issland, Brunei Darussalam, Cambodia, Macao SAR, Cook Islands, Democratic People's Republic of Korea, Falkland Islands (Malvinas), Faroe Islands, Fiji, French Guyana, French Polynesia, French Southern Territories, Gibraltar, Greenland, Guam, Guernsey, Holy See, Isle of Man, Jersey, Kiribati, Lao People's Democratic Republic, Marshall Islands, Micronesia (Federated States of), Monaco, Mongolia, Montenegro, Myanmar, Nauru, New Caledonia, Niue, Norfolk Island, Northern Mariana ,Islands, Occupied Palestinian Territory, Palau, Papua New Guinea, Pitcairn, Saint Pierre and Miquelon, Samoa, San Marino, Serbia, Solomon Islands, South Georgia and the South Sandwich Islands , The former Yugoslav Republic of Macedonia, Timor-Leste, Tokelau, Tonga, Tuvalu, US Minor Outlying Islands, Vanuatu, Western Sahara and Wallis and Futuna Islands.

Table A.4: Countries and composite regions in the database. Note: Computations were performed using the regional aggregation of GTAP 5. The table shows also countries which appear in later GTAP databases, which are, however, too small to change results. They are mainly small islands states or territories belonging to the jurisdiction of another country, which show up in one of the later composite regions (Wallis and Futuna, or Jersey for example). The only notable exceptions are Timor-Leste and Greenland.

Aggregate	**Countries and regions included**
	Countries that are part of an aggregate region in IEA data:
France	Monaco*
Italy	San Marino
Other non-OECD Asia	Cook Islands, Fiji, French Polynesia, Kiribati, New Caledonia, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga , Vanuatu, Macau (SAR), Lao People's Democratic Republic, Timor-Leste, Afghanistan, Bhutan, Maldives.
Other non-OECD America	Guyana, Belize, Puerto Rico, Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, British Virgin Islands, Cayman Islands, Dominica, Grenada, Montserrat, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, Turks and Caicos Islands, Bermuda.
Europe	Liechtenstein, Andorra, Occupied Palestinian Territory.
	GTAP countries that have been discarded
Discarded	American Samoa, Niue, Pitcairn, US Minor Outlying Islands, Saint Pierre and Miquelon, French Guyana, Netherl. Antilles, Faroe Islands, Holy See, Jersey, Saint Helena, Antarctica, British Indian Ocean Territory, Guam, Northern Mariana Islands, Tokelau, Wallis and Futuna, Falkland Islands (Malvinas), South Georgia and the South Sandwich Islands, US Virgin Islands Guernsey, Isle of Man, Western Sahara, Mayotte, Bouvet Island, French Southern Territories, Micronesia (Federated States of).

* The usage of nuclear energy was not splitted between France and Monaco according to their GDP shares because Monaco does not run a nuclear program.

Table A.5: Imputed and discarded GTAP countries and regions.

B Methodological appendix

B.1 Methodology to construct territorial production data

In this appendix we discuss in detail the steps required for the construction of the production-based national energy accounts. First, we match the usage of the different energy commodities in the countries and regions of our database, distinguished by the economic activities as captured in the IEA extended energy balances ("flows" in IEA terms), to the final economic sectors and private households in our database. We then bridge the territorial system boundary of the IEA data to the residential principle underlying the multi-region input-output (MRIO) tables used for the construction of the energy footprints. This last step ensures the comparability of our standard production and footprint accounts.

B.1.1 Matching the IEA flows to 57 sectors and private HH

The matching-process of the first step follows the International Standard Industrial Classification (ISIC) of the United Nations (see UN, 2008). We have to deviate from a strict application of the ISIC classification in some cases due to lack of information, problematic conventions or known misreporting in the IEA data. Most importantly, this was necessary for the treatment of combined heat and and power plants, electricity and heat production by industrial plants outside the electricity sector ("autoproducers") and the potential double counting of coal usage by coke ovens and blast furnaces in the IEA data. We refer to McDougall and Lee (2006) and Genty et al. (2012) for related discussions. Also, in the case of pure transformation processes, such as the usage of fossil fuels by the petroleum and coke industry as production inputs, the IEA data tracks the inflow as well as the outflow of energy commodities. Those outflows, however, become an inflow again in industries further downstream in the economy. To avoid double counting, we disregard the outflow of energy commodities in industries.

In some cases the sectors in our final dataset are more disaggregated than the economic activities in the IEA data, see also Table (A.3) in Appendix A. We split the usage of all 62 energy energy commodities used by the economic flows in Table (A.3) to the more disaggregated sectors in our final database as follows. First, each of the 62 commodities is linked to the sector in our database which predominantly produces this commodity. For example, the coal-based energy commodities, such as anthracite, are matched to the coal extraction sector ("coa"). This matching process is documented in Table (B.1) and is informed by ISIC classifications.[26] Second, from our input-output tables we observe the purchases of each of the detailed sectors in Table (A.3) from the energy commodity producing sectors in Table (B.1) in monetary terms. For each energy commodity we then split the IEA energy flows in (A.3) to the more detailed sectors in proportion to the intermediate purchases by the detailed sectors it is disaggregated to.[27]

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[26] We deviate from a strict application of ISIC in if the overall sales pattern of a sector is not representative for the sales of an energy commodity it produces. Specifically, following ISIC the production of bio-fuels should be allocated to the chemical sector ("crp" in our data) in Table (B.1). Bio-fuels, however, are only a tiny fraction of the sectors's overall production of intermediates such that its sales of intermediates cannot be considered to be representative for the sales-patterns of bio-fuels. Thus, we match bio-fuels to petroleum and coke ("p_c") sector, which also produces gasolines and diesels that show a similar sales pattern as bio-fuels. We refer to Genty et al. (2012) for a related discussion.

[27] For example, the usage of anthracite by the "textile and leather" (TEXTILES) flow has to be split to textiles ("tex"), wearing apparel ("wap"), and leather ("lea") sectors in our data. Assuming that each of those sectors buys about the same amount of intermediates from the coal extraction (coa) sector, then one third of the total anthracite used by "textile and leather" is allocated to each of these three sectors.

IEA Commodity	**IEA Code**	**Sector Name**	**Sector Code**
Correspondence of IEA energy products to economic sectors:			
Anthracite	ANTCOAL	Coal	coa
Coking Coal	COKCOAL		
Other Bituminous Coal	BITCOAL		
Sub-Bituminous Coal	SUBCOAL		
Lignite	LIGNITE		
Patent Fuel	PATFUEl		
Brown Coal Briquettes	BKB		
Peat	PEAT		
Peat Products	PEATPROD		
Oil Shale and Oil Sands	OILSHALE		
Natural Gas	NATGAS	Oil + Gas	oil + gas
Crude, nat. gas liquids and feedstocks	CRNGFEED		
Crude Oil	CRUDEOIL		
Natural Gas Liquids	NGL		
Refinery Feedstocks	REFFEEDS		
Additives and Blending Components	ADDITIVE		
Other Hydrocarbons	NONCRUDE		
Coke Oven Coke	OVENCOKE	Petroleum & Coke	p_c
Gas Coke	GASCOKE		
Coal Tar	COALTAR		
Coke Oven Gas	COKEOVGS		
Blast Furnace Gas	BLFURGS		
Other Recovered Gases	OGASES		
Refinery Gas	REFINGAS		
Ethane	ETHANE		
Liquefied Petroleum Gases	LPG		
Motor Gasolines excl. Biofuels	NONBIOGASOL		
Aviation Gasoline	AVGAS		
Gasoline Type Jet Fuel	JETGAS		
Kerosene Type Jet Fuel excl. Biofuels	NONBIOJETK		
Other Kerosene	OTHKERO		
Gas Diesel Oil excl. Biofuels	NONBIODIES		
Fuel Oil	RESFUEL		
Naphtha	NAPHTA		
White Spirit	WHITESP		
Lubricants	LUBRIC		
Bitumen	BITUMEN		
Paraffin Waxes	PARWAX		
Petroleum Coke	PETCOKE		
Other Oil Products	ONONSPEC		

Table B.1: Energy products in the IEA extended energy balances (2018 ed.) matched to economic sectors. Note: ^{a} Pure output flows as a result of transformation activities in the IEA data. Will be discarded in the final dataset. ^{b} In practice the use of energy released by nuclear fission or fusion is restricted to the electricity sector in all countries in all years such that there is no need to split this flow among several sectors.

IEA Commodity	**IEA Code**	**Sector Name**	**Sector Code**
Correspondence of IEA energy products to economic sectors:			
Biogasoline	BIOGASOL		
Biodiesels	BIODIESEL		
Bio Jet Kerosene	BIOJETKERO		
Other Liquid Biofuels	OBIOLIQ		
Non Specified Primary Biofuels and Waste	RENEWNS		
Elec/Heat Output from non-Specified Manufactured Gases	MANGAS		
Industrial Waste	INDWASTE	Other Ser. (Government)	osg
Municipal Waste Renewable	MUNWASTER		
Municipal Waste non-Renewable	MUNWASTEN		
Primary Solid Biofuels	PRIMSBIO	Cattle + Other Animal Prod. + Forestry	ctl + oap + frs
Gas Works Gas	GASWKSGS	Electricity + Gas Distribution	ely + gdt
Biogases	BIOGASES		
Heat Output from non-Specified Combustible Fuels[a]	HEATNS		
Nuclear[b]	NUCLEAR		
Hydro	HYDRO		
Geothermal	GEOTHERM		
Solar Photovoltaics	SOLARPV		
Solar Thermal	SOLARTH		
Tide Wave and Ocean	TIDE		
Wind	WIND		
Other Sources[a]	OTHER		
Electricity[a]	ELECTR		
Heat[a]	HEAT		
Charcoal	CHARCOAL	Chemical Rubber Products	crp

Table B.1: – continued.

B.1.2 Bridging the territorial and residential principles

The IEA energy balances are compiled according to a strict territorial system boundary, while the input-output (IO) data we use for the construction of the energy footprints follow the "residential principle". As the residents of a country mainly operate within the territory of their country residence, the difference in the system boundaries is inconsequential most cases (see Peters, 2008; Peters and Hertwich, 2008b). Considerable deviations between both concepts can occur, however, in the case of international road, -air, and -sea transport (Usubiaga and Acosta-Fernández, 2015; Usubiaga-Liaño et al., 2021).

Specifically, the IEA assigns fuels used for international aviation and navigation ("international bunker fuels") to the country from which territory the fuels are supplied, i.e. the location of harbours and airports. In the IO data, however, the economic activities of those air and shipping lines are accounted to their country of residency. As a result, the fuels captured in the IEA's "international bunker fuel" entries have to be distributed to the countries of residence of the air- and shipping lines that use those fuels. To do so, we rely on monetary data on the usage of modes of transport by country sourced from the Global Trade Analysis Project (GTAP, see Peters et al., 2011c, for a related application in the construction of multi-region input-output tables). Specifically, we first aggregate purchases of international aviation and navigation services of all countries, as well as all bunker fuel entries of the IEA data, to global pools. Then, we calculate for each country its share of usage of the global transportation service pool and assign the usage of bunker fuels to the individual countries based on those shares.

For similar reasons the territorial usage of energy in road transport in the IEA data has to be corrected for the residency principle. Especially in small European countries so called "tank tourism", i.e. fuels used by non-residents on a country's territory, can contribute a large amout of total fuel usage in that sector.[28] Data on energy usage in road transport by (non-)residents is scarce, however, so we rely on EUROSTAT data on carbon dioxide (CO_2) emissions from road transport as a proxy. It includes data on emissions from non-residents on the domestic territory of a country as well as emissions caused by residents abroad for EU and EFTA member states. A drawback of this approach is that non-European data is not available. However, most of the other other countries in the world have either limited cross-border traffic, are islands, or cross-border traffic is relatively small compared to the overall road sector of a country (see Stadler et al., 2018b).

The correction of fuel usage for cross-border road traffic is undertaken in two steps. First, we calculate for each country in the EUROSTAT data the ratios of CO_2 emissions from road transport caused by non-residents on its territory and by its residents abroad with respect to its territorial road sector total. We then multiply those ratios with IEA total fuel usage in road transport ("ROAD"), resulting in energy used by residents and non-residents in that sector. With those totals we bridge the territorial fuel usage of the IEA data to the usage of residents in our final dataset.[29]

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[28] According to BMLFUW (2004) the purchases of gasoline and diesels by non-residents in Austria accounted for 23 and 32% of total sales in 2003. In Germany in 2006, on the other hand, about 5 and 8% of total used gasoline and diesels in that country was purchased abroad (see Ratzenberger, 2007).

[29] After this last step we obtain a residual of fuels that is not allocated to any country as fuel usage by (non-)residents usually does not cancel out at the European level. The surplus fuels are allocated to the European countries for which EUROSTAT does not provide data, i.e. Greece, Slovakia and Slovenia, based on their total size of the road sector in monetary terms. As a result we treat the EU and EFTA as a closed system, an approach that was applied by Stadler et al. (2018b).

B.1.3 Summary

The dataset resulting from the steps described above follows a gross energy use perspective (see Genty et al., 2012, for a more detailed discussion) which allows to focus on a large variety on energy-related questions, ranging from carbon dioxide emissions from fossil fuel consumption, the efficiency of the transformation of primary energy to electricity and heat production, or to determine patterns of the efficiency of electricity usage by private households. In our study we are interested in assessing the determinants of the primary energy mix used in the European Union in order keep its economy producing. This includes the amount of primary fossil fuels and renewable sources directly used by firms and private household produce energy, but also amount of primary fossil fuels for the transformation into processed fuels, for example diesel and gasoline, used by the European industry and private households. Thus, in order to avoid double counting we disregard the category of derived fuels from out data. Also, as we take a input-perspective of energy usage, we also disregard the electricity and heat category from our data.

B.2 Methodology to construct energy footprint data

Here we provide a detailed discussion on the construction of the two energy footprints. We denote gross output produced by each of the s sectors (57 in our case) in one of the $i \subseteq [1, n]$ regions in our dataset as $x^i = (x^i_1, x^i_2, \ldots, x^i_s)'$, where n denotes the total number or regions which is 78. Each sector produces either intermediates, sold for further processing to other sectors at home or abroad, Ax, or final goods, purchased by domestic or foreign consumers for final consumption, $Y\iota_n$. That is,

$$x = Ax + Y\iota_n \tag{B.1}$$

or

$$\begin{pmatrix} x^1 \\ x^2 \\ x^3 \\ \vdots \\ x^n \end{pmatrix} = \begin{pmatrix} A^{11} & A^{12} & A^{13} & \cdots & A^{1n} \\ A^{21} & A^{22} & A^{23} & \cdots & A^{2n} \\ A^{31} & A^{32} & A^{33} & \cdots & A^{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A^{n1} & A^{n2} & A^{n3} & \cdots & A^{nn} \end{pmatrix} \begin{pmatrix} x^1 \\ x^2 \\ x^3 \\ \vdots \\ x^n \end{pmatrix} + \begin{pmatrix} y^{11} & y^{12} & \cdots & y^{1n} \\ y^{21} & y^{22} & \cdots & y^{2n} \\ y^{31} & y^{32} & \cdots & y^{3n} \\ \vdots & \vdots & \ddots & \vdots \\ y^{n1} & y^{n2} & \cdots & y^{nn} \end{pmatrix} \iota_n \; . \tag{B.2}$$

The $ns \times n$ dimensional matrix Y on the right-hand side of Equation (B.2), denotes the final goods demanded in each region by sector and country of origin. Accordingly, its elements, i.e. $y^{rp} = (y^{rp}_1, y^{rp}_2, \ldots, y^{rp}_s)'$ are column-vectors of dimension s. Each y^{rp}_z denotes the final goods from sector z in country r demanded by region p.[30] We collapse Y to a column vector of final demand with dimension $ns \times 1$ by multiplying it with ι_n, a column vector of ones with dimension n.

The matrix A on the right-hand side of Equation (B.2), the so-called global input requirements matrix, collects all the direct requirements of a specific sector from all the other sectors in the global economy to produce one unit of output. Its elements, i.e. A^{rp}, are matrices of dimension $s \times s$ that capture the intermediates exported by region r to region p, such that they denote domestic transactions whenever $r = p$. The elements of A^{rp}, i.e. a^{rp}_{kj}, are normalized to the output of the purchasing sector j such that a^{rp}_{kj} denotes the direct inputs required by sector j in country p from sector k in country r to produce one real dollar of output, where $k, j \subseteq [1, s]$.

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[30] We follow the standard conventions of the input-output literature and denote with the first super- or subscript the region or sector of origin and the second super- or subscript the region or sector of destination.

We construct matrices A and Y for each year in our database by linking national input-output (IO) tables with international trade data as described in Peters et al. (2011a), where the raw trade and IO data is sourced from the Global Trade Analysis Project (GTAP). We deflated all monetary values in the final tables to the year 1997. The next step is then to account for the indirect requirements of production, i.e. the requirements of the direct suppliers themselves, but also the suppliers of the suppliers, and so on.

To account for those indirect requirements of production we solve Equation (B.1) for x, the companion vector of gross output. This results in $x = (I - A)^{-1}y$, where I denotes the $ns \times ns$ dimensional identity matrix and $y = Y\iota_n$. Matrix $(I - A)^{-1}$, also of dimension $ns \times ns$, is denoted as the Leontief-inverse or total requirements matrix in the input-output literature. The elements of its sub-matrices, i.e. $\tilde{a}_{kj}^{rp}$ in $(I - A)_{rp}^{-1}$, denote the direct and indirect inputs sourced by sector j in region p from sector k in region r to produce one dollar of output. Thus, it accounts for global production structures along international supply chains, denoted in gross output.

As a next step we transform the direct and indirect linkages among the sectors in the world economy to value added as

$$\Lambda = V(I - A)^{-1}, \tag{B.3}$$

where V is a diagonal matrix of dimension $ns \times ns$. The elements on the main diagonal of V, i.e. $v = (v^1, v^2, \ldots, v^n)$, contain the value added intensity of production of the sectors in each region r. Each of these $s \times s$ dimensional elements v^r is also a diagonal matrix. Their elements v_k^r on the main diagonal contain the value added of sector k in region r denoted in the prices of 1997 divided by its total gross output produced, x_k^r. As a result, an element λ_{kj}^{rp} of Λ captures the direct and indirect usage of value added provided by sector k in region r to sector j in region p in order to produce one real dollar of gross output.

In order to obtain the amount of value added embodied in final goods assembled or consumed in a specific region, we multiply Λ with matrix Y and the $ns \times n$ dimensional matrix Y^o, respectively. While Y is defined as above and captures the value of final goods produced by each sector according to region of consumption, Y^o captures the total amount of final goods produced by the sectors of a specific region, i.e. its aggregated sector output of final goods produced for the domestic and foreign markets. Therefore,

$$\Phi^o = \Lambda Y^o \tag{B.4}$$

and

$$\Phi^c = \Lambda Y\ . \tag{B.5}$$

We derive Y^o by defining first the ns dimensional vector $y^o = Y\iota_n$, where ι_n is a row-summation vector of ones with dimension n. The s dimensional elements of $y^o = (y^{1*}, y^{2*}, \ldots, y^{n*})'$, denote all the final goods produced for the domestic and foreign markets by the s sectors of region r, i.e. $y^{r*} = y^{r1} + y^{r2} + \ldots + y^{rn}$. As a next step we define the $ns \times n$ dimensional matrix $I_{[ns,n]}$ as $\hat{\iota}_n \otimes \iota_s$, where ι_s is a s dimensional column-vector of ones, $\hat{\iota}_n$ is a diagonal matrix with the elements of ι_n on its main diagonal, and $\otimes$ denotes the Kronecker product. Matrix Y^o is then obtained as $Y^o = \hat{y}^o I_{[ns,n]}$ and its n columns capture the n elements y^{r*} of y^o. Specifically, its r^{th} column is equal to $y^o \circ o$, where o is a selection-vector of the same dimension as y^o that contains ones at the positions of elements y^{r*} and zero otherwise and $\circ$ is the Hadamard element-wise product.

Multiplying Y^o and Y by the re-scaled Leontief-inverse matrix Λ allows us to assess the total usage of value added required for final goods production (Φ^o) in each region as well as for the final goods consumed by region and sector of origin (Φ^c), respectively. By construction (see equations (B.4) and (B.5)) the energy usage embodied in these final goods is a function of the bundle of intermediates used in local and global supply chains, as determined by the re-scaled Leontief-inverse matrix, Λ. Specifically, the s dimensional elements of $\Phi^o = (\phi^{o,1r}, \phi^{o,2r}, \ldots, \phi^{o,nr})'$ denote the total amount of value added embodied in the intermediates used to produce final goods in region r, which are sourced worldwide, i.e. from sectors 1 to s in region 1 to n. The components of $\Phi^c = (\phi^{c,1r}, \phi^{c,2r}, \ldots, \phi^{c,nr})'$, which are also of dimension s, denote the amount of value added embodied in the domestic or imported final goods consumed in region r.

As a next step we complement matrices Φ^o and Φ^c with comparable matrices the capture the embodied flow of energy through the world's supply chains to the final goods assembled and consumed in each region of our dataset. For this, we pre-multiply both matrices with a matrix containing sectoral energy intensities, E, as

$$\Psi^o = E\Phi^o = E\Lambda Y^o \tag{B.6}$$

and

$$\Psi^c = E\Phi^c = E\Lambda Y\ . \tag{B.7}$$

Matrix E is a diagonal matrix of dimension $ns \times ns$ with main diagonal elements $e = (e^1, e^2, \dots, e^n)$ that contain the energy intensity of production of the sectors in each region r. Each of those elements e^r is a diagonal matrix again. They are of dimension $s \times s$ and an element e^r_k on its main diagonal contains the amount of energy, denoted in megatons of oil equivalents ($mtoe$), used by sector k in region r divided by its total value added v^r_k. Thus, the product of E and the Leontief-inverse, i.e. $E\Lambda$, is a matrix that captures the total usage of energy embodied in transactions of intermediates between all sectors in the global economy.

Matrices Ψ^o and Ψ^c are also of dimension $ns \times n$ and their s dimensional elements, i.e. $\Psi^o = (\psi^{o,1r}, \psi^{o,2r}, \dots, \psi^{o,nr})'$ and $\Psi^c = (\psi^{c,1r}, \psi^{c,2r}, \dots, \psi^{c,nr})'$, denote the amount of energy embodied in final goods production and consumption in region r by the sectors in the regions of origin 1 to n, respectively. Those flows of embodied energy are additionally determined by the energy intensity of all sectors involved in the supply chain of those final goods.

We aggregate the sectors by source regions from Ψ^o and Ψ^c. For this we create aggregation matrix $I_{[n,ns]} = \hat{\iota}_n \otimes \iota'_s$, which is of dimension $n \times ns$. The s elements of row-vector ι'_s are ones and $\hat{\iota}_n$ is defined as above. Multiplying $I_{[n,ns]}$ with Ψ^o and Ψ^c results in the $n \times n$ dimensional matrices $\Psi^o_a = I_{[n,ns]}\Psi^o$ and $\Psi^c_a = I_{[n,ns]}\Psi^c$. The scalar elements of those matrices, i.e. $\psi^{o,rp}_a = \iota'_s \psi^{o,rp}$ and $\psi^{c,rp}_a = \iota'_s \psi^{c,rp}$, denote the amount of energy originating in country r that is embodied in the final goods produced ($\psi^{o,rp}_a$) or consumed ($\psi^{c,rp}_a$) in region p. Thus, whenever $r \neq p$ those elements can be used to assess exports and imports of energy commodities embodied in intermediates and final goods between the regions in our dataset. These trade flows of embodied energy are related to the concept of trade in value added as defined by Johnson and Noguera (2012) in the sense that the energy commodities originating in region r can cross several sectors and borders before being absorbed in final goods produced or consumed in region p.[31]

It is straightforward to derive national energy accounts from matrices Ψ^o, Ψ^o_a, Ψ^c and Ψ^c_a, respectively. Remember, we obtain energy embodied in national final production by summing over all foreign and domestic sources of embodied energy in intermediate imports that ends up embodied in the final goods produced by a region. Thus, we obtain the vector of the n national final production-based energy accounts ψ^o by taking the column-sums of Ψ^o_a, or Ψ^o, respectively. Formally we derive $\psi^o = \iota'_n \Psi^o_a = \iota'_{ns} \Psi^o$, where ι'_n and ι'_{ns} are row vectors of ones of dimension n and ns, respectively. Similarly, we sum over all source-regions 1 to n to obtain the energy embodied in the final goods consumed in region

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[31] As a result, whenever $r = p$ the elements of Ψ^o_a and Ψ^c_a denote energy originating within the region of final production and consumption. This includes, however, energy embodied in intermediates that left the country for further processing to other countries before being assembled to a final good in the country of origin (see Koopman et al., 2014).

r. Formally we are taking the column-sum of Ψ_a^c and Ψ^c, which results in a vector ψ^c that captures the n national final consumption-based energy accounts, i.e. $\psi^c = \iota_n' \Psi_a^c = \iota_{ns}' \Psi^c$. The n scalar elements of ψ^o and ψ^c, i.e. $\psi^{o,r}$ and $\psi^{c,r}$, denote region r's national final production and -consumption footprints, respectively.

Matrices Ψ^o, Ψ_a^o, Ψ^c, and Ψ_a^c offer an alternative way to calculate the national territorial production-based energy accounts. We defined territorial production of energy as the amount of energy that is used in the territory of a region to produce intermediates and final goods. Some of those intermediates are assembled to final goods at home or become embodied in final goods consumed at home. Other final goods are exported for consumption abroad as are some of the intermediates that are produced on a region's territory. Thus, summing over all destination regions of embodied energy in matrices Ψ_a^o, Ψ_a^c and over all source sectors and destination regions in Ψ^o, Ψ^c, i.e. taking the row-sums of those matrices, results in vector ψ^v which n elements correspond to the territorial production-based accounts of regions 1 to n. We calculate vector ψ^v as $\psi^v = \Psi_a^o \iota_n = \Psi_a^c \iota_n = I_{[n,ns]} \Psi^o \iota_n = I_{[n,ns]} \Psi^c \iota_n$, where $I_{[n,ns]}$ and ι_n are defined as above.

The scalar elements $\psi^{\omega,r}$ of vectors ψ^ω, where $\omega \subseteq \{o, c, v\}$, thus, denote the national energy accounts according to final production (o), final consumption (c), and territorial production (v), respectively. So far we accounted only for the energy used in industrial activities to produce goods and services. Some energy commodities in our data, specifically fossil fuels, solar/photovoltaic, and biomass[32], are used by private households directly for heating and, to some degree, for electricity production. In a final step we add total energy usage by private households, denoted as ψ_{ehh}^r, to the elements elements of $\psi^{\omega,r}$ as $\hat{\psi}^{\omega,r} = \psi^{\omega,r} + \psi_{ehh}^r$. Similar aggregations can be performed for the matrices of embodied value added, i.e. Φ^o and Φ^c, where we will denote the national value added accounts as $\phi^{\omega,r}$.

B.3 Structural decomposition analysis

We now describe in detail how we derive the determinants of energy usage and intensity by applying the logarithmic mean divisia index I (LMDI-I) index decomposition to our detailed MRIO framework. We first discuss an extension of our MRIO framework in order to derive more detailed determinants for the national energy accounts derived above. Then we introduce the LMDI-I decomposition and apply it on the detailed components of the MRIO framework derived in the first step. Finally, we extend the decomposition method to energy intensity.

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[32] Biomass is part of the "other renewable energy" aggregate in our data.

B.3.1 Extending the MRIO framework

As an inspection of Equations (B.4) to (B.7) reveals, changes in the national energy ($\tilde{\psi}^{\omega,r}$) and value added ($\phi^{\omega,r}$) accounts are determined by changes in the Leontief-inverse matrix Λ, which elements capture direct and indirect supply-chain linkages, and and by changes in the matrices Y and Y^o, which elements capture the volume and composition of final goods produced and consumed, respectively. The energy accounts are also subject to changes in matrix E, which elements capture sector energy intensity defined as usage of energy per unit of value added produced and the direct usage of primary energy by private households.

We extend the framework derived in (B.4) to (B.7) further along two dimensions. First, we decompose Y and Y^o to separate matrices that contain information on (i) the volume of final goods produced and consumed in each region; (ii) the sector composition of those final goods, in the case of production and final consumption also by trading partner; (iii) and the geographical composition of trading partners.[33] Second, for the energy accounts we additionally derive explicitly the information on the energy mix used by the sectors to produce final goods and intermediates.

We begin with the decomposition of matrix Y in order to obtain the geographical composition of the trading partners of final goods for each region, separate for exports and imports. For the geographical composition of the imports of final goods in each region we first create the $n \times n$ dimensional matrix $Y_a = I_{[n,ns]}Y$, where $I_{[n,ns]}$ is defined as above, and which elements are the sums of the s dimensional elements of Y, i.e. $y_a^{rp} = \iota_s' y^{rp}$, where ι_s' is the s dimensional row vector of ones as defined in subsection B.2. Next, we calculate vector τ by taking the column-sums of matrix Y as $\tau = \iota_{ns}' Y$, where ι_{ns}' is again the ns dimensional row vector of ones as defined in subsection B.2. Each of the n elements in $\tau = (\tau^1, \tau^2, \ldots, \tau^n)'$ denotes the value of final goods consumed by regions 1 to n. From this we construct the $n \times n$ dimensional matrix $M = Y_a \hat{\tau}^{-1}$, where $\hat{\tau}^{-1}$ is a $n \times n$ dimensional diagonal matrix with the inverse elements of τ on its main diagonal. An element of M, i.e. μ^{pr}, captures the share of final goods imported by region r from region p with respect to the total amount of final goods consumed in region r.

In a similar way we obtain the geographical composition of region r's bilateral final goods exports. We define the $n \times n$ dimensional matrix X, which elements, i.e. χ^{rp}, denote final goods exported by region r to p as shares of region r's value of total final goods exports. For its construction we first require vector $\eta = (\eta^1, \eta^2, \ldots, \eta^n)'$, which n elements are the amount of final goods produced in regions 1 to n, either for the domestic market or for exports. It is constructed as $\eta = Y_a \iota_n$, where ι_n is is the n dimensional vector of ones

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[33] The geographic composition of trading partners can only be derived for the final consumption accounts, as from a final production perspective there is no trade in final goods.

as defined in subsection B.2. Matrix X is then calculated as $X = \hat{\eta}^{-1}Y_a$, where $\hat{\eta}^{-1}$ is a diagonal matrix with the inverse of the elements of η on its main diagonal.

The next step consists in the calculation of the sectoral composition of traded final goods, including the final goods sold domestically. For this we first derive the matrix $\Gamma = Y \oslash (Y_a \otimes \iota_s)$, where $\oslash$ denotes the Hadamard element-wise division operator and ι_s is defined as above. The elements of Γ, i.e. $\gamma^{pr} = (\gamma_1^{pr}, \gamma_2^{pr}, \ldots, \gamma_s^{pr})'$, are vectors of dimension s which elements denote region r's imports of final goods from sector s in region p as a share of the total value of region r's final goods imports from p.[34] As a result, the sectoral composition of the final goods consumed within a region r is a function of the sector composition of the final goods produced for the domestic market and the sectoral composition of final goods imports from each of its trading partners. Similarly, the composition of final goods produced in a region r is a function of the sector composition of final goods produced for the domestic market and the sector composition of final goods produced for each export partner.

We continue to derive a matrix capturing the sector composition of final goods assembled in each region.[35] For this we calculate the $ns \times n$ dimensional matrix $B = Y^o\hat{\eta}^{-1}$, where $\hat{\eta}^{-1}$ is defined as above. Its elements, i.e. β^{rp}, are vectors of dimension s and are zero whenever $r \neq p$. Whenever $r = p$, each scalar in β^{rp} denotes the share of the value of final goods assembled in sector s in region r relative to the value of all final goods assembled in that region.[36]

Finally, and for the energy accounts only, we derive the energy mix applied by each of the sectors in all the regions of our database. For this, we define Ξ^q as an $ns \times ns$ dimensional diagonal matrix. The elements on its main diagonal, i.e. $\xi^q = (\xi^{1,q}, \xi^{2,q}, \ldots, \xi^{n,q})'$, capture the usage of energy commodity q, where $q \subseteq [1, f]$ and f is the number of energy commodities (seven in our dataset), in each of the s sectors in each of the n regions in our dataset as a share of its usage of all energy commodities. Accordingly, each $\xi^{r,q}$ is an $s \times s$ dimensional diagonal matrix and the elements $\xi_k^{r,q}$ on their main diagonal denote the share of energy commodity q used by sector k in region r with respect to the total energy usage of sector k.[37] As a final step we stack all seven matrices Ξ^q, one for each energy commodity in our dataset, together, such that the resulting matrix Ξ is of dimension $fns \times ns$.

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[34] Similarly, the same element denotes the exports of final goods from sector s in region p as a share of the value of region p's total final goods exports to region r.

[35] Note that there is no trade of final goods in the final production footprints. As a result, we do not have to construct a matrix that captures the geographical composition of final goods trading partners for this account.

[36] As a result the all elements of β^{rp} sum to one.

[37] Note that as a result $I = \Xi^1 + \Xi^2 + \ldots + \Xi^f$, the $ns \times ns$ dimensional identity matrix

Using matrices $\Xi, M, X, B,$ and Γ we extend Equations (B.6) to (B.7) that describe the determinants of embodied energy to

$$\Psi^{o} = I_{[ns,fns]} \left[\Xi E \Lambda B \; I_{[n,ns]} Y^{o}\right], \tag{B.8}$$

$$\Psi^{c} = I_{[ns,fns]} \left[\Xi E \Lambda \;\; (\Gamma \circ M \hat{\tau} \otimes \iota_{s})\right], \tag{B.9}$$

where the aggregation matrix $I_{[ns,fns]}$ is of dimension $ns \times fns$ and sums over all f energy commodities. It is calculated as $I_{[ns,fns]} = i'_{f} \otimes \hat{i}_{ns}$, where i'_{f} is a row-vector of ones with dimension f and $\hat{i}_{ns}$ is a $ns \times ns$ dimensional diagonal matrix with ones on its main diagonal. Matrix I_{s} and vector ι_{s} are defined as above, and $\circ$ denotes the Hadamard element-wise product.

Analogously, we extend the expressions for embodied flows of value added, as described in Equations (B.4) and (B.5) to

$$\Phi^{o} = \Lambda \; B \; I_{[n,ns]} Y^{o} \tag{B.10}$$

and

$$\Phi^{c} = \Lambda \;\; (\Gamma \circ M \hat{\tau} \otimes \iota_{s}) \,. \tag{B.11}$$

Finally, in order to assess the effect of the composition of final goods export partners in the production-based accounts of energy and value added we decompose

$$\Psi^{v} = I_{[ns,fns]} \{\Xi E \Lambda \;\; \left[\Gamma \circ \left(X' \hat{\eta}\right)' \otimes \iota_{s}\right]\}, \tag{B.12}$$

and

$$\Phi^{v} = \Lambda \;\; \left[\Gamma \circ \left(X' \hat{\eta}\right)' \otimes \iota_{s}\right], \tag{B.13}$$

where $\hat{\eta}$ is a diagonal matrix with the elements of η on its main diagonal and X' is the transpose of X.

The decomposition described above does neither change matrices Ψ^{ω} and Φ^{ω}, nor their elements $\psi^{\omega,rp}$ and $\phi^{\omega,rp}$, respectively, where ω alternatively denotes final production (o), final consumption (c), or standard productions (v). The scalars $\psi_{k}^{o,pr}$, $\phi_{k}^{o,pr}$, and $\psi_{k}^{c,pr}$, $\phi_{k}^{c,pr}$, denote the volume of energy or value added used in region r for final production or consumption, respectively, which is sourced from sector k in region p. Their counterparts for the territorial production accounts, $\psi_k^{v,rp}$ and $\phi_k^{v,rp}$, denote the amount of energy or value added used by sector k in region r to produce intermediates or final goods that are eventually consumed in region p. As such those elements denote the most detailed of embodied transactions of energy and value added in our database and are, therefore, the starting point of our decomposition exercise.

B.3.2 Deriving the determinants of energy usage

We will now present the detailed decomposition of matrices Ψ^ω and their elements, respectively. For this, we turn to element-wise notation as a first step and then introduce the logarithmic mean divisia index I (LMDI-I) method in order to decompose the absolute usage of energy over time into six different factors for standard production and final consumption and five different factors for final production, respectively. Specifically, we will assess how the energy accounts of a specific region changes over time due to changes in the energy mix on the sector level (mix), the amount of energy used per unit of value added at the sector level (int), changes in the organization of supply chains (sup), changes in the sector composition of final goods produced and consumed (str), and due to changes in the volume of final goods produced or consumed (act). The value added accounts will be decomposed to the same factors, except the energy-specific energy mix and intensity factors. We will then turn from this indicator-based decomposition of absolute energy usage to an index-based decomposition of the relative energy usage over time.

We now use element-wise sum notation to illustrate how the elements in Ψ^ω are determined by the elements of the matrices on the right-hand side of Equations (B.8), (B.9), and (B.12):

$$\psi_k^{o,pr} = \sum_{q=1}^{f} \sum_{j=1}^{s} \sum_{g=1}^{n} \xi_k^{p,q} \; e_k^p \; \lambda_{kj}^{pg} \; \beta_j^{gr} \; \eta^r, \tag{B.14}$$

$$\psi_k^{c,pr} = \sum_{q=1}^{f} \sum_{j=1}^{s} \sum_{g=1}^{n} \xi_k^{p,q} \; e_k^p \; \lambda_{kj}^{pg} \; \gamma_j^{gr} \; \mu^{gr} \; \tau^r, \tag{B.15}$$

$$\psi_k^{v,rp} = \sum_{q=1}^{f} \sum_{j=1}^{s} \sum_{g=1}^{n} \xi_k^{r,q} \; e_k^r \; \lambda_{kj}^{rg} \; \gamma_j^{gp} \; \chi^{gp} \; \eta^g. \tag{B.16}$$

Scalars $\xi_k^{m,q}$, e_k^m, λ_{kj}^{mu}, γ_j^{mu}, β_j^{mu}, χ^{mu}, μ^{mu}, η^u, and τ^u denote the elements of matrices Ξ, E, Λ, Γ, B, X, M, and vectors η, and τ, respectively. These elements are interpreted as six different factors that determine energy usage: energy mix $\xi_k^{m,q}$ and energy-intensity (e_k^m), the sourcing of local and foreign intermediates along supply chains (λ_{kj}^{mu}), the sector composition of domestic final goods production (β_j^{mu}), the sector composition of domestically produced and traded final goods (γ_j^{mu}), the geographical composition of trading partners for exported (χ^{mu}) and imported (μ^{mu}) final goods, and the value of final goods produced (η^m) and consumed (τ^m), respectively.

Obviously, sectoral elements $\psi_k^{\omega,mu}$, will change over time due to changes in one, more, or all of the factors defined above, and with them the national accounts $\tilde{\psi}^{\omega,r}$. In what follows we isolate and quantify the contribution of changes in each factor to $\Delta\psi_k^{\omega,mu} = \psi_k^{\omega,mu,t} - \psi_k^{\omega,mu,0}$, the absolute change in the level of $\psi_k^{\omega,mu}$ between base period 0 and comparison period t. This kind of decomposition is known as structural decomposition analysis (SDA) in the input-output literature and we apply the "Logarithmic Mean Divisia Method I" (LMDI-I), as established by the work of Ang and Liu (2001) and Ang (2015), to quantify the determinants of $\Delta\psi_k^{\omega,mu}$ and $\Delta\phi_k^{\omega,mu}$, respectively.[38] In order to implement this decomposition we first express the changes bilateral embodied energy as

$$\Delta\psi_k^{\omega,mu} = \sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n}(v_{\psi,kj}^{\omega,mgu,q,t} - v_{\psi,kj}^{\omega,mgu,q,0}) =$$

$$= \sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} L(v_{\psi,kj}^{\omega,mgu,q,t}, v_{\psi,kj}^{\omega,mgu,q,0})\ ln\left(\frac{v_{\psi,kj}^{\omega,mgu,q,t}}{v_{\psi,kj}^{\omega,mgu,q,0}}\right), \tag{B.17}$$

where $v_{\psi,kj}^{\upsilon,rgp,q} = \xi_k^{r,q} e_k^r\ \lambda_{kj}^{rg}\ \gamma_j^{gp}\ \chi^{gp}\ \eta^g$, $v_{\psi,kj}^{o,pgr,q} = \xi_k^{p,q} e_k^p\ \lambda_{kj}^{pr}\ \beta_j^{gr}\ \eta^r$, and $v_{\psi,kj}^{c,pgr,q} = \xi_k^{p,q} e_k^p\ \lambda_{kj}^{pg}\ \gamma_j^{gr}\ \mu^{gr}\ \tau^r$ and $L(\cdot)$ denotes the logarithmic mean.[39]

The next step is to express indicator $\Delta\psi_k^{\omega,mu}$, as defined in Equation (B.17), as a sum of sub-indicators, where each of those sub-indicators represents one of the factors introduced

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[38] As described by de Boer and Rodrigues (2020) the LMDI-I approach can be seen as a generalization of the price indicator developed by Montgomery (1929, 1937). The Montgomery indicator was developed as a solution to the "classical" indicator problem: the decomposition of expenditures in a base and comparison period into two indicators, one representing changes in prices, and one representing changes in quantities (see de Boer, 2008; de Boer and Rodrigues, 2020). The generalized version of the Montgomery indicator extends this principle to more than two factors.

[39] For positive numbers the logarithmic mean is defined as

$$L(x,y) = \frac{x-y}{ln(x/y)};\quad L(x,x) = x.$$

above. Let's define a' to denote the factors from 1 to $\bar{a}$, where $\bar{a} = 6$ such that $a' \subseteq [1, \bar{a}]$. Then the desired sub-indicator for factor a' can be expressed as $\Delta\psi^{\omega,mu}_{a',k}$, such that

$$\Delta\psi^{\omega,mu}_{k} = \sum_{a'=1}^{\bar{a}} \Delta\psi^{\omega,mu}_{a',k}, \tag{B.18}$$

where $\Delta\psi^{\omega,mu}_{a',k} = 0$ if $\omega = o$ and $a' = trd$. Each sub-indicator $\Delta\psi^{\omega,mu}_{a',k}$ measures by how much $\Delta\psi^{\omega,mu}_{k}$ would change if only the factor it represents changes, while keeping all other factors constant.

To create sub-indicators $\Delta\psi^{\omega,mu}_{a',k}$ we first take the ratio of each element on the right-hand sides in Equations (B.14) – (B.16) in period t to its value in a base period 0 and take the natural logarithm thereof. Multiplying the logarithm of each of those ratios with $L(v^{\omega,mgu,q,t}_{\psi,kj} - v^{\omega,mgu,q,0}_{\psi,kj})$ results in the desired sub-indicators. As the term $L(v^{\omega,mgu,q,t}_{\psi,kj} - v^{\omega,mgu,q,0}_{\psi,kj})$ is the same in the calculations for all sub-indicators of an account, it acts as a weight in their calculations such that we denote it as $W^{\omega,mgu,q}_{\psi,kj} = L(v^{\omega,mgu,q,t}_{\psi,kj} - v^{\omega,mgu,q,0}_{\psi,kj})$.[40] We present the sub-indicators for each energy accounts in the upper part of Table (B.2).

B.3.3 Deriving the determinants of value added

We decompose the flows of embodied value added to a sum of factor-specific sub-indicators in an analogue way as

$$\Delta\phi^{\omega,mu}_{k} = \sum_{a'=1}^{\bar{a}} \Delta\phi^{\omega,mu}_{a',k}, \tag{B.19}$$

where again, $\Delta\phi^{\omega,mu}_{a',k} = 0$ if $\omega = o$ and $a' = trd$. It should be noted that for value added there are no sub-indicators for the energy-specific factors *mix* and *int* (see the lower part of Table (B.2), where the value added sub-indicators are presented in detail).[41]

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[40] Using the logarithmic mean in our decomposition offers two advantages for our analysis (see also de Boer and Rodrigues, 2020). First, due to its symmetry the indicator is robust to time reversal, i.e. $\Delta\psi^{\omega,mu}_{k} = \psi^{\omega,mu,t}_{k} - \psi^{\omega,mu,0}_{k} = \psi^{\omega,mu,0}_{k} - \psi^{\omega,mu,t}_{k}$. Second, well developed methods are available to deal with zeroes in the data, which is important in our case because not all energy commodities in our data are used by all of the countries. Ang and Choi (1997) and Ang et al. (1998) suggest to replace the zeroes in the data with small positive numbers. Wood and Lenzen (2006), however, demonstrate that such an approach can lead to significant errors in the decomposition. As an alternative, Ang et al. (1998) and Wood and Lenzen (2006) suggest the usage of analytical limits whenever zero values occur. We follow this second approach in our analysis.

[41] Note that for value added $v^{v,rgp}_{\phi,kj} = \lambda^{rg}_{kj}\ \gamma^{gp}_{j}\ \chi^{gp}\ \eta^{g}$, $v^{o,pgr}_{\phi,kj} = \lambda^{pr}_{kj}\ \beta^{gr}_{j}\ \eta^{r}$, and $v^{c,pgr}_{\phi,kj} = \lambda^{pg}_{kj}\ \gamma^{gr}_{j}\ \mu^{gr}\ \tau^{r}$. Accordingly, the weight for the value added sub-indicators is $W^{\omega,mgu,q}_{\phi,kj} = L(v^{\omega,mgu,t}_{\phi,kj} - v^{\omega,mgu,0}_{\phi,kj})$.

Indicator	Production	Final Production	Consumption
		LMDI-I decomposition of energy usage	
$\Delta\psi^{\omega,mu}_{mix,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\psi,kj}\ ln\left(\frac{\xi^{r,q,t}_{k}}{\xi^{r,q,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\psi,kj}\ ln\left(\frac{\xi^{m,q,t}_{k}}{\xi^{m,q,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\psi,kj}\ ln\left(\frac{\xi^{m,q,t}_{k}}{{}^{m,q,0}_{k}}\right)$
$\Delta\psi^{\omega,mu}_{int,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\psi,kj}\ ln\left(\frac{e^{r,t}_{k}}{e^{r,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\psi,kj}\ ln\left(\frac{e^{m,t}_{k}}{e^{m,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\psi,kj}\ ln\left(\frac{e^{m,t}_{k}}{e^{m,0}_{k}}\right)$
$\Delta\psi^{\omega,mu}_{sup,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\psi,kj}\ ln\left(\frac{\lambda^{rg,t}_{\psi,kj}}{\lambda^{rg,0}_{\psi,kj}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\psi,kj}\ ln\left(\frac{\lambda^{mgr,t}_{\psi,kj}}{\lambda^{mgr,0}_{\psi,kj}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\psi,kj}\ ln\left(\frac{\lambda^{mg,t}_{\psi,kj}}{\lambda^{mg,0}_{\psi,kj}}\right)$
$\Delta\psi^{\omega,mu}_{str,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\psi,kj}\ ln\left(\frac{\gamma^{gu,t}_{j}}{\gamma^{gu,0}_{j}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\psi,kj}\ ln\left(\frac{\beta^{r,t}_{j}}{\beta^{r,0}_{j}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\psi,kj}\ ln\left(\frac{\gamma^{gr,t}_{j}}{\gamma^{gr,0}_{j}}\right)$
$\Delta\psi^{\omega,mu}_{trd,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\psi,kj}\ ln\left(\frac{\chi^{gu,t}_{j}}{\chi^{gu,0}_{j}}\right)$	$--$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\psi,kj}\ ln\left(\frac{\mu^{gr,t}_{j}}{\mu^{gr,0}_{j}}\right)$
$\Delta\psi^{\omega,mu}_{act,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\psi,kj}\ ln\left(\frac{\eta^{g,t}_{k}}{\eta^{g,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\psi,kj}\ ln\left(\frac{\eta^{r,t}_{k}}{\eta^{r,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\psi,kj}\ ln\left(\frac{\tau^{r,t}_{k}}{\tau^{r,0}_{k}}\right)$
		LMDI-I decomposition of value added	
$\Delta\phi^{\omega,mu}_{sup,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\phi,kj}\ ln\left(\frac{\lambda^{rg,t}_{\phi,kj}}{\lambda^{rg,0}_{\phi,kj}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\phi,kj}\ ln\left(\frac{\lambda^{mgr,t}_{\phi,kj}}{\lambda^{mgr,0}_{\phi,kj}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\phi,kj}\ ln\left(\frac{\lambda^{mg,t}_{\phi,kj}}{\lambda^{mg,0}_{\phi,kj}}\right)$
$\Delta\phi^{\omega,mu}_{str,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\phi,kj}\ ln\left(\frac{\gamma^{gu,t}_{j}}{\gamma^{gu,0}_{j}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\phi,kj}\ ln\left(\frac{\beta^{r,t}_{j}}{\beta^{r,0}_{j}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\phi,kj}\ ln\left(\frac{\gamma^{gr,t}_{j}}{\gamma^{gr,0}_{j}}\right)$
$\Delta\phi^{\omega,mu}_{trd,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\phi,kj}\ ln\left(\frac{\chi^{gu,t}_{j}}{\chi^{gu,0}_{j}}\right)$	$--$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\phi,kj}\ ln\left(\frac{\mu^{gr,t}_{j}}{\mu^{gr,0}_{j}}\right)$
$\Delta\phi^{\omega,mu}_{act,k}$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{\upsilon,rgu,q}_{\phi,kj}\ ln\left(\frac{\eta^{g,t}_{k}}{\eta^{g,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{o,mgr,q}_{\phi,kj}\ ln\left(\frac{\eta^{r,t}_{k}}{\eta^{r,0}_{k}}\right)$	$\sum_{q=1}^{f}\sum_{j=1}^{s}\sum_{g=1}^{n} W^{c,mgr,q}_{\phi,kj}\ ln\left(\frac{\tau^{r,t}_{k}}{\tau^{r,0}_{k}}\right)$

Table B.2: Energy and VA sub-indicators for each factor and account. Note: $\Delta\psi^{\omega,mu}_{a,k}$ and $\Delta\phi^{\omega,mu}_{a,k}$ denote the absolute change in energy and value added, respectively, due to a change in factor a on the most detailed level of our MRIO framework involving region r either as the region of origin or destination. Whether r is the region of origin or the region of destination varies by account ω, as can be inferred from columns $2-5$ in the Figure.

B.3.4 Aggregating to changes in national energy accounts

The LMDI-I approach offers two further advantages. First, the indicators for the different factors sum up to total changes in embodied energy and value added without leaving a residual ("completeness"). Second, the indicators are consistent in aggregation, such that changes in national energy usage by account in region r ($\Delta\psi^{\omega,r}$) can be derived by first summing $\Delta\psi^{\omega,mu}_{k}$ over all s source sectors, or $\Delta\psi^{\omega,mu}_{a',k}$ over all s source sectors and all $\bar{a}$ factors. For final production and consumption accounts we then sum over all n source regions m that provide a region with embodied energy while for territorial production we aggregate over all n destination regions u of a region's embodied energy. As a result, we derive the total change of the final production ($\omega = o$) and consumption ($\omega = c$) footprints of a specific region r, i.e. $\Delta\psi^{\omega,r}$, as

$$\Delta\psi^{\omega,r} = \sum_{k=1}^{s}\sum_{m=1}^{n} \Delta\psi_k^{\omega,mr} = \sum_{a'=1}^{\bar{a}} \left(\sum_{k=1}^{s}\sum_{m=1}^{n} \Delta\psi_{a',k}^{\omega,mr} \right) = \sum_{a'=1}^{\bar{a}} \Delta\psi_{a'}^{\omega,r}. \tag{B.20}$$

In a similar way we calculate the change in a region r's territorial production, i.e. $\Delta\psi^{\omega,r}$ where $\omega = \upsilon$, as

$$\Delta\psi^{\omega,r} = \sum_{k=1}^{s}\sum_{u=1}^{n} \Delta\psi_k^{\omega,ru} = \sum_{a'=1}^{\bar{a}} \left(\sum_{k=1}^{s}\sum_{u=1}^{n} \Delta\psi_{a',k}^{\omega,ru} \right) = \sum_{a'=1}^{\bar{a}} \Delta\psi_{a'}^{\omega,r}. \tag{B.21}$$

The procedure for aggregating the value added accounts is exactly the same such that its description is omitted for the sake of brevity.

Until this point, $\Delta\psi^{\omega,r}$ does not account for the change in primary energy usage by private households. We treat changes in this energy usage by private households over time as separate seventh factor in our empirical analysis, denoted as $ehh = \Delta\psi_{ehh}^{r} = \psi_{ehh}^{r,t} - \psi_{ehh}^{r,0}$. The overall change in absolute energy usage by region is

$$\Delta\tilde{\psi}^{\omega,r} = \Delta\psi^{\omega,r} + \Delta\psi_{ehh}^{r} = \sum_{a=1}^{\tilde{a}} \Delta\psi_a^{\omega,m} + \Delta\psi_{ehh}^{r}\ , \tag{B.22}$$

where $\tilde{a}$ denotes now the number of the final seven factors, i.e. $\tilde{a} = 7$ and $a \subseteq [1, \tilde{a}]$.

B.3.5 Energy indicators for country aggregates

Changes in national energy usage can further be aggregated to country groups, such as the European Union or income aggregates. Let's define with z a region that is part of an aggregate country group such that $z \subseteq [1, \bar{z}]$ and $\bar{z}$ is the number of countries in that group. In order to obtain an indicator for the total change in the energy footprints of a country aggregate z^*, i.e. $\Delta\tilde{\psi}^{\omega,z^*}$ when $\omega = o$ or $\omega = c$, we add the individual indicators or factor-specific sub-indicators of all countries included in the group as

$$\Delta\tilde{\psi}^{\omega,z^*} = \sum_{z=1}^{\bar{z}} \Delta\tilde{\psi}^{\omega,z} = \sum_{z=1}^{\bar{z}} \left(\sum_{k=1}^{s}\sum_{m=1}^{n} \Delta\psi_k^{\omega,mz} + \Delta\psi_{ehh}^{z} \right) =$$

$$= \sum_{z=1}^{\bar{z}} \left[\sum_{a=1}^{\tilde{a}} \left(\sum_{k=1}^{s} \sum_{m=1}^{n} \Delta\psi_{a,k}^{\omega,mz} \right) \right]. \tag{B.23}$$

The procedure is similar if an indicator for a country aggregate describing its change in territorial energy production, i.e. $\Delta\tilde{\psi}^{\omega,z^*}$ where $\omega = \upsilon$, should be derived:

$$\Delta\tilde{\psi}^{\omega,z^*} = \sum_{z=1}^{\bar{z}} \Delta\tilde{\psi}^{\omega,z} = \sum_{z=1}^{\bar{z}} \left(\sum_{k=1}^{s} \sum_{u=1}^{n} \Delta\psi_{k}^{\omega,zu} + \Delta\psi_{ehh}^{z} \right) =$$

$$= \sum_{z=1}^{\bar{z}} \left[\sum_{a=1}^{\tilde{a}} \left(\sum_{k=1}^{s} \sum_{u=1}^{n} \Delta\psi_{a,k}^{\omega,zu} \right) \right]. \tag{B.24}$$

Aggregating the (sub-)indicators of changes in embodied value added to country aggregates is done analogously and we omit its discussion for the sake of brevity.

B.3.6 Deriving indices for the relative change of the energy accounts

One disadvantage of the additive LMDI-I decomposition arises when the energy usage of regions that are different in size are to be compared. A more insightful comparison of the development in energy usage in different regions can be obtained by the comparison of relative changes. Furthermore, targets for energy efficiency in Directive 2006/32/EC and its successors are measured in relative changes as well. Thus, we first define the relative change of $\psi_{k}^{\omega,mu}$ between periods 0 and t as

$$\underline{\Delta}\psi_{k}^{\omega,mu} = \frac{\psi_{k}^{\omega,mu,t}}{\psi_{k}^{\omega,mu,0}}. \tag{B.25}$$

The next step is to decompose Equation (B.25) into a product of factor-specific sub-indices, one for each factor in our analysis. Each of those sub-indices $\underline{\Delta}\psi_{a',k}^{\omega,mu}$ measures the change of $\underline{\Delta}\psi_{k}^{\omega,mu}$ that would arise if only a specific factor changes, while the others remain constant. Index $\underline{\Delta}\psi_{k}^{\omega,mu}$ can then be represented as the product of its sub-indices as

$$\underline{\Delta}\psi_{k}^{\omega,mu} = \prod_{a'=1}^{\bar{a}} \underline{\Delta}\psi_{a',k}^{\omega,mu}. \tag{B.26}$$

For the construction of sub-indices $\underline{\Delta}\psi_{a',k}^{\omega,mu}$ we exploit that sub-indicators obtained from the LMDI-I approach, which belongs to the class of indicator decompositions based on the logarithmic mean, can easily be transformed to indices (compare de Boer and Rodrigues, 2020). When we look at region r's footprint accounts we construct $\underline{\Delta}\psi_{a',k}^{\omega,mr}$ as

$$\underline{\Delta}\psi_{a',k}^{\omega,mr} = exp\left[\frac{\Delta\psi_{a',k}^{\omega,mr}}{L(\tilde{\psi}^{\omega,r,t},\tilde{\psi}^{\omega,r,0})}\right], \tag{B.27}$$

and for its territorial production of energy we construct $\underline{\Delta}\psi_{a',k}^{\omega,ru}$ as

$$\underline{\Delta}\psi_{a',k}^{\omega,ru} = exp\left[\frac{\Delta\psi_{a',k}^{\omega,ru}}{L(\tilde{\psi}^{\omega,r,t},\tilde{\psi}^{\omega,r,0})}\right], \tag{B.28}$$

where $L(\tilde{\psi}^{\omega,r,t},\tilde{\psi}^{\omega,r,0})$ is the logarithmic mean of region r's national energy account ω, including primary energy used directly by private households. It serves as the weight for the sub-indices in the resulting index decomposition of $\underline{\Delta}\psi_{k}^{\omega,mu}$, which is known in the literature as the "multiplicative Logarithmic Mean Divisia method I", (compare Ang and Liu, 2001; Ang, 2015).[42]

Analogue to the additive decomposition, we derive indices for energy usage at the regional level as

$$\underline{\Delta}\psi^{\omega,r} = \prod_{k=1}^{s}\prod_{m=1}^{n}\underline{\Delta}\psi_{k}^{\omega,mr} = \prod_{a'=1}^{\bar{a}}\underline{\Delta}\psi_{a'}^{\omega,r} = \prod_{a'=1}^{\bar{a}}\left(\prod_{k=1}^{s}\prod_{m=1}^{n}\underline{\Delta}\psi_{a',k}^{\omega,mr}\right), \tag{B.29}$$

and

$$\underline{\Delta}\psi^{\omega,r} = \prod_{k=1}^{s}\prod_{u=1}^{n}\underline{\Delta}\psi_{k}^{\omega,ru} = \prod_{a'=1}^{\bar{a}}\underline{\Delta}\psi_{a}^{\omega,r} = \prod_{a'=1}^{\bar{a}}\left(\prod_{k=1}^{s}\prod_{u=1}^{n}\underline{\Delta}\psi_{a',k}^{\omega,ru}\right), \tag{B.30}$$

depending on account ω. The construction of (sub-)indices for country aggregates is done by further aggregating of $\underline{\Delta}\psi^{\omega,r}$ and its factor-specific sub-indices. Again, $\underline{\Delta}\psi^{\omega,r}$ does not consider changes from the usage of energy directly by private households. For this we define an own sub-index for the factor ehh as

$$\underline{\Delta}\psi_{ehh}^{r} = exp\left[\frac{\Delta\psi_{ehh}^{r}}{L(\tilde{\psi}^{\omega,r,t},\tilde{\psi}^{\omega,r,0})}\right], \tag{B.31}$$

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[42] As discussed in de Boer and Rodrigues (2020), the multiplicative version of the LMDI-I approach can also be described as a generalization of the price index developed independently by Montgomery (1929, 1937) and Vartia (1974, 1976). Like the Montgomery price indicator, the Montgomery-Vartia price index was developed to solve the "classical" index problem (compare de Boer and Rodrigues, 2020): the decomposition of the ratio of two expenditures of a base and comparison period into the product of a price- and a quantity index.

such that

$$\underline{\Delta}\tilde{\psi}^{\omega,r} = \underline{\Delta}\psi^{\omega,r} * \underline{\Delta}\psi^{\omega,r}_{ehh} = \prod_{a=1}^{\tilde{a}} \underline{\Delta}\psi^{\omega,r}_{a}. \tag{B.32}$$

B.3.7 Structural decomposition analysis of national energy efficiency

We conclude this section by extending the results derived so far to an analysis of energy intensity.

We express the energy intensity for account ω of region r as $\zeta^{\omega,r} = \frac{\tilde{\psi}^{\omega,r}}{\phi^{\omega,r}}$, which at the most detailed level in our MRIO framework becomes $\theta_k^{\omega,mu} = \frac{\psi_k^{\omega,mu}}{\phi_k^{\omega,mu}}$, where, depending on the account, r is either the region of origin (m) or destination (u). As a result, the change of this ratio in account ω between period 0 and period t is (see also Su and Ang, 2015)

$$\underline{\Delta}\theta_k^{\omega,mu} = \frac{\theta_k^{\omega,mu,t}}{\theta_k^{\omega,mu,0}} = \frac{\psi_k^{\omega,mu,t}/\phi_k^{\omega,mu,t}}{\psi_k^{\omega,mu,0}/\phi_k^{\omega,mu,0}} = \frac{\psi_k^{\omega,mu,t}/\psi_k^{\omega,mu,0}}{\phi_k^{\omega,mu,t}/\phi_k^{\omega,mu,0}} = \frac{\underline{\Delta}\psi_k^{\omega,mu}}{\underline{\Delta}\phi_k^{\omega,mu}}. \tag{B.33}$$

We proceed by decomposing $\underline{\Delta}\theta_k^{\omega,mu}$ into changes of the seven factors derived above, relying again on the multiplicative LMDI-I procedure.[43] As a first step we decompose separately the numerator and denominator of Equation (B.33) into indices for all the factors in our analysis:

$$\underline{\Delta}\theta_k^{\omega,mu} = \frac{\underline{\Delta}\psi_k^{\omega,mu}}{\underline{\Delta}\phi_k^{\omega,mu}} = \prod_{a'=1}^{\bar{a}} \exp\left[\underline{\Delta}\psi_{a',k}^{\omega,mu} - \underline{\Delta}\phi_{a',k}^{\omega,mu}\right] = \prod_{a'=1}^{\bar{a}} \underline{\Delta}\theta_{a',k}^{\omega,mu}, \tag{B.35}$$

where both terms in the brackets of Equation (B.35) are zero when $a' = trd$ and $\omega = o$. Also, $\underline{\Delta}\phi_{a',k}^{\omega,mu}$ is zero whenever $a' = mix$ or $a' = int$ because these factors do not exist for the value added accounts. As a result, for those two factors energy efficiency, i.e. $\underline{\Delta}\theta_k^{\omega,mu}$, is only driven by relative changes in energy usage and not by change in value added. Finally, $\underline{\Delta}\theta_k^{\omega,mu}$ can be easily aggregated to indices expressing the national changes

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[43] Note that the multiplicative LMDI-I decomposition of $\underline{\Delta}\phi_k^{\omega,mu}$ is defined as

$$\underline{\Delta}\phi_k^{\omega,mr} = \prod_{a'=1}^{\bar{a}} \exp\left[\frac{\Delta\phi_{a,k}^{\omega,mr}}{L(\phi^{\omega,r,t},\phi^{\omega,r,0})}\right] \text{ and } \underline{\Delta}\phi_k^{\omega,ru} = \prod_{a'=1}^{\bar{a}} \exp\left[\frac{\Delta\phi_{a,k}^{\omega,ru}}{L(\phi^{\omega,r,t},\phi^{\omega,r,0})}\right], \tag{B.34}$$

depending on the account.

in energy intensity of a specific region r, not accounting for changes in energy usage by private households, in each account ω as

$$\underline{\Delta}\theta^{\omega,r} = \prod_{m=1}^{n}\prod_{k=1}^{s}\underline{\Delta}\theta_{k}^{\omega,mr} = \prod_{a'=1}^{\bar{a}}\underline{\Delta}\theta_{a'}^{\omega,r} = \prod_{a'=1}^{\bar{a}}\left(\prod_{m=1}^{n}\prod_{k=1}^{s}\underline{\Delta}\theta_{a',k}^{\omega,mr}\right), \tag{B.36}$$

and

$$\underline{\Delta}\theta^{\omega,r} = \prod_{u=1}^{n}\prod_{k=1}^{s}\underline{\Delta}\theta_{k}^{\omega,ru} = \prod_{a'=1}^{\bar{a}}\underline{\Delta}\theta_{a'}^{\omega,r} = \prod_{a'=1}^{\bar{a}}\left(\prod_{u=1}^{n}\prod_{k=1}^{s}\underline{\Delta}\theta_{a',k}^{\omega,ru}\right), \tag{B.37}$$

where $\underline{\Delta}\theta_{a'}^{\omega,r}$ denotes the sub-index for factor a' aggregated for the specific region r.

Changes in energy efficiency for country aggregates, such as the European Union, are obtained by aggregating $\underline{\Delta}\theta^{\omega,r}$, and its sub-indices, further, i.e. $\underline{\Delta}\theta^{\omega,r^*} = \prod_{r=1}^{n^*}\underline{\Delta}\theta^{\omega,r}$, where r^* denotes the country aggregate and n^* the number of single countries included in the aggregate. Care has to be taken, however, when defining the weights in the calculation of $\underline{\Delta}\psi_{a',k}^{\omega,mr}$ and $\underline{\Delta}\psi_{a',k}^{\omega,ru}$ in Equations (B.27) and (B.28). The denominator in those equations has to be replaced with the logarithmic mean of the energy accounts ω of the aggregated region, i.e. $L(\tilde{\psi}^{\omega,r^*,t}, \tilde{\psi}^{\omega,r^*,0})$. Similar changes have to be applied in the calculation of $\underline{\Delta}\phi_{a',k}^{\omega,mr}$ and $\underline{\Delta}\phi_{a',k}^{\omega,ru}$, respectively.

In order to account for changes in national energy efficiency due to change in the primary energy usage of private households we define first index

$$\underline{\Delta}\theta_{ehh}^{r} = \exp\left[\underline{\Delta}\psi_{ehh}^{r}\right], \tag{B.38}$$

such that

$$\underline{\Delta}\tilde{\theta}^{\omega,r} = \underline{\Delta}\theta^{\omega,r} * \underline{\Delta}\theta_{ehh}^{r} = \prod_{a=1}^{\tilde{a}}\underline{\Delta}\theta_{a}^{\omega,r} \tag{B.39}$$

denotes the relative change in the energy efficiency of region r that takes into account changes in household energy usage. Again, further aggregations to country aggregates are straightforward by replacing $\underline{\Delta}\theta_{ehh}^{r}$ with $\underline{\Delta}\theta_{ehh}^{r^*}$.

C Supplementary analyses

C.1 Decomposition results for selected regions

Table C.1 presents the results of the multiplicative LMDI-I decomposition of changes in energy usage according to the three energy accounts for selected regions in the period 1997–2014 in index-form. The indices refer to changes in the aggregate energy usage accounts (in the column *total*) and in the seven contributing factors (*act, int, sup, str, trd, mix,* and *ehh*) expressed as ratios of their values in 2014 relative to 1997. Thus, each of the seven factor indices denotes the contribution of the respective factor to the change in aggregate energy usage if only this specific factor changes, while the others are held constant. An index smaller (larger) than 1 indicates that the factor contributed to a decrease (increase) in aggregate energy usage. The product of all seven indices results in the overall energy ratio reported in the column *total.*

Region	**act**	**int**	**sup**	**str**	**trd**	**mix**	**ehh**	**total**
				Territorial Production				
EU 28	1.4792	0.7290	0.8492	1.0350	0.9968	1.0009	1.0027	0.9482
EU 15	1.4547	0.8244	0.7620	1.0382	0.9965	1.0022	1.0027	0.9501
EEU	1.6099	0.3911	1.4702	1.0186	0.9983	0.9942	1.0026	0.9383
R.o. OECD	1.5696	0.9883	0.6742	1.0364	0.9993	1.0020	1.0083	1.0943
R.o. World	1.8225	0.6270	1.3820	1.0999	1.0049	1.0081	1.0222	1.7987
				Final Production				
EU 28	1.4503	0.6862	1.1016	1.0204	NA	1.0023	1.0022	1.1238
EU 15	1.4116	0.7364	1.0466	1.0190	NA	1.0026	1.0022	1.1139
EEU	1.6992	0.4535	1.4879	1.0288	NA	1.0008	1.0024	1.1833
R.o. OECD	1.5381	0.8929	0.7798	1.0227	NA	1.0025	1.0077	1.1066
R.o. World	1.9129	0.6501	1.2525	1.1113	NA	1.0081	1.0240	1.7866
				Final Consumption				
EU 28	1.4145	0.6950	1.1008	1.0279	1.0055	1.0025	1.0022	1.1238
EU 15	1.3758	0.7344	1.0597	1.0228	1.0066	1.0026	1.0021	1.1076
EEU	1.6845	0.4914	1.3979	1.0606	0.9990	1.0019	1.0025	1.2315
R.o. OECD	1.5230	0.8684	0.8159	1.0199	1.0071	1.0027	1.0074	1.1196
R.o. World	1.9475	0.6622	1.2294	1.1197	0.9818	1.0079	1.0247	1.8002

Table C.1: Decomposition of changes in energy usage, 1997–2014 – index form
Results from the multiplicative LMDI-I decomposition. The same results are summarized graphically in Figure 1 in the main text.

We additionally present the results of the multiplicative LMDI-I decomposition of changes in national energy efficiency for all three accounts in index form. For the selected regions discussed in the main text these results are given in Table (C.2) for the period 1997 – 2014. In Tables (C.3) and (C.4) the same results are presented for the sub-periods from 1997 to 2007 and from 2007 to 2014, respectively. The indices refer to changes in energy intensity, defined as usage of energy per unit of value added. Each of the seven indices we consider, denotes the contribution of the factor that it represents to the change in energy intensityenergy intensity, if all the other factors would stay constant. Thus, indices smaller (larger) than 1 indicate that their factor contributed to and improvement (deterioration) in energy efficiency. The product of all seven indices results in the overall ratio of energy intensity reported in the column *total*.

Note that changes in three of the seven factors, i.e. the energy mix (*mix*), sector energy intensity (*int*) and energy usage by private households (*ehh*), affect only energy usage, or the numerator of energy intensity. As a result, the indices representing those factors are the same as for the decomposition of energy usage. Changes in the remaining factors, i.e. activity (*act*), supply chains (*sup*), final goods sector composition (*str*) and geographical composition of final goods trading partners (*trd*), affect the numerator as well as the denominator of energy intensity, as can be seen in Section (B.3).

Region	**act**	**int**	**sup**	**str**	**trd**	**mix**	**ehh**	**total**
Territorial Production								
EU 28	0.9866	0.7290	1.0645	1.0209	0.9973	1.0009	1.0027	0.7823
EU 15	0.9795	0.8244	0.9691	1.0266	0.9964	1.0022	1.0027	0.8046
EEU	0.8924	0.3911	1.4169	0.9596	1.0094	0.9942	1.0026	0.4775
R.o. OECD	1.0016	0.9883	0.7851	1.0224	0.9994	1.0020	1.0083	0.8024
R.o. World	0.8292	0.6270	1.2727	1.0437	1.0010	1.0081	1.0222	0.7123
Final Production								
EU 28	0.9770	0.6862	1.3349	1.0123	NA	1.0023	1.0022	0.9100
EU 15	0.9643	0.7364	1.2817	1.0124	NA	1.0026	1.0022	0.9259
EEU	0.8961	0.4535	1.5101	0.9945	NA	1.0008	1.0024	0.6123
R.o. OECD	0.9907	0.8929	0.8978	1.0139	NA	1.0025	1.0077	0.8135
R.o. World	0.8243	0.6501	1.2198	1.0610	NA	1.0081	1.0240	0.7159
Final Consumption								
EU 28	0.9753	0.6950	1.3251	1.0168	1.0040	1.0025	1.0022	0.9213
EU 15	0.9628	0.7344	1.2863	1.0140	1.0050	1.0026	1.0021	0.9312
EEU	0.8989	0.4914	1.4662	1.0094	0.9997	1.0019	1.0025	0.6565
R.o. OECD	0.9868	0.8684	0.9363	1.0083	1.0066	1.0027	1.0074	0.8226
R.o. World	0.8389	0.6622	1.2117	1.0559	0.9816	1.0079	1.0247	0.7206

Table C.2: Decomposition of changes in energy efficiency, 1997–2014 – index form
Results from the multiplicative LMDI-I decomposition. The same results are summarized graphically in Figure (2). in the main text.

Region	**act**	**int**	**sup**	**str**	**trd**	**mix**	**ehh**	**total**
				Territorial Production				
EU 28	0.9824	0.8977	0.9960	1.0043	0.9930	1.0001	1.0077	0.8828
EU 15	0.9771	1.0237	0.9040	1.0050	0.9915	1.0002	1.0093	0.9096
EEU	0.9087	0.4525	1.4312	0.9764	1.0046	0.9996	0.9992	0.5765
R.o. OECD	1.0009	1.1503	0.7380	1.0154	0.9990	1.0039	1.0022	0.8671
R.o. World	0.8709	0.5872	1.4370	1.0872	1.0050	1.0022	1.0129	0.8151
				Final Production				
EU 28	0.9875	0.7932	1.2927	0.9881	NA	1.0008	1.0063	1.0076
EU 15	0.9779	0.8571	1.2347	0.9846	NA	1.0008	1.0075	1.0273
EEU	0.9256	0.4974	1.5406	0.9950	NA	1.0003	0.9993	0.7055
R.o. OECD	0.9948	1.0127	0.8864	1.0053	NA	1.0037	1.0020	0.9028
R.o. World	0.8581	0.6178	1.3566	1.1155	NA	1.0021	1.0143	0.8155
				Final Consumption				
EU 28	0.9876	0.7898	1.2908	1.0038	0.9971	1.0010	1.0061	1.0148
EU 15	0.9748	0.8400	1.2470	0.9994	0.9982	1.0010	1.0072	1.0269
EEU	0.9263	0.5331	1.4898	1.0098	0.9899	1.0008	0.9993	0.7355
R.o. OECD	0.9940	0.9776	0.9229	1.0099	1.0064	1.0038	1.0019	0.9168
R.o. World	0.8742	0.6316	1.3418	1.1045	0.9827	1.0020	1.0149	0.8176

Table C.3: Decomposition of changes in energy efficiency, 1997–2007 – index form
Results from the multiplicative LMDI-I decomposition. The same results are summarized graphically in Figure (3) in the main text.

Region	**act**	**int**	**sup**	**str**	**trd**	**mix**	**ehh**	**total**
				Territorial Production				
EU 28	1.012	0.8061	1.0659	1.0192	1.0063	0.9988	0.9948	0.8861
EU 15	1.008	0.8052	1.0660	1.0232	1.0064	0.9995	0.9931	0.8845
EEU	0.992	0.8108	1.0240	0.9961	1.0111	0.9951	1.0034	0.8282
R.o. OECD	1.011	0.8661	1.0403	1.0114	1.0014	0.9976	1.0058	0.9253
R.o. World	0.947	1.0641	0.8937	0.9622	0.9984	1.0013	1.0090	0.8739
				Final Production				
EU 28	0.995	0.8773	1.0156	1.0236	NA	0.9991	0.9960	0.9031
EU 15	0.991	0.8750	1.0185	1.0262	NA	0.9995	0.9949	0.9013
EEU	0.978	0.8904	0.9912	1.0062	NA	0.9968	1.0028	0.8679
R.o. OECD	1.004	0.8888	0.9946	1.0114	NA	0.9982	1.0053	0.9010
R.o. World	0.952	1.0534	0.9041	0.9580	NA	1.0013	1.0100	0.8778
				Final Consumption				
EU 28	0.995	0.8891	1.0099	1.0108	1.0105	0.9990	0.9962	0.9078
EU 15	0.993	0.8868	1.0122	1.0125	1.0100	0.9994	0.9951	0.9068
EEU	0.984	0.9036	0.9905	1.0010	1.0132	0.9968	1.0028	0.8925
R.o. OECD	1.003	0.8970	0.9915	1.0007	1.0018	0.9985	1.0051	0.8973
R.o. World	0.948	1.0521	0.9093	0.9611	0.9999	1.0013	1.0103	0.8813

Table C.4: Decomposition of changes in energy efficiency, 2007–2014 – index form
Results from the multiplicative LMDI-I decomposition. The same results are summarized graphically in Figure (3) in the main text.

C.2 Average annual growth rates of energy intensity for selected regions

Table C.5 reports average annual growth rates in energy intensity and in energy efficiency factor for selected regions for the period 1997–2014 and the two sub-periods 1997–2007 and 2007–2014. The last two columns in the table show energy intensity (defined as energy usage divided by value added) at the beginning of each sub-period.

Region	**%Δ Energy Intensity**			**%Δ Energy Efficiency Factor**			**Energy Intensity**	
	97 – 14	97 – 07	07 – 14	97 – 14	97 – 07	07 – 14	1997	2007
				percent			*kgoe/USD*	
				Production				
EU 28	-1.28	-1.17	-1.63	-1.59	-1.02	-2.77	0.24	0.21
EU 15	-1.15	-0.90	-1.65	-1.03	0.24	-2.78	0.21	0.19
EEU	-3.07	-4.23	-2.45	-3.58	-5.48	-2.70	1.01	0.58
R.o. OECD	-1.16	-1.33	-1.07	-0.07	1.50	-1.91	0.26	0.23
R.o. World	-1.69	-1.85	-1.80	-2.19	-4.13	0.92	1.64	1.07
				Final Production				
EU 28	-0.53	0.08	-1.38	-1.85	-2.07	-1.75	0.27	0.27
EU 15	-0.44	0.27	-1.41	-1.55	-1.43	-1.79	0.24	0.25
EEU	-2.28	-2.95	-1.89	-3.21	-5.03	-1.57	0.87	0.61
R.o. OECD	-1.10	-0.97	-1.41	-0.63	0.13	-1.59	0.28	0.25
R.o. World	-1.67	-1.84	-1.75	-2.06	-3.82	0.76	1.50	0.94
				Consumption				
EU 28	-0.46	0.15	-1.32	-1.79	-2.10	-1.58	0.28	0.28
EU 15	-0.40	0.27	-1.33	-1.56	-1.60	-1.62	0.25	0.26
EEU	-2.02	-2.64	-1.54	-2.99	-4.67	-1.38	0.82	0.60
R.o. OECD	-1.04	-0.83	-1.47	-0.77	-0.22	-1.47	0.29	0.26
R.o. World	-1.64	-1.82	-1.70	-1.99	-3.68	0.74	1.50	0.92

Table C.5: Average annual growth rates of energy intensities
Note: Energy intensity is defined asr economy-wide energy usage in kilogram of oil equivalents (*kgoe*) per unit of national value added expressed in 1997 US dollars.

C.3 Decomposition results for individual EU countries

Figures C.1 – C.3 provide a graphical summary of the results of the multiplicative LMDI-I decompositions for 27 members of the EU28. Malta was excluded from the analysis because of it reported no energy usage in some of the earlier years in our sample, which resulted in problems for the decompositions.We present the same information as in Figures C.1–C.3 in index form in Tables C.6 – C.8.

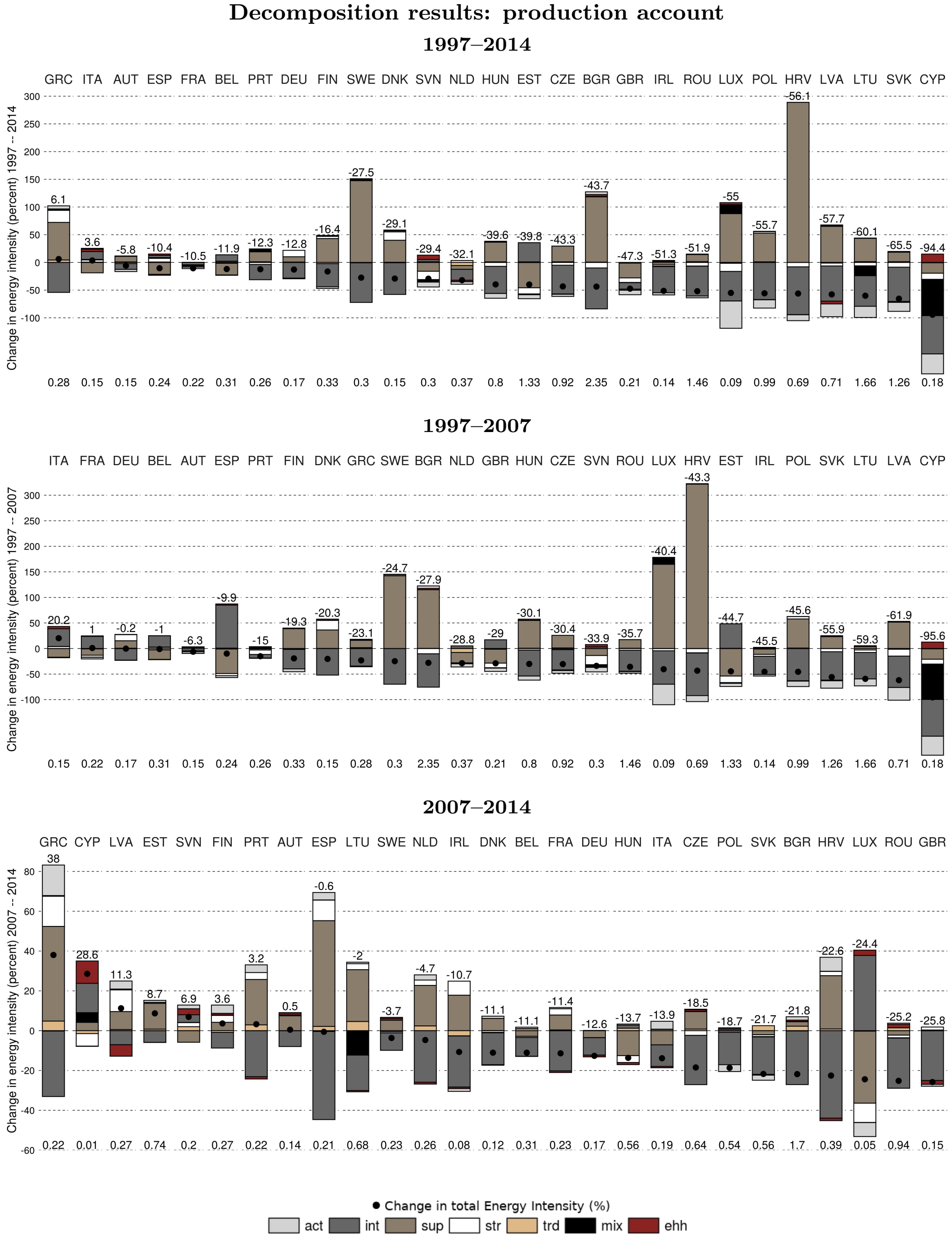

Figure C.1: Decomposition of changes in energy intensity (production account)

Note: Countries, referred to by their ISO-3 codes, are sorted according to the magnitude of the change in their energy intensity, which is shown at the top of the stacked bars (and denoted by the black dots). The values reported beneath the x-axis refer to the energy intensity of the member-state at the beginning of the period (measured in *kgoe* per dollar of value added). All monetary values are deflated using the base year 1997.

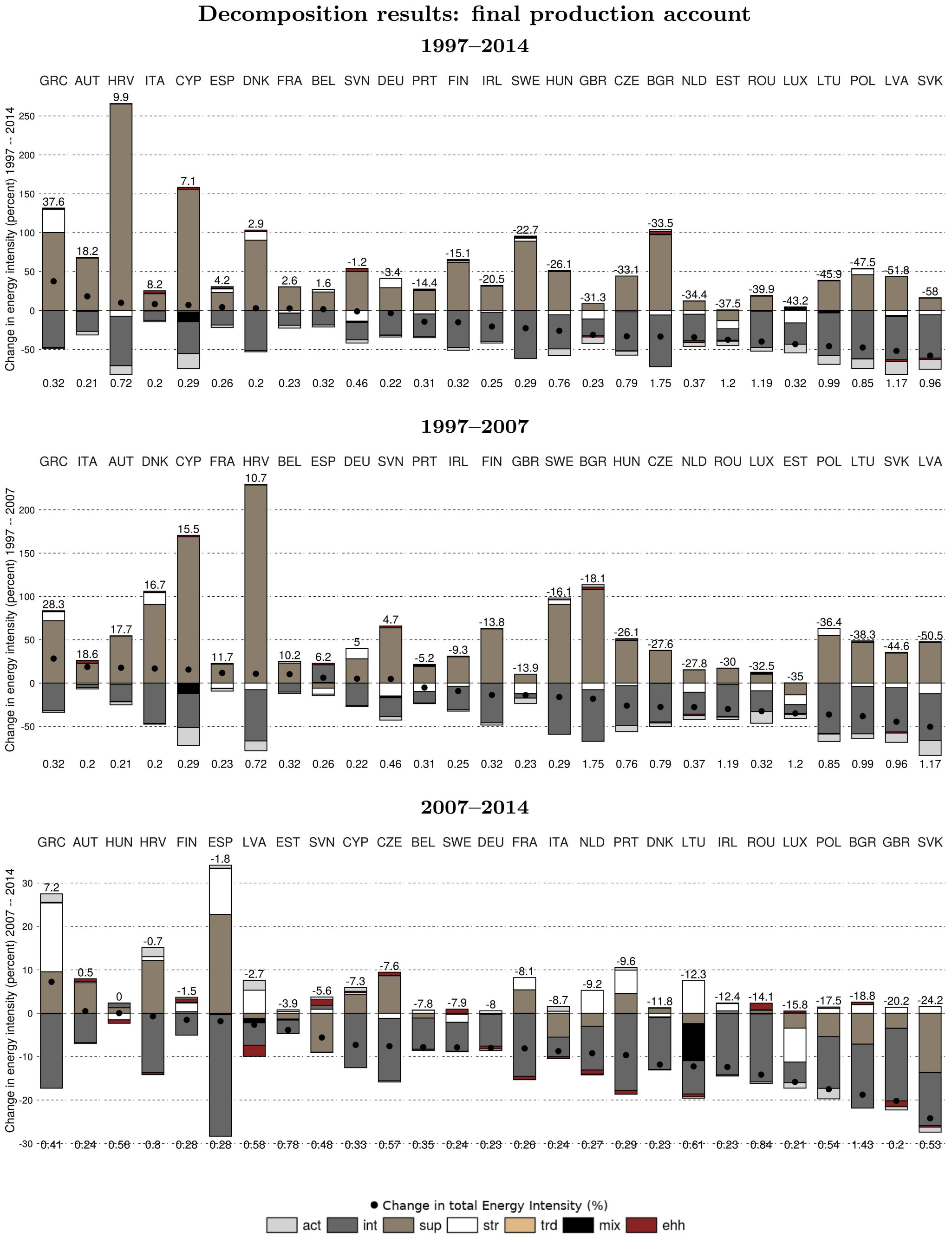

Figure C.2: Decomposition of changes in energy intensity (final production account)
Notes as in Figure C.1.

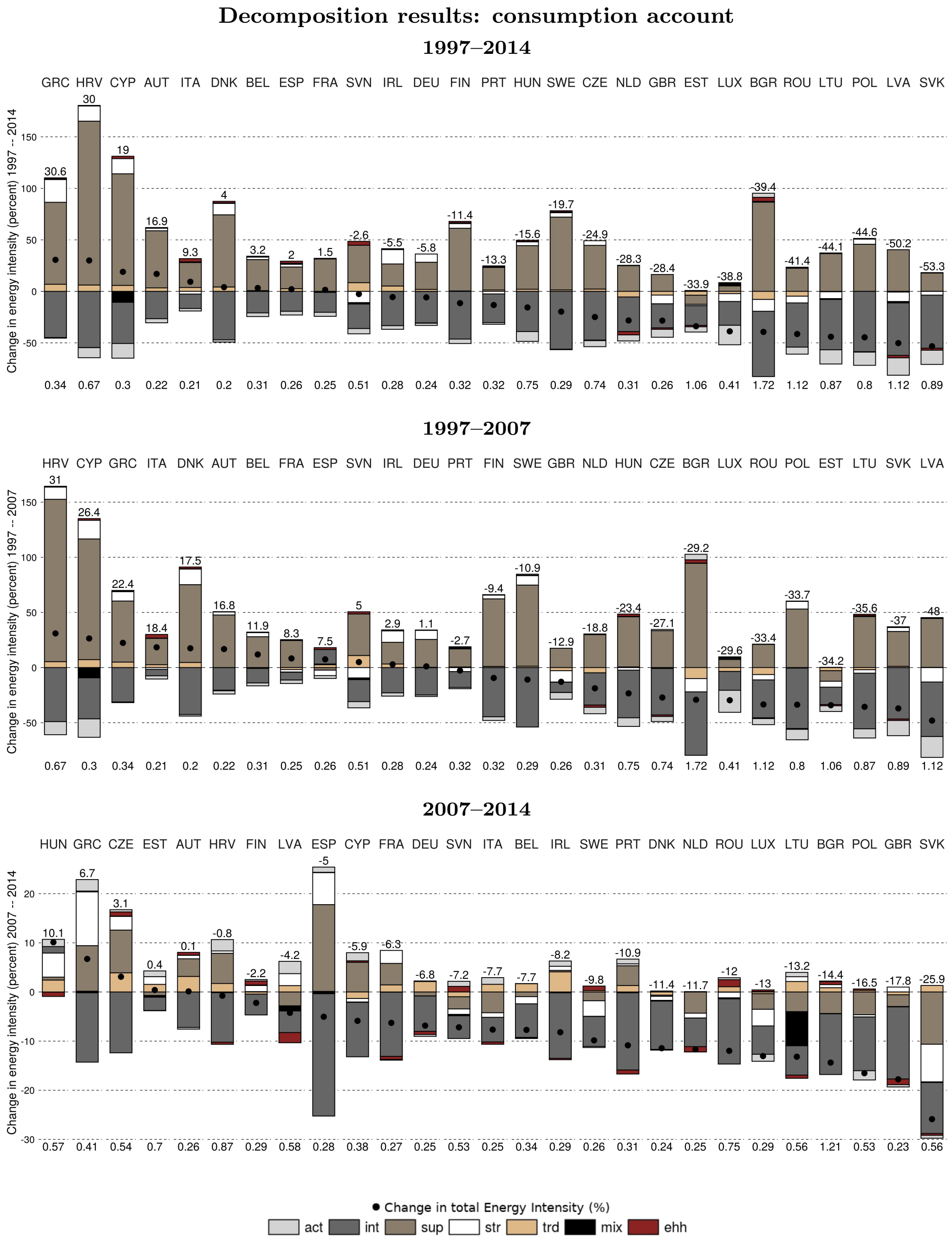

Figure C.3: Decomposition of changes in energy intensity (consumption account)
Notes as in Figure C.1.

For all energy accounts, the majority of the member states improved their energy intensity between 1997 and 2014. This pattern was most pronounced for energy usage for territorial production, where all members except two (Greece and Italy) showed such improvements. For the footprint-based accounts, nine member states (Greece, Italy, and also Austria, Belgium, Croatia, Cyprus, Denmark, France, and Spain) did not show improvements. Energy intensity gains in the new Central and Eastern European (EEU) members states were above average in general. These countries started out with a relatively high energy intensity in 1997.

Region	**act**	**int**	**sup**	**str**	**trd**	**mix**	**ehh**	**Total**
				Total Period: 1997 – 2014				
AUT	0.9599	0.8951	1.1007	0.9800	1.0082	1.0057	1.0022	0.9418
BEL	0.9939	1.1153	0.7892	1.0178	0.9850	1.0039	1.0002	0.8807
BGR	1.0496	0.2614	2.1782	0.9004	1.0051	1.0066	1.0349	0.5634
CYP	0.6401	0.3093	0.8118	0.8897	0.9940	0.3446	1.1507	0.0564
CZE	0.9606	0.4809	1.2834	0.9499	1.0109	1.0008	0.9953	0.5671
DEU	0.9919	0.7174	1.0957	1.1164	1.0059	0.9993	0.9961	0.8716
DNK	1.0100	0.4274	1.3972	1.1515	1.0024	0.9945	1.0234	0.7087
ESP	0.9833	1.0410	0.7850	1.0652	1.0076	1.0129	1.0253	0.8957
EST	0.9279	1.3474	0.5453	0.8888	0.9980	1.0093	0.9856	0.6015
FIN	0.9684	0.5840	1.4304	1.0396	0.9777	1.0037	1.0131	0.8362
FRA	0.9721	0.9777	0.9626	0.9845	0.9968	0.9949	1.0019	0.8949
GBR	0.9184	0.8844	0.7334	0.9181	0.9878	0.9954	0.9799	0.5269
GRC	1.0573	0.4591	1.6786	1.2181	1.0431	1.0088	1.0159	1.0608
HRV	0.8933	0.1374	3.8883	0.9225	0.9985	1.0009	0.9975	0.4387
HUN	0.9131	0.5106	1.3546	0.9297	1.0100	1.0048	1.0130	0.6035
IRL	0.9604	0.5276	0.9594	0.9950	0.9708	1.0334	1.0026	0.4866
ITA	1.0145	1.1424	0.8123	1.0387	1.0051	1.0093	1.0441	1.0356
LTU	0.7971	0.4478	1.4219	0.9389	1.0133	0.8222	1.0050	0.3990
LUX	0.5071	0.4660	1.8800	0.8536	0.9849	1.1602	1.0388	0.4501
LVA	0.7701	0.3650	1.6511	0.9482	0.9883	1.0254	0.9496	0.4235
NLD	0.9549	0.8023	0.9320	1.0334	0.9444	1.0014	0.9729	0.6789
POL	0.8499	0.3299	1.5175	1.0270	1.0107	1.0065	0.9962	0.4427
PRT	1.0146	0.7237	1.1803	0.9642	1.0109	1.0378	1.0005	0.8771
ROU	0.9668	0.4623	1.1291	0.9356	1.0128	0.9967	1.0089	0.4809
SVK	0.8380	0.3813	1.1725	0.9146	1.0120	1.0135	0.9830	0.3455
SVN	0.9116	1.0416	0.8411	0.8496	1.0111	0.9545	1.0787	0.7063
SWE	1.0005	0.2848	2.4748	1.0145	0.9933	1.0096	1.0107	0.7250
				First Period: 1997 – 2007				
AUT	0.9671	0.9711	1.0205	0.9736	1.0089	1.0045	0.9914	0.9374
BEL	0.9934	1.2223	0.8136	1.0245	0.9743	1.0030	1.0011	0.9901
BGR	1.0482	0.3463	2.1479	0.8979	1.0026	1.0007	1.0260	0.7206
CYP	0.6274	0.2816	0.7957	0.9063	0.9947	0.3071	1.1262	0.0438
CZE	0.9468	0.6034	1.2468	0.9815	1.0110	0.9965	0.9874	0.6956
DEU	0.9956	0.7738	1.1460	1.1198	1.0052	0.9992	1.0048	0.9978
DNK	1.0007	0.4803	1.3618	1.1867	1.0013	1.0002	1.0242	0.7967
ESP	0.9633	1.8414	0.5179	0.9588	0.9919	1.0076	1.0235	0.9009
EST	0.9372	1.4797	0.4624	0.8716	1.0014	1.0027	0.9860	0.5534
FIN	0.9441	0.6182	1.3881	1.0082	0.9877	0.9962	1.0041	0.8069
FRA	0.9672	1.2376	0.8765	0.9630	0.9931	0.9965	1.0098	1.0098
GBR	0.9345	1.1715	0.7283	0.9094	0.9868	0.9942	0.9987	0.7105
GRC	0.9867	0.6566	1.1446	1.0008	1.0160	1.0073	1.0120	0.7686
HRV	0.8830	0.1650	4.2168	0.9196	0.9976	0.9964	1.0089	0.5665
HUN	0.9188	0.4922	1.5437	0.9705	1.0055	1.0036	1.0223	0.6990
IRL	0.9690	0.6431	0.8970	0.9628	0.9900	1.0119	1.0107	0.5449
ITA	0.9897	1.3460	0.8299	1.0374	1.0003	1.0023	1.0455	1.2022
LTU	0.8635	0.4831	1.0383	0.9496	0.9733	1.0050	1.0115	0.4069
LUX	0.5984	0.3458	2.6478	0.9582	0.9980	1.1334	1.0027	0.5955
LVA	0.7505	0.3859	1.5164	0.8664	0.9860	1.0030	1.0115	0.3806
NLD	0.9371	1.0507	0.7971	0.9996	0.9229	1.0015	0.9825	0.7124
POL	0.8931	0.3697	1.5696	1.0459	1.0085	1.0027	0.9929	0.5443
PRT	0.9942	0.9294	0.9778	0.9128	0.9938	1.0230	1.0132	0.8495
ROU	0.9683	0.5886	1.1687	0.9670	1.0049	1.0006	0.9928	0.6430
SVK	0.8551	0.4441	1.2321	0.9380	0.9997	1.0187	0.9876	0.4414
SVN	0.9115	1.0302	0.8641	0.8200	1.0005	0.9480	1.0468	0.6606
SWE	1.0040	0.3018	2.4231	1.0218	0.9995	1.0026	1.0013	0.7527
				Second Period: 2007 – 2014				
AUT	1.0016	0.9204	1.0746	1.0037	0.9998	1.0001	1.0105	1.0047
BEL	1.0075	0.9054	0.9717	0.9943	1.0089	1.0011	0.9991	0.8894
BGR	1.0173	0.7306	1.0224	0.9985	1.0223	1.0011	1.0069	0.7818
CYP	0.9985	1.1472	1.0415	0.9373	0.9853	1.0488	1.1125	1.2856
CZE	1.0029	0.7521	1.0877	0.9767	1.0079	1.0013	1.0080	0.8152
DEU	0.9995	0.9124	0.9652	1.0005	1.0007	0.9998	0.9914	0.8735
DNK	1.0114	0.8397	1.0611	0.9919	1.0003	0.9975	0.9973	0.8895
ESP	1.0375	0.5571	1.5312	1.1032	1.0213	0.9962	1.0010	0.9943
EST	1.0103	0.9418	1.1295	1.0048	1.0077	0.9997	0.9992	1.0869
FIN	1.0416	0.9213	1.0418	1.0348	0.9914	1.0023	1.0081	1.0362
FRA	1.0064	0.7983	1.0748	1.0314	1.0037	0.9998	0.9917	0.8862
GBR	0.9902	0.7504	1.0028	1.0150	1.0004	0.9994	0.9808	0.7417
GRC	1.1536	0.6709	1.4756	1.1515	1.0480	0.9982	1.0033	1.3802
HRV	1.0706	0.5608	1.2674	1.0214	1.0085	1.0007	0.9873	0.7744
HUN	1.0059	1.0149	0.8748	0.9653	1.0123	0.9998	0.9895	0.8634
IRL	0.9858	0.7435	1.1782	1.0706	0.9742	0.9991	0.9924	0.8930
ITA	1.0400	0.8913	0.9290	1.0011	1.0061	1.0001	0.9932	0.8615
LTU	1.0079	0.8220	1.2604	1.0298	1.0459	0.8774	0.9936	0.9805
LUX	0.9298	1.3777	0.6382	0.9031	0.9978	0.9992	1.0268	0.7558
LVA	1.0404	0.9296	1.0902	1.1090	1.0055	1.0043	0.9421	1.1125
NLD	1.0260	0.7412	1.2036	1.0268	1.0237	1.0001	0.9904	0.9530
POL	0.9656	0.8372	0.9918	1.0054	1.0055	1.0001	1.0032	0.8133
PRT	1.0389	0.7691	1.2280	1.0346	1.0291	1.0000	0.9882	1.0324
ROU	1.0062	0.7479	0.9778	0.9867	1.0139	0.9985	1.0176	0.7479
SVK	0.9743	0.8119	0.9794	0.9911	1.0250	0.9982	0.9962	0.7826
SVN	1.0188	1.0386	0.9418	1.0204	1.0199	1.0009	1.0300	1.0692
SWE	1.0049	0.9123	1.0524	0.9937	0.9952	1.0000	1.0096	0.9632

Table C.6: Decomposition of changes in EU member energy intensity – index form
Note: Results from the multiplicative LMDI-I decomposition on production-based energy usage of the individual EU member states. Identical results are summarized graphically in Figure (C.1) in this appendix.

Region	**act**	**int**	**sup**	**str**	**trd**	**mix**	**ehh**	**Total**
				Total Period: 1997 – 2014				
AUT	0.9550	0.7424	1.6732	0.9884	NA	1.0069	1.0015	1.1822
BEL	0.9733	0.8150	1.2377	1.0290	NA	1.0057	1.0002	1.0162
BGR	1.0255	0.3346	1.9745	0.9428	NA	1.0059	1.0356	0.6652
CYP	0.8053	0.5915	2.5569	0.9838	NA	0.8715	1.0258	1.0711
CZE	0.9478	0.4992	1.4428	0.9845	NA	0.9995	0.9953	0.6686
DEU	0.9772	0.6852	1.2928	1.1191	NA	1.0000	0.9970	0.9659
DNK	0.9830	0.4862	1.9033	1.1115	NA	1.0028	1.0152	1.0292
ESP	0.9664	0.8137	1.2317	1.0451	NA	1.0094	1.0202	1.0424
EST	0.9445	0.8534	0.8697	0.8952	NA	1.0083	0.9873	0.6247
FIN	0.9650	0.5241	1.6187	1.0187	NA	1.0043	1.0139	0.8491
FRA	0.9641	0.8449	1.3031	0.9680	NA	0.9972	1.0016	1.0263
GBR	0.9183	0.7843	1.0874	0.8920	NA	0.9990	0.9840	0.6867
GRC	0.9888	0.5261	2.0009	1.2979	NA	1.0067	1.0115	1.3758
HRV	0.8844	0.3655	3.6534	0.9270	NA	1.0055	0.9985	1.0993
HUN	0.9136	0.5625	1.5010	0.9446	NA	1.0044	1.0105	0.7395
IRL	0.9775	0.6281	1.3129	0.9766	NA	1.0079	1.0013	0.7945
ITA	0.9814	0.8786	1.2153	0.9945	NA	1.0068	1.0317	1.0824
LTU	0.8849	0.4543	1.3811	0.9991	NA	0.9699	1.0063	0.5413
LUX	0.8883	0.7261	1.0067	0.8409	NA	1.0325	1.0073	0.5679
LVA	0.8358	0.4461	1.4363	0.9363	NA	0.9866	0.9738	0.4817
NLD	0.9520	0.6609	1.1210	0.9529	NA	1.0027	0.9728	0.6556
POL	0.8755	0.3814	1.4599	1.0740	NA	1.0065	0.9962	0.5249
PRT	0.9839	0.7108	1.2557	0.9560	NA	1.0195	1.0004	0.8563
ROU	0.9546	0.5320	1.1842	0.9913	NA	0.9997	1.0088	0.6013
SVK	0.8744	0.4441	1.1588	0.9455	NA	1.0056	0.9816	0.4200
SVN	0.9583	0.7797	1.5008	0.8639	NA	0.9805	1.0404	0.9884
SWE	1.0080	0.3832	1.8907	1.0384	NA	1.0076	1.0112	0.7726
				First Period: 1997 – 2007				
AUT	0.9654	0.8033	1.5417	0.9861	NA	1.0037	0.9943	1.1767
BEL	0.9811	0.8962	1.2291	1.0160	NA	1.0030	1.0009	1.1023
BGR	1.0277	0.4038	2.0798	0.9233	NA	1.0014	1.0264	0.8190
CYP	0.7904	0.6078	2.6870	0.9980	NA	0.8811	1.0180	1.1554
CZE	0.9607	0.5549	1.3740	1.0031	NA	0.9972	0.9874	0.7235
DEU	0.9857	0.7423	1.2796	1.1175	NA	0.9996	1.0038	1.0498
DNK	0.9914	0.5338	1.9067	1.1366	NA	1.0023	1.0155	1.1674
ESP	0.9820	1.2040	0.9415	0.9315	NA	1.0064	1.0178	1.0619
EST	0.9525	0.8976	0.8643	0.8877	NA	1.0023	0.9884	0.6499
FIN	0.9736	0.5433	1.6240	1.0014	NA	0.9981	1.0042	0.8622
FRA	0.9706	0.9974	1.2179	0.9412	NA	0.9977	1.0087	1.1168
GBR	0.9376	0.9516	1.1024	0.8784	NA	0.9972	0.9989	0.8607
GRC	0.9805	0.6813	1.7197	1.1031	NA	1.0049	1.0075	1.2829
HRV	0.8861	0.4085	3.2856	0.9236	NA	1.0026	1.0055	1.1072
HUN	0.9323	0.5365	1.4903	0.9704	NA	1.0033	1.0188	0.7393
IRL	0.9828	0.7293	1.3020	0.9632	NA	1.0040	1.0048	0.9068
ITA	0.9810	0.9672	1.2266	0.9840	NA	1.0025	1.0332	1.1862
LTU	0.9479	0.4523	1.4666	0.9613	NA	1.0070	1.0135	0.6169
LUX	0.8644	0.7604	1.1020	0.9109	NA	1.0220	1.0006	0.6747
LVA	0.8256	0.4617	1.4686	0.8768	NA	1.0028	1.0053	0.4949
NLD	0.9522	0.7485	1.1514	0.8934	NA	1.0021	0.9829	0.7222
POL	0.9136	0.4187	1.5494	1.0781	NA	1.0030	0.9930	0.6364
PRT	0.9921	0.8677	1.1919	0.9025	NA	1.0136	1.0098	0.9478
ROU	0.9704	0.6293	1.1711	0.9852	NA	1.0015	0.9926	0.7004
SVK	0.8926	0.4901	1.3454	0.9457	NA	1.0089	0.9869	0.5542
SVN	0.9596	0.7819	1.6369	0.8518	NA	0.9792	1.0220	1.0469
SWE	1.0188	0.4086	1.9074	1.0522	NA	1.0025	1.0013	0.8386
				Second Period: 2007 – 2014				
AUT	0.9975	0.9326	1.0702	1.0028	NA	1.0002	1.0062	1.0047
BEL	0.9974	0.9284	0.9889	1.0069	NA	1.0005	0.9994	0.9219
BGR	1.0000	0.8526	0.9290	1.0196	NA	0.9998	1.0059	0.8123
CYP	1.0087	0.8745	1.0437	1.0032	NA	1.0004	1.0033	0.9270
CZE	0.9973	0.8560	1.0863	0.9883	NA	1.0007	1.0075	0.9241
DEU	0.9961	0.9265	0.9980	1.0056	NA	0.9998	0.9936	0.9201
DNK	1.0010	0.8804	1.0117	0.9917	NA	0.9986	0.9986	0.8817
ESP	1.0072	0.7197	1.2277	1.1057	NA	0.9968	1.0007	0.9816
EST	1.0036	0.9695	0.9868	1.0043	NA	0.9976	0.9994	0.9613
FIN	1.0039	0.9495	1.0034	1.0202	NA	1.0012	1.0081	0.9848
FRA	0.9987	0.8551	1.0538	1.0283	NA	0.9996	0.9934	0.9189
GBR	0.9925	0.8329	0.9658	1.0137	NA	0.9994	0.9865	0.7979
GRC	1.0194	0.8284	1.0954	1.1586	NA	0.9989	1.0018	1.0724
HRV	1.0212	0.8644	1.1215	1.0089	NA	0.9993	0.9949	0.9929
HUN	1.0004	1.0107	1.0126	0.9850	NA	0.9996	0.9921	1.0002
IRL	1.0015	0.8594	1.0054	1.0168	NA	0.9989	0.9969	0.8762
ITA	1.0112	0.9552	0.9449	1.0046	NA	1.0001	0.9952	0.9125
LTU	0.9970	0.9233	0.9763	1.0750	NA	0.9143	0.9934	0.8775
LUX	0.9874	0.9523	0.9659	0.9218	NA	1.0006	1.0046	0.8417
LVA	1.0229	0.9483	0.9881	1.0531	NA	0.9900	0.9743	0.9735
NLD	0.9981	0.8992	0.9701	1.0527	NA	1.0000	0.9905	0.9078
POL	0.9757	0.8808	0.9462	1.0112	NA	1.0001	1.0030	0.8248
PRT	1.0060	0.8237	1.0457	1.0536	NA	0.9988	0.9909	0.9035
ROU	0.9962	0.8434	1.0068	1.0009	NA	0.9984	1.0156	0.8585
SVK	0.9884	0.8783	0.8640	1.0153	NA	0.9988	0.9963	0.7579
SVN	1.0064	1.0093	0.9104	1.0091	NA	0.9991	1.0125	0.9441
SWE	0.9985	0.9335	0.9975	0.9819	NA	0.9997	1.0095	0.9213

Table C.7: Decomposition of changes in EU member final production-based energy intensity – index form

Note: Results from the multiplicative LMDI-I decomposition on final production-based energy usage of the individual EU member states. Identical results are summarized graphically in Figure (C.2) in this appendix.

Region	act	int	sup	str	trd	mix	ehh	Total
				Total Period: 1997 – 2014				
AUT	0.9601	0.7347	1.5542	1.0245	1.0337	1.0056	1.0013	1.1692
BEL	0.9642	0.7912	1.3014	1.0246	1.0064	1.0083	1.0002	1.0324
BGR	1.0398	0.3659	1.8655	0.8847	0.9221	1.0071	1.0401	0.6064
CYP	0.8573	0.5998	2.0835	1.1475	1.0573	0.8943	1.0233	1.1896
CZE	0.9412	0.5275	1.4247	1.0452	1.0217	0.9996	0.9948	0.7511
DEU	0.9786	0.6942	1.2633	1.0805	1.0189	0.9995	0.9972	0.9416
DNK	0.9782	0.5295	1.7009	1.1109	1.0418	1.0049	1.0155	1.0404
ESP	0.9635	0.8068	1.2109	1.0262	1.0256	1.0091	1.0209	1.0205
EST	0.9487	0.8084	0.9115	0.9871	0.9627	1.0083	0.9867	0.6609
FIN	0.9573	0.5364	1.6085	1.0454	1.0037	1.0074	1.0143	0.8855
FRA	0.9608	0.8060	1.3144	1.0046	0.9928	0.9979	1.0015	1.0146
GBR	0.9224	0.7666	1.1637	0.9156	0.9638	0.9996	0.9863	0.7160
GRC	0.9946	0.5513	1.7960	1.2205	1.0686	1.0065	1.0104	1.3062
HRV	0.9019	0.4551	2.5912	1.1472	1.0610	1.0055	0.9987	1.2998
HUN	0.9043	0.6101	1.4225	1.0373	1.0207	1.0039	1.0115	0.8437
IRL	0.9648	0.6670	1.2144	1.1392	1.0513	1.0082	1.0012	0.9447
ITA	0.9756	0.8599	1.2419	0.9738	1.0376	1.0065	1.0318	1.0933
LTU	0.8624	0.5113	1.3661	0.9334	0.9963	0.9916	1.0067	0.5592
LUX	0.8104	0.7691	1.0526	0.9238	0.9782	1.0265	1.0056	0.6119
LVA	0.8308	0.4908	1.4043	0.9081	0.9935	0.9860	0.9768	0.4975
NLD	0.9412	0.6648	1.2493	1.0002	0.9455	1.0036	0.9670	0.7174
POL	0.8718	0.4141	1.4568	1.0499	1.0003	1.0065	0.9961	0.5538
PRT	0.9837	0.7212	1.2188	0.9753	1.0131	1.0146	1.0004	0.8673
ROU	0.9318	0.5707	1.2241	0.9343	0.9536	1.0016	1.0088	0.5860
SVK	0.8619	0.4848	1.1767	0.9636	1.0008	1.0043	0.9805	0.4669
SVN	0.9488	0.7614	1.3633	0.8909	1.0840	0.9867	1.0379	0.9742
SWE	0.9951	0.4387	1.7066	1.0429	1.0136	1.0082	1.0114	0.8032
				First Period: 1997 – 2007				
AUT	0.9704	0.7955	1.4763	1.0277	0.9996	1.0029	0.9947	1.1679
BEL	0.9734	0.8680	1.2796	1.0371	0.9929	1.0040	1.0009	1.1188
BGR	1.0505	0.4242	1.9450	0.8801	0.9000	1.0022	1.0295	0.7082
CYP	0.8324	0.6280	2.0942	1.1692	1.0717	0.9073	1.0156	1.2639
CZE	0.9538	0.5786	1.3342	1.0115	0.9942	0.9978	0.9859	0.7285
DEU	0.9861	0.7522	1.2531	1.0818	1.0022	0.9996	1.0036	1.0108
DNK	0.9858	0.5745	1.7054	1.1415	1.0460	1.0031	1.0157	1.1749
ESP	0.9740	1.1312	0.9771	0.9504	1.0254	1.0065	1.0176	1.0747
EST	0.9481	0.8424	0.9040	0.9465	0.9721	1.0025	0.9884	0.6583
FIN	0.9664	0.5539	1.6126	1.0341	1.0101	1.0000	1.0044	0.9057
FRA	0.9686	0.9293	1.2449	0.9781	0.9819	0.9978	1.0082	1.0827
GBR	0.9391	0.9076	1.1751	0.8971	0.9720	0.9980	0.9991	0.8708
GRC	0.9939	0.6882	1.5536	1.0850	1.0493	1.0049	1.0066	1.2239
HRV	0.8812	0.5101	2.4724	1.1107	1.0533	1.0027	1.0048	1.3098
HUN	0.9214	0.5678	1.4549	0.9771	1.0056	1.0034	1.0211	0.7663
IRL	0.9702	0.7711	1.1969	1.1035	1.0320	1.0046	1.0045	1.0290
ITA	0.9707	0.9416	1.2384	0.9839	1.0261	1.0026	1.0333	1.1841
LTU	0.9163	0.4956	1.4620	0.9690	0.9804	1.0075	1.0136	0.6441
LUX	0.8003	0.8288	1.0725	1.0088	0.9653	1.0153	1.0005	0.7037
LVA	0.8103	0.5059	1.4428	0.8692	1.0020	1.0040	1.0045	0.5195
NLD	0.9413	0.7075	1.2987	1.0030	0.9529	1.0028	0.9798	0.8123
POL	0.9048	0.4518	1.5302	1.0694	0.9954	1.0032	0.9930	0.6634
PRT	0.9881	0.8563	1.1640	0.9637	1.0051	1.0111	1.0087	0.9729
ROU	0.9450	0.6564	1.2102	0.9515	0.9368	1.0023	0.9928	0.6658
SVK	0.8621	0.5335	1.3161	1.0360	1.0109	1.0069	0.9868	0.6299
SVN	0.9435	0.8005	1.3770	0.9064	1.1089	0.9846	1.0200	1.0496
SWE	1.0092	0.4610	1.7352	1.0856	1.0124	1.0028	1.0013	0.8909
				Second Period: 2007 – 2014				
AUT	0.9965	0.9279	1.0360	1.0070	1.0315	1.0003	1.0059	1.0012
BEL	0.9985	0.9316	0.9905	0.9854	1.0168	1.0003	0.9993	0.9228
BGR	1.0011	0.8764	0.9562	1.0063	1.0086	0.9994	1.0062	0.8563
CYP	1.0166	0.8892	1.0603	0.9929	0.9868	0.9992	1.0030	0.9412
CZE	1.0046	0.8762	1.0870	1.0278	1.0389	1.0006	1.0086	1.0310
DEU	0.9962	0.9279	0.9920	1.0012	1.0212	0.9999	0.9936	0.9315
DNK	1.0020	0.9016	0.9976	0.9918	0.9936	0.9985	0.9986	0.8855
ESP	1.0107	0.7510	1.1766	1.0650	1.0011	0.9965	1.0007	0.9496
EST	1.0118	0.9730	0.9929	1.0157	1.0154	0.9964	0.9994	1.0040
FIN	1.0031	0.9575	1.0006	1.0125	0.9957	1.0010	1.0081	0.9778
FRA	0.9986	0.8692	1.0437	1.0265	1.0143	0.9997	0.9937	0.9371
GBR	0.9952	0.8533	0.9761	1.0100	0.9943	0.9993	0.9885	0.8222
GRC	1.0235	0.8589	1.0927	1.1095	1.0015	0.9984	1.0016	1.0673
HRV	1.0230	0.8992	1.0613	1.0049	1.0173	0.9987	0.9956	0.9923
HUN	1.0146	1.0134	1.0060	1.0489	1.0241	0.9997	0.9912	1.1011
IRL	1.0108	0.8666	1.0029	1.0083	1.0409	0.9983	0.9972	0.9180
ITA	1.0137	0.9499	0.9578	0.9907	1.0155	1.0000	0.9952	0.9234
LTU	1.0089	0.9402	0.9600	1.0097	1.0212	0.9306	0.9935	0.8682
LUX	0.9857	0.9423	0.9682	0.9661	0.9966	1.0007	1.0035	0.8695
LVA	1.0251	0.9560	0.9719	1.0243	1.0129	0.9896	0.9793	0.9576
NLD	1.0003	0.9418	0.9569	0.9902	1.0004	0.9999	0.9891	0.8832
POL	0.9812	0.8905	0.9537	0.9956	1.0032	0.9999	1.0030	0.8347
PRT	1.0097	0.8429	1.0402	1.0039	1.0130	0.9983	0.9918	0.8915
ROU	1.0040	0.8673	0.9996	0.9886	1.0106	0.9978	1.0144	0.8802
SVK	0.9940	0.8961	0.8937	0.9235	1.0132	0.9987	0.9964	0.7412
SVN	1.0104	0.9537	0.9753	0.9889	0.9903	0.9972	1.0113	0.9281
SWE	0.9977	0.9390	0.9822	0.9684	1.0028	0.9997	1.0093	0.9015

Table C.8: Decomposition of changes in EU member final consumption-based energy intensity – index form

Note: Results from the multiplicative LMDI-I decomposition on final consumption-based energy usage of the individual EU member states. The same results are summarized graphically in Figure (C.3) in this appendix.

As for the EU as a whole, changes in energy intensity in territorial production in the member states were mainly determined by changes in the efficiency factor (*int*) and changes in supply chains (*sup*). The efficiency factor was the most important factor in improving energy intensity in a majority of the members, in general more so for the Eastern European (EEU) members. Changes in supply chains acted typically as a counterforce to those gains, but different patterns between old EU-15 and new EEU members could be observed. Unlike for EEU members, and contrary to the European trend, seven EU-15 states reorganized their supply chains in a way that improved energy-wide energy efficiency. This points to a reduction of and/or changes in the composition of the production of intermediates towards less energy-intensive products. In three further EU-15 countries, the supply chain factor led only to minor deteriorations of energy efficiency. The development of the supply chain factor in the EEU members indicates that part of the production of those intermediates may have shifted towards EEU countries as this factor contributes of significantly to a deterioration of their energy efficiency.

Of the remaining factors that determine energy intensity of the EU member states in territorial production, the most important ones were changes in the sector composition of final goods produced (*str*), changes in economic activity (*act*), and changes in the usage of primary energy by private households (*ehh*). In general, changes in the sector composition of final goods led to a deterioration of energy efficiency in EU-15 states, but improved it in EEU members. Similarly, we observe that economic activity tended to improve energy efficiency in EEU members. This points towards a catch-up in income of the new member states relative to the old ones between 1997 and 2014. For some specific regions also the energy mix (*mix*) and the composition of trading partners for final goods (*trd*) had some effect on their energy intensity. Interestingly, in the period from 2007 to 2014, energy usage by private households contributed to deteriorating efficiency in many EU members. This could reflect the promotion of solar energy and biomass, both produced at the household level, in the EU.

For the two footprint accounts, the general pattern is roughly the same as for energy used for production, with the exception that changes in the supply chain factor were more pronounced and contributed to a deterioration in energy intensity in more member states. This indicates that improvements in energy intensity were partly achieved by outsourcing of energy intensive productions stages, especially by EU-15. At the same time, efficiency gains from declining sectoral energy intensity were less pronounced in the footprints, indicating the less efficient technology of the trading partners of the EU. Also, some of the remaining factors were more important in the footprints than in territorial production, especially in the second sub-period from 2007 to 2014. Specifically, this was the case for changes in the composition of final goods produced and consumed, the composition of the trading partners of final goods consumed, and household energy usage. As a result, energy intensity gains were lower in the footprint accounts of the members than for territorial production, explaining the EU-wide result.

Comparing the developments for efficiency measured in territorial production across the two sub-periods, we find that while for the EU as a whole efficiency gains after 2007 are larger than in the period before, a detailed perspective on the individual EU member states offers a very heterogeneous picture. More EU members showed energy intensity gains in the first compared to the second period. While from 1997 to 2007 only Italy, and, to a very moderate degree, France became less efficient, this was the case for eight countries between 2007 and 2014. Their effect on the EU's energy intensity was low, however, as all of them are among the smaller members of the EU. Furthermore, except in four cases, sector energy intensity in those countries improved in all member states between 2007 and 2014, while the contribution of other factors decreased energy intensity.

As a result, the reductions in the efficiency factor are almost the only source by which the EU members became more efficient in the period 2007–2014. While in between 1997 and 2007 this factor contributed to improving energy efficiency in only 19 of the EU members, this was the case for 23 members after 2007. Responsible for this was primarily a reverse in the trend of the growth rate of sector energy intensity in many of the EU-15 states, especially in the large energy users France, Great Britain, Italy, and Spain, but also in the Netherlands, Belgium, and Estonia. For the larger energy users, changes in the pattern of sector energy intensity have a large effect on the Union's energy intensity, explaining the aggregate effects described in the main text.

C.4 Average annual growth rates of the efficiency factor at country level

Table C.9 reports the average annual growth rate of the energy efficiency factor (*int*) for individual countries and composite regions for the period 1997–2014 and the sub-periods 1997–2007 and 2007–2014. The last two columns in the table show the energy intensity (defined as energy usage by all sectors of an economy divided by their value added) at the beginning of each sub-period.

Region	**%Δ Efficiency Factor**			**Sector Intensity**	
	97 – 14	97 – 07	07 – 14	1997	2007
		percent		*kgoe/USD*	
		EU-15			
Austria	-0.62	-0.29	-1.14	0.14	0.13
Belgium	0.68	2.22	-1.35	0.29	0.29
Germany	-1.66	-2.26	-1.25	0.16	0.16
Denmark	-3.37	-5.20	-2.29	0.15	0.11
Spain	0.24	8.41	-6.33	0.23	0.20
Finland	-2.45	-3.82	-1.12	0.32	0.26
France	-0.13	2.38	-2.88	0.21	0.21
United Kingdom	-0.68	1.71	-3.57	0.18	0.13
Greece	-3.18	-3.43	-4.70	0.28	0.21
Ireland	-2.78	-3.57	-3.66	0.13	0.07
Italy	0.84	3.46	-1.55	0.14	0.16
Luxembourg	-3.14	-6.54	5.40	0.07	0.05
Netherlands	-1.16	0.51	-3.70	0.33	0.24
Portugal	-1.63	-0.71	-3.30	0.25	0.21
Sweden	-4.21	-6.98	-1.25	0.30	0.22
		EEU			
Bulgaria	-4.34	-6.54	-3.85	2.33	1.63
Cyprus	-4.06	-7.18	2.10	0.18	0.00
Czechia	-3.05	-3.97	-3.54	0.82	0.58
Estonia	2.04	4.80	-0.83	1.18	0.68
Croatia	-5.07	-8.35	-6.27	0.58	0.33
Hungary	-2.88	-5.08	0.21	0.68	0.47
Lithuania	-3.25	-5.17	-2.54	1.56	0.63
Latvia	-3.74	-6.14	-1.01	0.48	0.19
Poland	-3.94	-6.30	-2.33	0.87	0.47
Romania	-3.16	-4.11	-3.60	1.29	0.83
Slovakia	-3.64	-5.56	-2.69	1.16	0.52
Slovenia	0.24	0.30	0.55	0.29	0.18
		Rest of OECD			
Australia	-1.85	-2.08	-2.10	0.28	0.21
Canada	-2.80	-3.84	-2.87	0.42	0.34
Switzerland	2.15	-4.31	21.88	0.08	0.06
Chile	-0.99	-3.09	2.36	0.27	0.18
Japan	2.06	8.70	-3.24	0.14	0.14
Korea	0.75	2.70	-1.51	0.49	0.37
Mexico	-2.40	0.04	-5.52	0.38	0.29
New Zealand	-0.20	-0.58	0.28	0.27	0.19
Turkey	3.05	5.67	-0.35	0.32	0.37
United States	0.18	1.44	-1.45	0.27	0.22
R.o. EFTA	-3.01	-4.02	-3.17	0.23	0.27
		BRICS			
Brazil	-0.95	-3.03	2.68	0.23	0.26
China	-1.95	-3.85	2.08	1.25	0.96
India	-2.66	-4.40	-0.13	0.76	0.57
Russia	-4.10	-7.76	5.11	1.59	1.36

Table C.9: Average annual growth rates of energy efficiency factor – continued on next page
Note: Data refers to energy usage for production. Sector intensity is given as energy usage by all sectors of an economy in kilogram of oil equivalent (kgoe) per unit of value added expressed in 1997 US dollars. Malta was excluded because of zero reported energy usage in some years. Rest of EFTA refers to the composite region including Norway, Iceland, and Liechtenstein. R.o. SACU refers to Southern African Customs Union. South Africa is not included in the BRICS group because is part of the composite region Rest of SACU. Israel is not included in the OECD group because it is part of the composite region Rest of Middle East. For details on composite regions see Table (A.4).

Region	**%Δ Energy Efficiency Factor**			**Sector Intensity**	
	97 – 14	97 – 07	07 – 14	1997	2007
		percent		*kgoe/USD*	
	ROW Single Countries				
Albania	-0.55	0.47	-2.05	0.58	0.20
Argentina	0.68	-0.93	2.65	0.19	0.20
Bangladesh	0.10	-0.62	1.01	0.13	0.14
Botswana	0.99	-0.87	0.76	0.10	0.07
Colombia	-4.38	-7.73	0.44	0.35	0.24
Hong Kong	-2.22	-4.17	1.02	0.05	0.04
Indonesia	-1.26	-1.71	-2.64	0.51	0.46
Sri Lanka	-3.56	-4.63	-4.15	0.24	0.19
Morocco	-0.92	2.34	-4.48	0.29	0.21
Mozambique	-3.99	-5.84	-1.53	0.67	0.36
Malawi	0.09	0.87	-1.56	0.26	0.16
Malaysia	2.45	0.44	4.49	0.39	0.52
Peru	0.37	-0.80	2.23	0.18	0.20
Philippines	-1.58	-4.22	4.44	0.49	0.29
Singapore	-4.36	-7.04	-2.63	0.85	0.43
Thailand	-1.74	-4.42	3.72	0.56	0.58
Taiwan	-2.78	-3.19	-3.74	0.26	0.33
Tanzania	-0.12	-0.63	0.58	0.62	0.55
Uganda	-0.24	-0.33	-0.12	0.25	0.16
Uruguay	-1.78	-4.69	3.34	0.15	0.13
Venezuela	-0.01	-1.21	2.24	1.25	0.79
Vietnam	-0.28	-2.12	0.92	0.55	0.50
Zambia	2.49	4.29	-0.91	1.02	0.65
Zimbabwe	-0.43	-0.75	0.32	0.45	0.74
	ROW Composite Regions				
R.o. Southern Africa	-2.15	6.93	-6.02	0.71	0.37
R.o. Andean Pact	-2.73	-7.28	10.46	0.47	0.34
R.o. Central America	-3.24	-5.47	-0.68	2.41	0.96
R.o. Middle East	-3.51	-5.74	-1.54	1.10	0.75
R.o. Nothern Africa	0.26	-1.62	3.01	0.76	0.57
R.o. Southern Asia	-2.40	-4.08	-0.07	0.90	1.03
R.o. SACU	3.32	2.05	4.82	0.91	0.63
R.o. South America	-0.82	-4.10	8.01	2.39	1.48
R.o. Sub-Saharan Africa	0.35	0.60	-0.17	0.52	0.44
R.o. Former SU	-2.40	-4.60	0.95	2.38	1.51
R.o. World	-1.41	-2.21	-0.29	4.60	11.05

Table C.9: – continued from last page.

C.5 Supplementary regression results

The figures and tables presented in this sections complement the regression analyses undertaken in the main text.

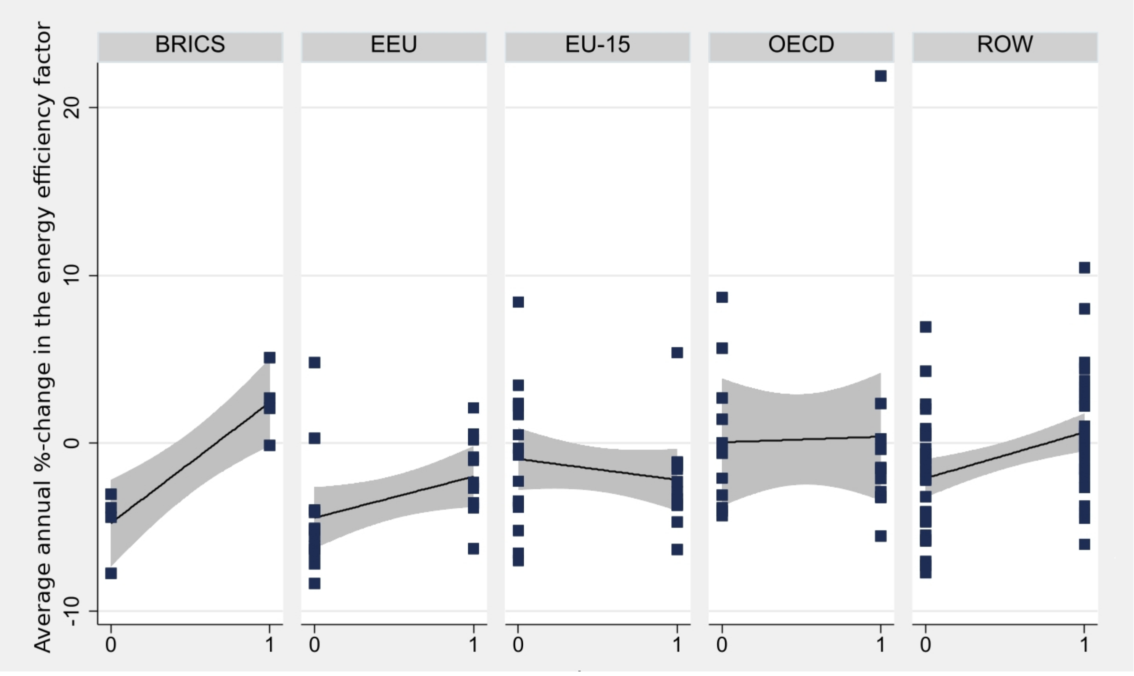

Figure C.4: Growth in the energy efficiency factor pre- and post 2007
Note: Average annual percentages changes in the energy efficiency factor for different country-groups. BRICS comprises Brazil, Russia, India and China, EEU stands for the Eastern European Union, EU-15 stands for the old EU15 members, OECD refers to non-EU OECD countries, and ROW stands for the rest of the world. 0 refers to the period 1997–2007, 1 to the period 2007–2014. The rectangles represent individual countries. Linear fit and 95% confidence interval (grey areas) are shown.

Figure C.4 displays the evolution of the efficiency factor (*int*), benchmarked to territorial production, for the periods before and after 2007 for different country groups. EU countries are grouped into the old EU15 members and new Central and Eastern European (EEU) members that joined the EU since 2004, to account for potentially different developments across these two economically heterogeneous groups[44], the rest of the OECD (which includes all non-EU OECD countries in our data), and the rest of the world aggregate (ROW).[45]

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[44] EU15 members were already considerably more energy efficient than EEU members at the beginning of our sample, which may impact on their potential for sectoral energy intensity improvements (see Tables C.6 and C.9 in this Appendix.

[45] South Africa is not included in the BRICs group because it is not included as an individual country in the IO tables used in the construction of our dataset. It is grouped together with Lesotho, Namibia, and Swaziland. Israel is not included in the OECD group because it is also part of a composite region (see Table A.4 in Appendix A).

Out of the regions in Figure C.4, only the group of EU15 countries experienced a stronger improvement in sectoral energy-intensity after 2007 compared to before. All other country-groups experienced on average smaller improvements or even increases in the sectoral energy-intensity term after 2007 as compared to the period before. However, the graph for the non-EU OECD countries seems to be influenced by an outlier (Switzerland). Excluding Switzerland from the group results in a stronger decrease in the energy-intensity term in the second period also in the non-EU OECD group.[46]

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[46] In Switzerland, the large increase in sectoral energy intensity between 2007 and 2014 was driven by the electricity sector, which experienced a strong decline in value added in this period. The electricity sector shows by far the largest energy usage across all Swiss sectors, thus receiving a large weight in the computation of the sectoral energy intensity factor.

Average annual growth rate of the energy efficiency factor, production					
	(1)	(2)	(3)	(4)	(5)
Constant	-1.895***	-1.819**	-1.433**	-2.217***	-2.053***
	(-2.775)	(-2.534)	(-2.292)	(-3.397)	(-3.274)
Sector Intensity	-0.262	-0.202	-0.193	-0.176	-0.178
	(-1.407)	(-1.353)	(-1.270)	(-1.420)	(-1.464)
GDP pc	0.000	0.000	0.000	0.000	0.000
	(0.579)	(0.262)	(-0.634)	(-0.002)	(-0.589)
2007–2014	2.488***	2.524***	2.140***	3.191***	3.246***
	(3.162)	(3.215)	(2.965)	(4.161)	(4.275)
EU	-0.930				
	(-0.894)				
EU · (2007–2014)	-2.311*				
	(-1.814)				
EU15		0.590	1.098	1.317	1.793
		(0.413)	(0.833)	(0.872)	(1.270)
EU15 · (2007–2014)		-3.868**	-3.220**	-4.436***	-4.303***
		(-2.508)	(-2.267)	(-3.026)	(-2.963)
EEU		-2.571**	-2.588**	-2.056*	-1.949*
		(-2.229)	(-2.240)	(-1.734)	(-1.661)
EEU · (2007–2014)		-0.231	0.384	-0.803	-0.696
		(-0.153)	(0.274)	(-0.554)	(-0.480)
R.o.OECD				2.326	3.129**
				(1.498)	(2.107)
R.o.OECD · (2007–2014)				-2.863	-5.377***
				(-1.102)	(-3.261)
N	154	154	152	154	152
R^2	0.121	0.146	0.146	0.165	0.206

Table C.10: Regressions with controls – production

Note: t-statistics, based on robust standard errors, in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. R.o.OECD stands for the rest of the OECD aggregate. Regressions (3) and (5) exclude Switzerland in both periods.

C.5.1 Graphs and regressions for footprint accounts

Final production

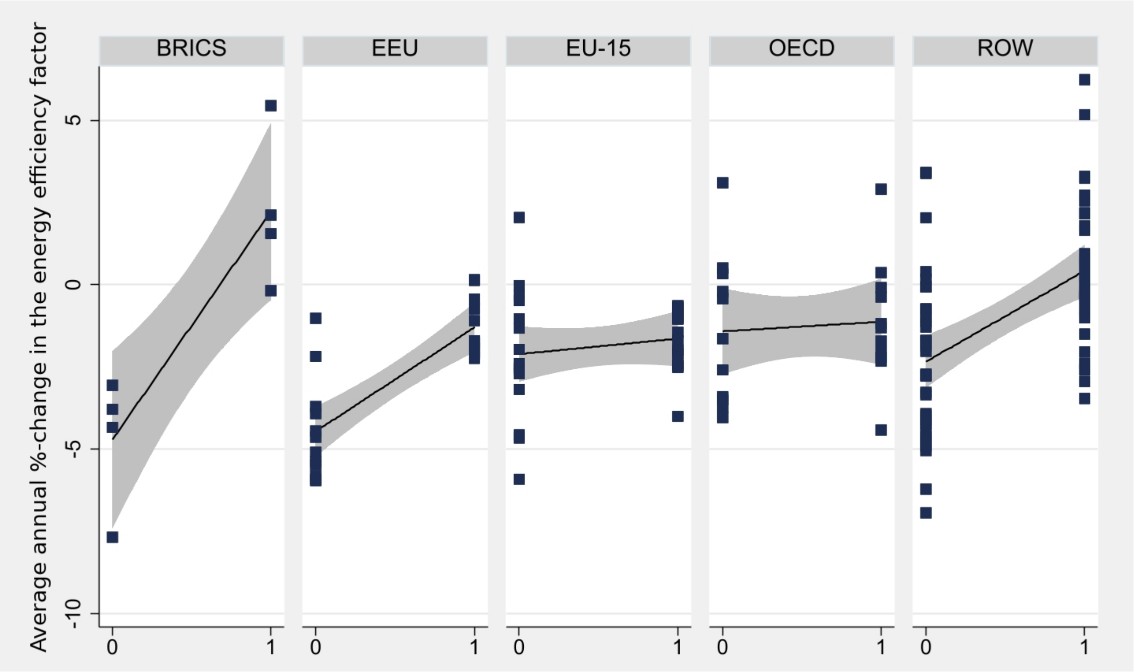

Figure C.5: Growth in the energy efficiency factor, final production

Notes as in Figure C.4.

Consumption

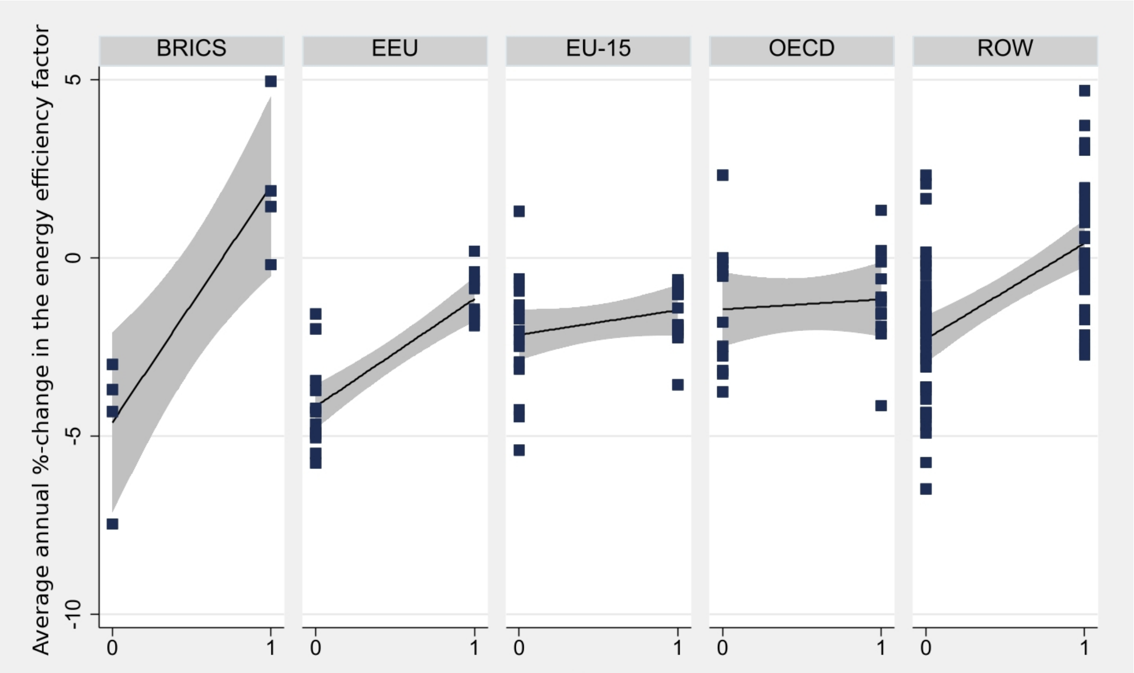

Figure C.6: Growth in the energy efficiency factor, consumption

Notes as in Figure C.4.

Average annual growth rate of the energy efficiency factor, final production					
	(1)	(2)	(3)	(4)	(5)
Constant	-2.329***	-2.329***	-2.307***	-2.585***	-2.585***
	(-6.560)	(-6.516)	(-6.336)	(-6.290)	(-6.288)
2007–2014	2.555***	2.555***	2.479***	3.194***	3.194***
	(5.320)	(5.284)	(5.061)	(5.795)	(5.793)
EU	-0.828				
	(-1.518)				
EU · (2007–2014)	-0.887				
	(-1.349)				
EU15		0.219	0.197	0.475	0.475
		(0.347)	(0.310)	(0.715)	(0.715)
EU15 · (2007–2014)		-2.086***	-2.010***	-2.725***	-2.725***
		(-2.788)	(-2.671)	(-3.421)	(-3.420)
EEU		-2.136***	-2.158***	-1.879***	-1.879***
		(-3.785)	(-3.794)	(-3.122)	(-3.121)
EEU · (2007–2014)		0.613	0.689	-0.026	-0.026
		(0.880)	(0.983)	(-0.034)	(-0.034)
R.o.OECD				1.166	1.365*
				(1.483)	(1.670)
R.o.OECD · (2007–2014)				-2.902***	-3.502***
				(-2.823)	(-3.536)
N	154	154	152	154	152
R^2	0.268	0.307	0.299	0.346	0.353
P1: base	-2.329	-2.329	-2.307	-2.585	-2.585
P1: EU	-3.156				
P1: EU 15		-2.110	-2.110	-2.110	-2.110
P1: EEU		-4.464	-4.464	-4.464	-4.464
P1: R.o. OECD				-1.419	-1.221
P2: base	0.227	0.227	0.172	0.608	0.608
P2: EU	-1.488				
P2: EU 15		-1.641	-1.641	-1.641	-1.641
P2: EEU		-1.296	-1.296	-1.296	-1.296
P2: R.o. OECD				-1.127	-1.529
p-value: P1 EU15 – EEU		0.001	0.001	0.001	0.001
p-value: P1 EU15 – OECD				0.417	0.313
p-value: P1 EEU – OECD				0.000	0.000
p-value: P2 base – EU	0.000				
p-value: P2 base – EU 15		0.000	0.000	0.000	0.000
p-value: P2 base – EEU		0.000	0.001	0.000	0.000
p-value: P2 base – OECD				0.010	0.000
p-value: P2 EU15 – EEU		0.316	0.317	0.320	0.320
p-value: P2 EU15 – OECD				0.393	0.819
p-value: P2 EEU – OECD				0.779	0.635
p-value: P1-P2 base	0.000	0.000	0.000	0.000	0.000
p-value: P1-P2 EU	0.000				
p-value: P1-P2 EU15		0.413	0.413	0.416	0.416
p-value: P1-P2 EEU		0.000	0.000	0.000	0.000
p-value: P1-P2 OECD				0.737	0.708
p-value: DID EU15 – EEU		0.001	0.001	0.001	0.001
p-value: DID EU15 – OECD				0.865	0.440
p-value: DID EEU – OECD				0.005	0.000

Table C.11: Regressions: energy efficiency factor, final production
Note: t-statistics, based on robust standard errors, in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variables measure the average annual percentage change of the energy efficiency factor of final production. R.o.OECD stands for the rest of the OECD aggregate. The panel below the R^2 reports the average annual percentage change in the energy efficiency factor for each of the country-groups and periods. *P1* refers to the period 1997–2007, *P2* to the period 2007–2014. *base* stands for the base-group (i.e. non-EU countries in regressions (1)–(3), non-EU non-OECD countries in regressions (4) and (5)). The bottom panel reports a series of Wald-tests for differences across country-groups and/or periods. *DID* stands for difference-in-differences and tests for differences in the interaction-terms (i.e. differences in changes from P1 to P2 across country-groups). Regressions (3) and (5) exclude Switzerland in both periods.

Average annual growth rate of the energy efficiency factor, final consumption					
	(1)	(2)	(3)	(4)	(5)
Constant	-2.282***	-2.282***	-2.272***	-2.518***	-2.518***
	(-7.456)	(-7.406)	(-7.229)	(-7.057)	(-7.055)
2007–2014	2.476***	2.476***	2.443***	3.095***	3.095***
	(6.052)	(6.011)	(5.822)	(6.603)	(6.601)
EU	-0.770*				
	(-1.655)				
EU · (2007–2014)	-0.751				
	(-1.348)				
EU15		0.126	0.116	0.362	0.362
		(0.236)	(0.216)	(0.640)	(0.639)
EU15 · (2007–2014)		-1.785***	-1.752***	-2.405***	-2.405***
		(-2.812)	(-2.738)	(-3.560)	(-3.558)
EEU		-1.889***	-1.899***	-1.653***	-1.653***
		(-3.945)	(-3.932)	(-3.220)	(-3.219)
EEU · (2007–2014)		0.542	0.575	-0.077	-0.077
		(0.931)	(0.978)	(-0.123)	(-0.123)
R.o.OECD				1.075	1.206*
				(1.641)	(1.755)
R.o.OECD · (2007–2014)				-2.814***	-3.195***
				(-3.368)	(-3.801)
N	154	154	152	154	152
R^2	0.109	0.142	0.140	0.163	0.200
P1: base	-2.282	-2.282	-2.272	-2.518	-2.518
P1: EU	-3.051				
P1: EU 15		-2.155	-2.155	-2.155	-2.155
P1: EEU		-4.171	-4.171	-4.171	-4.171
P1: R.o. OECD				-1.443	-1.312
P2: base	0.194	0.194	0.171	0.577	0.577
P2: EU	-1.327				
P2: EU 15		-1.465	-1.465	-1.465	-1.465
P2: EEU		-1.153	-1.153	-1.153	-1.153
P2: R.o. OECD				-1.163	-1.413
p-value: P1 EU15 – EEU		0.001	0.001	0.001	0.001
p-value: P1 EU15 – OECD				0.313	0.253
p-value: P1 EEU – OECD				0.000	0.000
p-value: P2 base – EU	0.000				
p-value: P2 base – EU 15		0.000	0.000	0.000	0.000
p-value: P2 base – EEU		0.000	0.000	0.000	0.000
p-value: P2 base – OECD				0.001	0.000
p-value: P2 EU15 – EEU		0.264	0.264	0.267	0.267
p-value: P2 EU15 – OECD				0.520	0.903
p-value: P2 EEU – OECD				0.983	0.539
p-value: P1-P2 base	0.000	0.000	0.000	0.000	0.000
p-value: P1-P2 EU	0.000				
p-value: P1-P2 EU15		0.155	0.155	0.158	0.158
p-value: P1-P2 EEU		0.000	0.000	0.000	0.000
p-value: P1-P2 OECD				0.686	0.886
p-value: DID EU15 – EEU		0.000	0.000	0.000	0.000
p-value: DID EU15 – OECD				0.629	0.354
p-value: DID EEU – OECD				0.001	0.000

Table C.12: Regressions: energy efficiency factor, final consumption
Note: *t*-statistics, based on robust standard errors, in parenthesis. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variables measure the average annual percentage change in the energy efficiency factor of final consumption. R.o.OECD stands for the rest of the OECD aggregate. The panel below the R^2 reports the average annual percentage change in the energy efficiency factor for each of the country-groups and periods. *P1* refers to the period 1997–2007, *P2* to the period 2007–2014. *base* stands for the base-group (i.e. non-EU countries in regressions (1)–(3), non-EU non-OECD countries in regressions (4) and (5)). The bottom panel reports a series of Wald-tests for differences across country-groups and/or periods. *DID* stands for difference-in-differences and tests for differences in the interaction-terms (i.e. differences in changes from P1 to P2 across country-groups). Regressions (3) and (5) exclude Switzerland in both periods.

	non-renewable			**renewable**			
	fossil	nuclear	other n-ren	hydro	wind	solar	other ren
Constant	0.154	-0.014	0.004**	0.021	0.003***	0.001***	-0.169*
	(1.495)	(-1.234)	(2.418)	(0.554)	(4.569)	(2.624)	(-1.868)
2007–2014	0.266*	0.018	-0.000	-0.029	0.017***	0.008***	-0.280*
	(1.683)	(1.435)	(-0.152)	(-0.601)	(3.789)	(3.561)	(-1.865)
EU15	-0.039	-0.202***	0.008*	-0.056	0.036***	0.001	0.252**
	(-0.280)	(-3.682)	(1.786)	(-1.384)	(4.256)	(1.083)	(2.502)
EU15 · (2007–2014)	-0.914***	0.187**	0.018***	0.119**	0.058**	0.051***	0.482***
	(-4.550)	(2.561)	(2.767)	(2.250)	(2.511)	(3.664)	(2.956)
EEU	-0.161	-0.051	-0.006	-0.011	0.005***	-0.001	0.224*
	(-1.034)	(-0.504)	(-0.765)	(-0.274)	(5.570)	(-1.301)	(1.746)
EEU · (2007–2014)	-0.717**	-0.065	0.040***	0.095*	0.034***	0.022***	0.591***
	(-2.424)	(-0.260)	(2.997)	(1.728)	(2.832)	(3.398)	(3.135)
R.o.OECD	0.011	-0.032	0.003	-0.151*	0.008***	0.001	0.161
	(0.077)	(-0.519)	(0.637)	(-1.901)	(2.744)	(0.595)	(1.554)
R.o.OECD · (2007–2014)	-0.582**	-0.100	0.007	0.193**	0.022**	0.014***	0.446**
	(-2.323)	(-0.695)	(0.931)	(2.217)	(2.397)	(2.693)	(2.312)
N	152	152	152	152	152	152	152
R^2	0.220	0.061	0.322	0.077	0.506	0.482	0.233
P1: base	0.154	-0.014	0.004	0.021	0.003	0.001	-0.169
P1: EU15	0.115	-0.216	0.011	-0.035	0.039	0.003	0.083
P1: EEU	-0.007	-0.064	-0.003	0.009	0.008	0.001	0.055
P1: R.o.OECD	0.165	-0.046	0.006	-0.130	0.011	0.002	-0.008
P2: base	0.420	0.004	0.003	-0.008	0.020	0.009	-0.448
P2: EU15	-0.533	-0.011	0.029	0.055	0.114	0.061	0.285
P2: EEU	-0.457	-0.112	0.037	0.076	0.060	0.030	0.367
P2: R.o.OECD	-0.151	-0.128	0.013	0.033	0.050	0.025	0.159
p-value: P1: EU15–EEU	0.416	0.183	0.118	0.050	0.000	0.056	0.784
p-value: P1: EU15–OECD	0.710	0.036	0.343	0.187	0.002	0.731	0.174
p-value: P1: EEU–OECD	0.256	0.872	0.321	0.054	0.341	0.189	0.543
p-value: P2: base–EU15	0.000	0.752	0.000	0.067	0.000	0.000	0.000
p-value: P2: base–EEU	0.001	0.615	0.002	0.024	0.001	0.001	0.000
p-value: P2: base–OECD	0.007	0.314	0.151	0.239	0.001	0.004	0.000
p-value: P2: EU15–EEU	0.748	0.669	0.498	0.429	0.023	0.040	0.331
p-value: P2: EU15–OECD	0.045	0.402	0.058	0.356	0.004	0.012	0.293
p-value: P2: EEU–OECD	0.274	0.951	0.062	0.121	0.472	0.443	0.113
p-value: P1–P2 base	0.094	0.153	0.880	0.549	0.000	0.001	0.064
p-value: P1–P2 EU15	0.000	0.005	0.005	0.000	0.001	0.000	0.002
p-value: P1–P2 EEU	0.073	0.850	0.003	0.014	0.000	0.000	0.007
p-value: P1–P2 OECD	0.106	0.567	0.359	0.025	0.000	0.000	0.172
p-value: DID EU15–EEU	0.480	0.335	0.137	0.487	0.351	0.054	0.406
p-value: DID EU15–OECD	0.152	0.076	0.294	0.332	0.133	0.014	0.796
p-value: DID EEU–OECD	0.672	0.903	0.036	0.207	0.361	0.346	0.387

Table C.13: Regressions: energy mix of final production
Note: t-statistics, based on robust standard errors, in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. *other n-ren* and *other ren* stand for the group of other non-renewable energy commodities, and other renewable energy commodities, respectively. The dependent variables measure the average annual change in the share (expressed in percent) of the respective energy commodity in the total energy mix. The panel below the R^2 reports the average annual change in the share of the energy commodity for each of the country-groups and periods. *P1* refers to the period 1997–2007, *P2* to the period 2007–2014. *base* stands for the base-group of non-EU non-OECD countries. The bottom panel reports a series of Wald-tests for differences across country-groups and/or periods. *DID* stands for difference-in-differences and tests for differences in the interaction-terms (i.e. differences in changes from P1 to P2 across country-groups). Cyprus is excluded from the regressions.

	non-renewable			**renewable**			
	fossil	nuclear	other n-ren	hydro	wind	solar	other ren
Constant	0.210**	-0.014	0.004**	0.045*	0.004***	0.001**	-0.250**
	(2.007)	(-1.147)	(2.453)	(1.663)	(5.624)	(2.431)	(-2.509)
2007–2014	0.247	0.012	-0.000	-0.071*	0.018***	0.010***	-0.216
	(1.569)	(0.897)	(-0.061)	(-1.913)	(4.833)	(4.258)	(-1.386)
EU15	-0.127	-0.194***	0.007*	-0.075**	0.032***	0.001	0.356***
	(-1.033)	(-5.013)	(1.915)	(-2.520)	(4.364)	(1.169)	(3.359)
EU15 · (2007–2014)	-0.844***	0.174***	0.018***	0.162***	0.052***	0.047***	0.390**
	(-4.455)	(2.920)	(2.994)	(3.860)	(2.631)	(3.713)	(2.364)
EEU	-0.221	-0.072	-0.005	-0.025	0.006***	-0.001	0.317**
	(-1.383)	(-0.703)	(-0.835)	(-0.759)	(6.726)	(-0.902)	(2.167)
EEU · (2007–2014)	-0.672**	-0.039	0.034***	0.124**	0.031***	0.020***	0.502**
	(-2.572)	(-0.185)	(3.164)	(2.380)	(3.103)	(3.620)	(2.437)
R.o.OECD	-0.045	-0.032	0.004	-0.156**	0.007***	0.001	0.221**
	(-0.326)	(-0.665)	(0.944)	(-2.376)	(2.747)	(0.467)	(1.990)
R.o.OECD · (2007–2014)	-0.522**	-0.080	0.007	0.201***	0.020***	0.013***	0.362*
	(-2.242)	(-0.623)	(0.828)	(2.817)	(2.615)	(2.727)	(1.932)
N	152	152	152	152	152	152	152
R^2	0.243	0.074	0.325	0.121	0.544	0.509	0.236
P1: base	0.210	-0.014	0.004	0.045	0.004	0.001	-0.250
P1: EU15	0.083	-0.207	0.011	-0.030	0.036	0.003	0.105
P1: EEU	-0.011	-0.085	-0.001	0.020	0.010	0.001	0.067
P1: R.o.OECD	0.165	-0.046	0.008	-0.110	0.010	0.002	-0.029
P2: base	0.457	-0.002	0.004	-0.026	0.022	0.011	-0.466
P2: EU15	-0.514	-0.022	0.028	0.061	0.106	0.060	0.280
P2: EEU	-0.436	-0.112	0.032	0.073	0.059	0.031	0.353
P2: R.o.OECD	-0.110	-0.115	0.014	0.020	0.049	0.024	0.117
p-value: P1: EU15–EEU	0.495	0.260	0.078	0.028	0.000	0.059	0.736
p-value: P1: EU15–OECD	0.458	0.008	0.612	0.188	0.001	0.565	0.029
p-value: P1: EEU–OECD_p	0.244	0.726	0.201	0.039	0.728	0.278	0.417
p-value: P2: base–EU15	0.000	0.661	0.000	0.004	0.000	0.000	0.000
p-value: P2: base–EEU	0.000	0.545	0.001	0.015	0.000	0.001	0.000
p-value: P2: base–OECD	0.003	0.346	0.107	0.112	0.000	0.004	0.000
p-value: P2: EU15–EEU	0.680	0.630	0.673	0.747	0.021	0.034	0.425
p-value: P2: EU15–OECD	0.017	0.467	0.090	0.041	0.003	0.008	0.107
p-value: P2: EEU–OECD	0.148	0.991	0.105	0.117	0.369	0.319	0.055
p-value: P1–P2 base	0.119	0.371	0.952	0.058	0.000	0.000	0.168
p-value: P1–P2 EU15	0.000	0.002	0.002	0.000	0.000	0.000	0.002
p-value: P1–P2 EEU	0.043	0.898	0.002	0.150	0.000	0.000	0.035
p-value: P1–P2 OECD	0.111	0.594	0.404	0.035	0.000	0.000	0.162
p-value: DID EU15–EEU	0.463	0.328	0.176	0.349	0.332	0.047	0.445
p-value: DID EU15–OECD	0.111	0.073	0.255	0.546	0.123	0.010	0.806
p-value: DID EEU–OECD	0.579	0.865	0.040	0.277	0.341	0.253	0.411

Table C.14: Regressions: energy mix of final consumption
Note: t-statistics, based on robust standard errors, in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. *other n-ren* and *other ren* stand for the group of other non-renewable energy commodities, and other renewable energy commodities, respectively. The dependent variables measure the average annual change in the share (expressed in percent) of the respective energy commodity in the total energy mix. The panel below the R^2 reports the average annual change in the share of the energy commodity for each of the country-groups and periods. *P1* refers to the period 1997–2007, *P2* to the period 2007–2014. *base* stands for the base-group of non-EU non-OECD countries. The bottom panel reports a series of Wald-tests for differences across country-groups and/or periods. *DID* stands for difference-in-differences and tests for differences in the interaction-terms (i.e. differences in changes from P1 to P2 across country-groups). Cyprus is excluded from the regressions.