Paying the carbon price

An input-output perspective on the carbon emission trade balance for rural growth

Final Version

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Abstract

Within the EU, rural regions have become important drivers of growth. While the EU encourages rural growth, it has also committed to strong carbon emission reduction targets. This research attempts to uncover the emissions that are embedded in rural growth. In order to do so, we use a unique regional input-output dataset for NUTS-2 regions in 25 EU countries, that allows us to find the change in emissions in rural production and consumption between 2000 and 2007, as well as the drivers of that change. We find that production-based emissions have increased more strongly in the rural regions than in the intermediate or urban regions. Similarly, consumption-based emissions for rural regions have increased by 23% compared to 18% and 15% for intermediate and urban regions respectively. As a result, the emission trade balance has decreased for all three types of regions, but mostly in rural regions. The results indicate that this is not due to an increase in per capita rural consumption, but rather due to different preferences in consumption.

Keywords: rural growth, production-based emissions, consumption-based emissions, environmentally extended regional input-output tables, emission trade balance

1. INTRODUCTION

Anthropogenic climate change is primarily driven by carbon dioxide emissions that follow the burning of fossil fuels, contributing nearly 78% of the increase in total greenhouse gas (GHG) emissions between 1970 and 2010 (IPCC, 2015). Economic growth and population growth are the most important causes of the increase in these anthropogenic CO_2 emissions. While climate change is still disputed, there is a global consensus that we need to find ways to reduce GHG emissions in order to preserve the earth for future generations. This consensus resulted in the Kyoto Protocol and Paris Agreements, as well as other emission reduction targets, that attempt to reconcile the need for economic growth on the one hand and the need to reduce emissions on the other hand. The European Union has committed to reducing its GHG emissions to 20% below the emission levels of 1990 as part of the Europe 2020 strategy, and aims to realize this reduction at the subnational level (European Commission, 2011; 2016).

Furthermore, there is a burgeoning awareness that the strongest growth rates do no longer occur in the urban areas, but that primarily rural or intermediate regions are becoming the primary drivers of growth (see for instance Broersma & Van Dijk, 2008, and the OECD, 2009). Economic growth is commonly associated with increased emissions, because of increases in total output and, more indirectly, because of increases in per capita consumption that result from this economic growth. The EU has also committed to rural growth in its rural development policy agendas. The question then arises whether we can reconcile growth in the rural regions with reductions in carbon dioxide emissions. Or, to put it differently, has growth in rural regions in the EU been underpinned by large emissions, or has it been relatively clean? As of yet, this has not been measured empirically, and this paper will be the first to do so.

To that end, this paper exploits a unique dataset with input-output data for all NUTS-2[1] regions in 25 countries of the European Union (regional data for Bulgaria, Croatia and Romania are not available) to assess whether growth in primarily rural regions comes with an increase in emissions, or whether rural growth takes place without a concomitant increase in emissions. Furthermore, structural decomposition analysis will shed light on the sources of changes in emission coefficients in these regions. We distinguish nine of these sources: population growth; changes in emission coefficients per unit of output, which essentially represents cleaner production processes; changes in technical intermediate input coefficients; increases in import; the increase in the total per capita final demand volume; changes in the composition of consumption, investment and export patterns; and finally, changes in direct emissions by households. This will allows us to disentangle the contributions of each of these nine sources on the changes in emissions for the rural and intermediate regions.

The remainder of the paper is organized as follows. Section 2 provides a brief theoretical background on rise of rural and intermediate regions as the drivers of economic growth, as well as an overview of different emission accounting measures, and provides a conceptual model for this research. Section 3 describes the structure of the data available, as well as the methodology that we employ to answer the research question. Section 4 provides the results, while section 5 discusses the findings and suggests avenues for further research. Furthermore, a reflection has been attached as a separate document to this paper. This reflection contains a discussion on how assumptions and limitations that underlie this paper, as well as some of the choices made, may have influenced the results.

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[1] NUTS is an abbreviation that stands for Nomenclature of Territorial Units for Statistics. The NUTS classification has been created by Eurostat in order to produce regional statistics for the European Community, and has been revised at many points throughout since its inception in the 1970s (Eurostat, s.d.).

2. THEORETICAL FRAMEWORK

2.1 Changing patterns of economic growth: from urban to rural

The location of economic growth and activities are at the core of economic geography. The general consensus is that, throughout history, there is some clear-cut link between urbanization and productivity. We can already see this link in the ancient civilizations that often grew around a central, urban area that prospered, because increased economies of scale allowed inhabitants of these urbanities to take on more specialized roles. This link between urbanization and economic performance continued far into the 20th century (McCann, 2013). As a result of this understanding, a space-neutral perspective on regional development developed, which is often equated to the World Bank approach. The underlying argument of this World Bank approach is '…that promoting factor mobility to urban concentrations is the optimal development model for most countries' (McCann, 2013, p. 358).

However, the negative effects of congestion seem to have begun to outweigh the benefits from agglomeration from the late 1990s onward. Broersma & Van Dijk (2008) found that non-core regions in The Netherlands grew faster than core regions between 1995 and 2002. The OECD (2009) found similar evidence for other European countries. While cities still play a crucial role in economic development within countries, for instance within the BRIICS[2] countries, the location of growth shifts towards these non-metropolitan, non-core areas. In fact, the importance of small and medium-sized cities has become a key feature of the European Union (Barca et al., 2012). From the 2000s onward the predominantly rural or intermediate regions have driven economic growth, rather than the large cities (OECD, 2011; McCann, 2013). McCann & Acs (2011) illustrate this finding by demonstrating that the largest cities are no longer in the richest countries. Apparently, the World Bank perspective that promotes urban growth and exploitation of agglomeration economies without taking the size of the agglomeration and other contextual factors account seems not fully adequate to explain the location of economic growth.

As a response to the space-neural perspective on growth, the place-based approach puts the interaction between institutions and geography at its core. This approach contends that the entire urban and regional system (including the smaller and more peripheral areas) drives growth, rather than merely the cities at the top of the urban hierarchy (Barca et al., 2012). This perspective corresponds to the available data: a report by the Eurostat (2017) demonstrates that between 2000 and 2010 the gap between urban regions on the one hand and intermediate and rural on the other decreased. The same report also finds that GDP has increased more strongly in the rural and intermediate areas than in the urban areas. Similarly, Dijkstra and al (2015) find that the speed of this convergence has been exacerbated since the start of the Financial Crisis. Therefore, the available evidence suggests that rural and intermediate regions are catching-up to the urban areas since the start of the 21st century.

There are multiple perspectives on the mechanisms through which this catching-up occurs. Broersma & Van Dijk (2008) point to congestion effects in urban areas that hinder growth. Furthermore, neoclassical models dictate that capital-labour ratios will converge between regions, which implies that rural regions will grow at a quicker pace than urban regions. Gennaioli et al. (2013) suggest that, in the medium- to long-run, convergence between region occurs at a speed of 2.5% per year. Other authors point to the role of higher start-up rates (Delfmann et al., 2014), Cohesion Policy (Gagliardi & Percoco, 2014) or the historical architectural make-up of European cities that constrains economic growth (in line with Ashworth & Tunbridge's (2000) tourist-historic city concept).

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[2] Brazil, Russia, India, Indonesia, China and South-Africa

This is not to say that all rural regions outperformed the urban areas: the picture is complicated, and regional growth depends on the balance between a large number of factors. This complicated picture lies at the core of the place-based approach and the New Economic Geography, the latter considering the location of growth as a result of centrifugal and centripetal forces (Krugman, 1991). However, the highest growth rates since the start of the millennium have generally been realized by rural regions, and not by the cities.

Primarily rural regions tend to derive a relatively large proportion from their value added from the primary and secondary sector (European Union, 2017). While improved technology, reductions in energy use, policy measures and increased awareness have made a (substantial) contribution to EU-wide decreases in emissions, the primary and secondary sectors of the economy are still more energy intensive than the tertiary sector. As a consequence, these sectors emit more CO_2 than the tertiary sector (Van Rossum & Schenau, 2010). If the growth of rural and intermediate regions does to a large extent result from growth in these primary and secondary sector activities, then we can assume that growth in these regions comes at the price of a concomitant large increases in total emissions. However, this assumption has never been tested empirically before this article.

2.2 Environmental Accounting

There are two mainstream perspectives on measuring the emissions of a country or region. The first measure is a production-based emission accounting measure (PB), which looks at all the emissions that have been generated by the activities that take place in that region or country, regardless of who consumes that activity. The second measure is consumption-based emission accounting (CB), which measures the emissions that have been emitted to satisfy all final demand within a region, regardless of the location of those emissions. International emission trade constitutes the difference between these two measures (Dietzenbacher et al., 2012). Afionis et al. (2017) argue that reduction of PB emissions, and not of CB emissions, is generally at the centre of climate policy arrangements.

There are some arguments against the use of PB measures. Peters (2008) points to the emissions associated with international transportation, which cannot be attributed to any country or region in PB measures. In similar fashion, Peters (2008) and Afionis et al. (2017) make the important point that PB accounting is not able to capture ‘carbon offshoring’ (Aichele & Felbermayr, 2012) or ‘carbon leakage’ (Peters & Solli, 2010). Indeed, Aichele and Felbermayr find that imports to countries that have signed the Kyoto Protocol contain approximately 8% more carbon than those of countries who have not committed to the protocol. The strictly territorial perspective on emissions in the PB perspective prompts countries to focus on reducing emissions within their territory, and not on reducing emissions altogether (Andonova & Mitchell, 2010).

The downsides against a shift towards CB measures are listed in Peters (2008): it requires more data, it represents a shift from one extreme (PB) to another extreme (CB), while ideally both are taken into account; and finally, acting upon CB measures needs to go beyond the scale of countries as a political entity, which will at least be a politically sensitive and contentious issue. Yet, in policy practice emissions and emission mitigation strategies and targets are discussed solely in PB terms (Afionis et al., 2017). Under the Kyoto Protocol, and in a more bottom-up fashion under the Paris Agreements as well, emission reduction is exclusively considered at the point of production.

Despite the limitations of PB measures, using them is common and there are merits to the use of PB measures. After all, emissions are emitted at the point where they are produced, and reducing emissions can only occur at these points of production. While CB emission statistics are better poised to appoint responsibility, and perhaps divide the costs of reducing emissions, understanding the drivers of changes in PB emissions is equally crucial in bringing down emissions. Therefore, an understanding of PB measures can help estimate where action needs to take place, or the costs that a region might incur as a result of emissions. For instance, according to a study by the European Environmental Agency (EEA, 2014), production in the new member states of the European Union tends to be more polluting than in the older member states. As a result of the air pollution that is emitted in the production process, these member states can expect higher damage costs in the years to come. While consumption in other countries may be to blame for these damage costs, action needs to take place in these new member states.

2.3 Conceptual Model

Based on the previous sections, we conceptualize the following relations for this research. Output growth in a region has two direct consequences that are relevant for this research: on the one hand it will increase consumption, both domestic and foreign (i.e. outside the region of production); on the other hand, it will lead to an increase in domestic and foreign emissions. However, the extent to which productivity growth increases domestic emissions depends on the emission intensity of the production process, and on regional specialization, i.e. the sectors and activities in which a region specializes.

As a result, there are two main relationships of interest for this paper: the first relationship is that regional growth increases the regional production-based emissions. Emission reduction strategies aim to reduce these PB emissions, while region growth strategies aim to increase regional production. These strategies can only be reconciled under relatively strict circumstances relating to emission intensity, specialization patterns and economies of scale. The second relationship is that productivity growth within a region increases regional income: economic theory dictates that part of income will be spent on consumption. As a result, a region's consumption-based emissions will also increase, although the extent depends on the structure of that consumption. Similarly, there exists a certain feedback relationship between production and consumption, where increased consumption can spur increased production within a region, depending on the extent to which people consume locally produced goods. When increases in local consumption induce an increase in local production, local PB emissions will increase as well.

We hypothesize that PB emissions will have increased strongly in the primarily rural regions, if their economy has indeed grown faster and if rural growth has been based in the more polluting sectors of the economy. We also hypothesize that rural output growth will be *dirtier* than urban output growth, as the latter is more grounded in tertiary sector activities and the former is more grounded in primary and secondary activities. Whether the trade balance for rural regions will have increased or decreased, will depend on the extent to which the output growth has spurred a concomitant consumption growth, as well as taste: will rural residents tend to consume more products that require a lot of CO_2 to produce or will they consume more services and other activities that are relatively clean?

3. EMPIRICAL STRATEGY

This extensive section will lay out the methodological approach of this thesis, as well as describe the data that will be used to analyse the research questions. Since the regional input-output data is available at the NUTS-2 level, we will need to develop criteria to classify NUTS-2 regions as urban, rural or intermediate. Section 3.1 will describe the urban-rural typology for NUTS-2 regions. Section 3.2 describes the sources and structure of input-output data, as well as the aggregation scheme that is necessary to combine global and regional input-output data. Section 3.3 provides the methodology for analysing regional changes in productivity, consumption, production-based emissions and consumption-based emissions. Furthermore, section 3.4 gives the decomposition equation that we will use to analyse the determinants of changes in emissions in the NUTS-2 regions. Finally, there are some assumptions and limitations that underlie this research. Some of these will be discussed implicitly in this chapter. However, the reflection contains a more explicit discussion of these assumptions and limitations.

3.1 An urban-rural typology for NUTS-2 regions.

In order to apply an input-output framework to the research question, we need to establish which regions we consider to be intermediate regions. The most common starting point is the urban-rural typology that has been published by Eurostat (2010). They have classified each NUTS-3 region in the European Union as either predominantly rural, predominantly urban or intermediate, based on three steps (Dijkstra & Poelman, 2011). Firstly, Eurostat creates grid cells of 1 km^2. They calculate the rural area population based on the population density in these grid cells plus the population size of adjacent grid cells (for a more extensive explanation, see Eurostat, 2017). Secondly, a NUTS-3 region is classified as predominantly rural if more than 50% of the total population of the region lives in predominantly rural grid cells, while it is classified as intermediate when the rural population lies between 20% and 50%. Finally, a region is classified as urban when the share of the population in rural grids is less than 20% or when the region contains a city of more than 500.000 inhabitants that represent at least 25% of the population.

We follow the method that has been proposed by De Beer et al. (2014), who have developed a method to aggregate the Eurostat classification of NUTS-3 regions to the NUTS-2 level. While it is true that an urban-rural typology at the NUTS-2 level would hide differences that exist between NUTS-3 regions, it can be useful to create a classification for the NUTS-2 level when the data is not available at any lower levels of disaggregation. Their method attempts to mimic the method that has been employed by Eurostat to a large extent. The urban-rural typology for NUTS-2 regions, proposed by De Beer et al., is based on the difference between the proportion of the population of a NUTS-2 area that lives in a primarily rural NUTS-3 region and the proportion that lives in a primarily urban NUTS-3 region. When the difference exceeds a certain threshold value, the region is either considered primarily rural (if the difference exceeds the threshold in the direction of the primarily rural) or primarily urban. These threshold values are determined in such a way that the proportion of NUTS-2 regions that is considered primarily urban roughly corresponds to the proportion in the definition by Eurostat: concretely, this boils down to a threshold value of 40% for the primarily urban NUTS-2 regions and a threshold value of 33% for the primarily rural NUTS-2 regions. Imagine a NUTS-2 region where 52% of the population lives in primarily urban NUTS-3 regions and 10% in primarily urban NUTS-3 regions: this region would be classified as primarily urban, since the difference exceeds the threshold value of 40%.

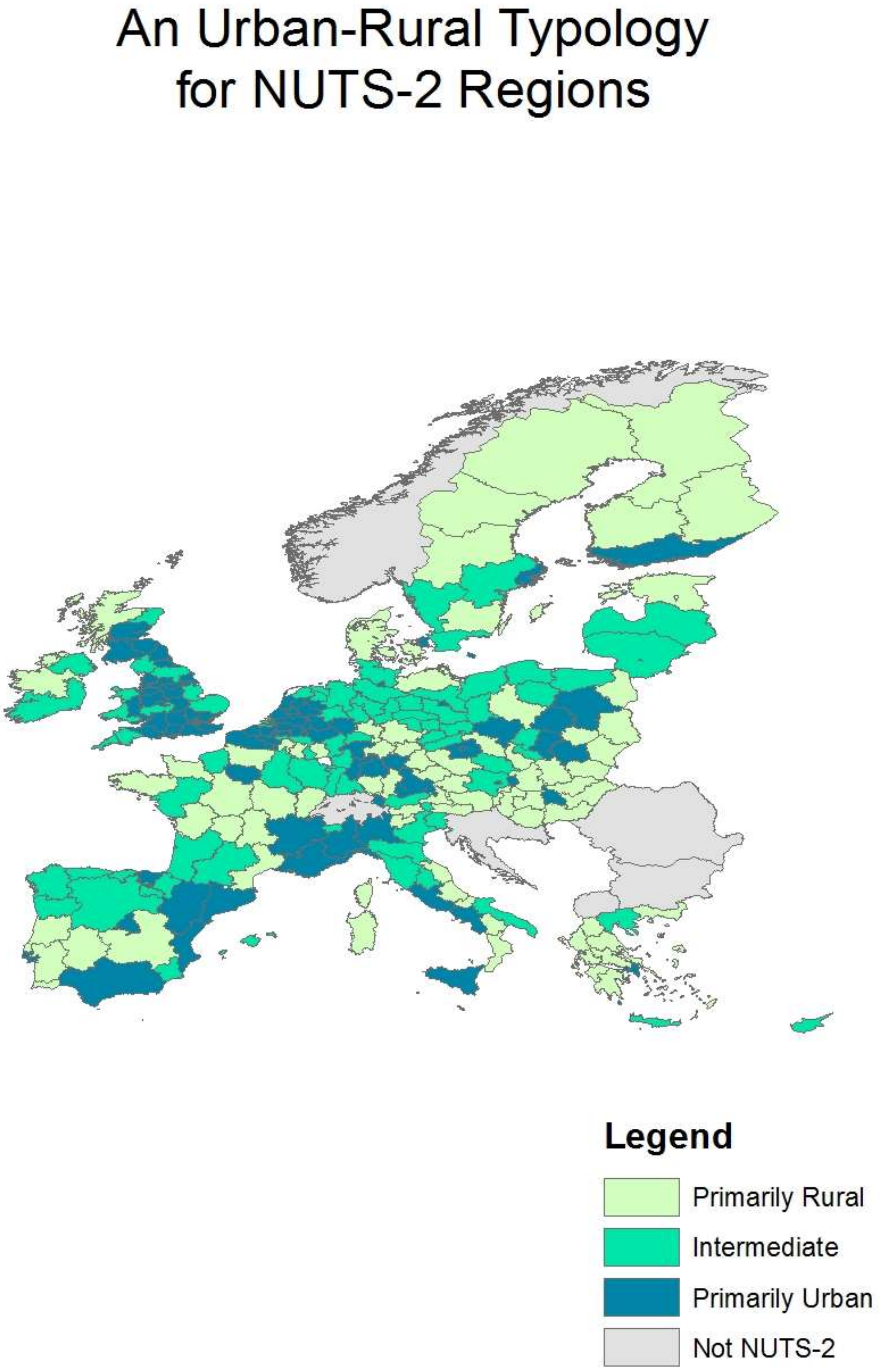
Furthermore, and along the lines of the Eurostat classification, De Beer et al. reclassify all intermediate regions as primarily urban if the NUTS-2 region satisfies two criteria: it contains a city of more than 500.000 inhabitants and the share of the population that lives in a primarily urban NUTS-3 region exceeds the share that lives in a primarily rural NUTS-3 region. This additional criterion has led to a further reclassification of 10 intermediate regions.

Next, the Eurostat classification applies to the 2010 edition of the NUTS classification. However, our input-output data has been gathered for NUTS-2 regions as they were classified in the 2006 edition. Therefore, we had to find a way to convert the urban-rural typology from the NUTS-2010 classification to the 2006 edition. In order to do so, we followed the conversion that has been proposed by López-Cobo (2016). The result is a collection of 250 NUTS-2 regions that have been classified as either of the three categories: 82 of these are primarily rural, 74 intermediate, and the remainder classified as primarily rural. Map 1 shows the spread of rural, intermediate and urban NUTS-2 regions across Europe.

3.2 Input Output Data

This research will use three different datasets to analyse the emission intensity of the shift of economic activities from Western Europe to the Eastern European member states. The first of these is the World Input Output Database (WIOD), which is freely accessible and has been created by Timmer et al. (2015). There have been two releases of the WIOD: we will use the 2013 release, which is the older of the two. This release contains annual input-output data for the period 1995-2009 for 40 countries, including all 27 member states of the European Union up until 2009, and for a region called ‘Rest of the World’. The World Input Output Tables (WIOT) have been constructed by combining national input-output tables and bilateral international trade data (Los et al., 2015). The 2013 release of the WIOD contains input-output data for N industries and S countries, where $n = \{1,35\}$ and $s = \{1,40\}$, whereas the 2016 release (the newer release) contains data for 43 countries and 56 industries and runs from 2000-2014. The reason we will use the 2013 rather than the 2016 release is that, while both releases have accompanying socio-economic accounts, the 2013 release is the only release that is compatible with the environmental accounts, which are the second dataset we will use. These environmental accounts will provide the emissions along the entire value chain that are involved in the production of the output of an industry of any of the countries in the WIOD.

Table 1 provides the structure of a WIOT with S industries and N countries. Starting in the top left, the (SN x SN) matrix $\mathbf{Z}$ contains all submatrices $\mathbf{Z}_{11}$, $\mathbf{Z}_{1N}$, $\mathbf{Z}_{NN}$ and represents the monetary value of intermediate deliveries. The element z_{ij} in submatrix $\mathbf{Z}_{12}$ represents the deliveries from industry i in country 1 that are sold to industry j in country 2. While the element z_{ij} represents the monetary value of the flow of goods from i to j, the money flows from j to i. Therefore, any row in this matrix $\mathbf{Z}$ represents the intermediate deliveries from an industry to all industries in all countries.



Map 1 – Urban-Rural Typology for NUTS-2 regions. The threshold value for primarily rural regions is 33%, and for primarily urban regions 40%

	Intermediate inputs			Final Demand			Output
	Country 1	*Country 2*	*Country N*	*Country 1*	*Country 2*	*Country N*	
Country 1	$\mathbf{Z}_{11}$	$\mathbf{Z}_{12}$	$\mathbf{Z}_{1N}$	$\mathbf{F}_{11}$	$\mathbf{F}_{12}$	$\mathbf{F}_{1N}$	$\mathbf{x}_1$
Country 2	$\mathbf{Z}_{21}$	$\mathbf{Z}_{22}$	$\mathbf{Z}_{2N}$	$\mathbf{F}_{21}$	$\mathbf{F}_{22}$	$\mathbf{F}_{2N}$	$\mathbf{x}_2$
Country N	$\mathbf{Z}_{N1}$	$\mathbf{Z}_{N2}$	$\mathbf{Z}_{NN}$	$\mathbf{F}_{N1}$	$\mathbf{F}_{N2}$	$\mathbf{F}_{NN}$	$\mathbf{x}_N$
Value Added	$(\mathbf{w}_1)'$	$(\mathbf{w}_2)'$	$(\mathbf{w}_N)'$				
Total Output	$(\mathbf{x}_1)'$	$(\mathbf{x}_2)'$	$(\mathbf{x}_N)'$				
Emissions	$(\mathbf{c}_1)'$	$(\mathbf{c}_2)'$	$(\mathbf{c}_N)'$				

Table 1 - A standard world input output table. Adapted from Los et al. (2015).

Moving to the right, the matrix **F** represents the deliveries to the final demand categories. There are C final demand categories, where in the 2013 release $c = \{1,5\}$ which means there are five final demand categories: consumption by households (1), by NGOs that serve households (2) and by governments (3); the last two categories are gross fixed capital formation (4) and changes in inventories and valuables (5). The (SN x CN)-matrix **F** contains all (C x N)-submatrices $\mathbf{F}_{11}$, $\mathbf{F}_{1N}$, $\mathbf{F}_{NN}$, where each element f_{ij} represents deliveries from industry i to final demand category j. Furthermore, the (1 x SN) row vector $(\mathbf{w}_1)'$ represents the value added for each industry: in the most stylized example this vector simply provides the difference between an industry's total output and expenditure on intermediate inputs.

The (SN x 1) column vector **x** represents the total output or total sales for each industry, so that each element x_i represents the total sales for industry i which is the sum of all intermediate sales from that industry to other industries and to all final demand categories. In similar fashion, the (1 x SN) row vector $(\mathbf{x})'$ represents the sum of all intermediate inputs plus the value added of an industry. Since input-output tables are based on double-entry bookkeeping, $x_i = (x_i)'$ (Timmer et al., 2015). Or, to put it in words, for every industry the sum of its inputs equals the sum of its sales.

The part of the input-output table that has been described up until this point is contained in a standard input-output table. When we attach the environmental accounts to this standard IO-table, we add a (1 x SN) row vector $(\mathbf{c})'$ to the bottom of the table. Each element $(c_j)'$ represents the CO_2 emissions that are required to produce the total output of that industry j. While emission data is available up to 2009, the data for 2008 and 2009 are strongly influenced by the Financial Crisis that has had an uneven impact across Europe: as such, we believe that using data for the time period 2000-2007 is justifiable.

The third dataset we will use in this research are the Regional Input Output Tables (RIOT). These tables provide input-output data for 25 of the 27 EU countries at the NUTS-2 level for 14 industries and 4 final demand categories. Only for Bulgaria and Romania is no regional data available. This RIOT spans the period 2000-2010. Apart from regional data, national data is available for 15 countries, including Bulgaria and Romania, and once again including a residual region 'Rest of the World': the availability of this national data in the RIOT allows us to capture intermediate deliveries from region A in Austria to China. The structure of the RIOT is similar to that of the structure described in figure 1. Furthermore, while the WIOT provides data for 35 industries, the RIOT only provides data for 14 industries. In order to be able to combine the WIOT and RIOT, we need to aggregate the 35 industries from the WIOT to the 14 industries from the RIOT so that the differences between the WIOT and RIOT, measured at the 14-industry level, is zero. Appendix 1 gives an overview of this aggregation. We had to create this aggregation scheme from scratch, since it is not yet available: in order to do so, we looked at countries that consist of a single NUTS-2 region. Aggregating country-level data from the 35 industries in WIOD to 14 industries should result in similar output levels as the 14 industries in the RIOT, since for these countries the country level equals that of the region. Appendix 2 provides examples for Luxembourg and Malta: for both countries, there is no difference between the total output level as provided in the RIOT and the output as aggregated from the WIOD. Therefore, the aggregation scheme holds.

A final feature of these datasets is that prices in the world input-output tables are expressed in current dollars, while the regional input-output tables are expressed in current euros. Therefore, we first convert all values to euros by using corresponding exchange rates. Subsequently, we follow Timmer et al. (2013) and Brakman & Van Marrewijk (2016) in deflating the input-output tables to constant prices by using a Eurozone GDP deflator[3]. As a result, all monetary values are converted to constant values of the euro in the year 2000.

3.3 Calculating emission production and consumption

The first step is transforming the input levels from the table to input coefficients, in order to the value of intermediate inputs or the CO2-emissions that are required to create one unit of an industry's product. Starting at the top-left again, we can transform the matrix **Z** into an (SN x SN)-matrix $\mathbf{A} = \mathbf{Z}(\hat{\boldsymbol{x}})^{-1}$, where in our case S represents the number of industries and $s = \{1,14\}$ and N is the number of regions. Each element a_{ij} gives the quantity of units from industry i that is required to produce one unit of output in industry j. In similar fashion, the vectors $\mathbf{v}' = \mathbf{w}'(\hat{\boldsymbol{x}})^{-1}$and $\mathbf{k}' = \mathbf{c}'(\hat{\boldsymbol{x}})^{-1}$ represent the value added generated per unit of output and the CO_2 emissions generated per unit of output.

Production-based measures are merely focusing on the sum of the emissions generated by all fourteen industries within a region. We can calculate $C = \sum_{j=1}^{S} k_{jn}$ for any region n, where C is a scalar that gives the total tons of emissions associated with the production in that region in any given year in the sample. Consumption-based measures look at the emissions that have been generated in order to satisfy a region's final demand. Here we can calculate a (SN x CN)-matrix **D**, where each element d_{ij} represents the emissions in a certain region that have been generated as a result of consumption of 'goods' from industry i by final demand category j. We can calculate this matrix $\mathbf{D} = \mathbf{k}'(\mathbf{I}-\mathbf{A})^{-1}\mathbf{F}$. Here the row vector $\mathbf{k}'$ represents the industry-specific emission coefficients, $(\mathbf{I}-\mathbf{A})^{-1}$ the famous Leontief inverse and **F** is the (SN x CN) matrix for total levels of final demand. Summing a (S x C) submatrix $\mathbf{D}_{NN}$ over both the rows and the columns gives the world-wide CO_2-emissions that have been produced as a result of a region's total final demand. Crudely, the difference between a region's production-based emissions and consumption-based emissions are its emission trade balance. When a region consumes more CO_2 than it produces, it is a net consumer of CO_2. On the other hand, a region is a net producer or net exporter of emissions when its production exceeds its consumption. Section 4.4 will discuss the regional emission trade balance of the NUTS-2 regions.

Finally, we have to make a relatively strict assumption in order to arrive at the regional emission coefficients. Since we have no emission data available at the regional level, but only at the national level, we have to assume that emission coefficients are equal for each industry in each region within a country. This means that, for instance, the production of one unit of agricultural output in German region 1 emits as much carbon dioxide as the production of one unit of agricultural output in region 2. Essentially, what we assume is that a firm within a certain industry uses the same technology and has similar energy requirements to produce one unit of output, which does not seem an unreasonable assumption.

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[3] As a practice, using a common GDP deflator is generally accepted, although it may not account fully for price changes in imported intermediate inputs. However, within the EU oil is generally imported, rather than produced domestically, and oil represents a substantial part of a country's consumption. Oil prices nearly quadrupled between 2000 and 2007: since GDP deflators do not take the price of imported oil into account, they tend to underestimate the changes in CPI when oil prices increase, and overstate changes in CPI when oil prices decrease

	Intermediate inputs			Final demand			Output
	Industry 1	*Industry 2*	*Industry S*	*C*	*V*	*E*	
Ind 1 *Ind 2* *Ind S*	z_{11} z_{21} z_{S1}	z_{12} z_{22} z_{S2}	z_{1S} z_{2S} z_{SS}	c_1 c_2 c_s	v_1 v_2 v_s	e_1 e_2 e_s	x_1 x_2 x_S
Ind 1 *Ind 2* *Ind S*	m_{11} m_{21} m_{S1}	m_{12} m_{22} m_{S2}	m_{1S} m_{2S} m_{SS}	c_{m1} c_{m2} c_{mS}	v_{m1} v_{m2} v_{mS}	e_{m1} e_{m2} e_{mS}	
Value Added	$(w_1)'$	$(w_2)'$	$(w_S)'$				
Total Output	$(x_1)'$	$(x_2)'$	$(x_S)'$				
Emissions	$(c_1)'$	$(c_2)'$	$(c_S)'$				

Table 2 – Reorganized RIOTs to correspond one of three super-regions. The matrix **M** represents imports from other regions, or intermediate deliveries from a non-super-region to a super-region.

3.4 Decomposing emission growth

In order to decompose the drivers of emission growth, we have to reorganize the data in such a way that they resemble a national input-output table rather than a global input-output table. Table 2 shows the structure of such a national input-output table. Since we attempt to decompose emission growth for three types of aggregate regions (i.e. all rural regions, all intermediate regions and all urban regions), we create three of these reorganized input-output tables. Here, we recognize three categories of final demand: domestic consumption by households and governments (*C*), domestic demand for investments and inventory changes (*V*), and exports to foreign industries and foreign consumption and investment demand (*E*).

In section 3.3 we defined the scalar of total emissions $CO2$ as the sum of all emissions associated with production plus the emissions that have been emitted directly by households. Therefore we can write $CO2 = C + HH_{dir}$ where all elements are scalars. We can rewrite the total emissions associated with production $C = \mathbf{kx}$, where **k** is a vector of emissions per unit of output per industry and **x** represents total output per industry. Similarly, in a static open demand-driven input-output model $\mathbf{x} = (\mathbf{I}-\mathbf{A})^{-1}\mathbf{f}$ (Dietzenbacher et al, 2007). Therefore, we can rewrite the function for total emissions as follows:

$$(1)\quad CO_2 = \mathbf{k}(\mathbf{I}-\mathbf{A})^{-1}\mathbf{f} + HH_{dir}$$

Furthermore, we follow Dietzenbacher et al. (2007) in redefining $\mathbf{A} = \mathbf{D}^{\mathbf{A}} \circ \mathbf{A}^{\mathbf{T}}$, where $\mathbf{A}^{\mathbf{T}}$ is the (14x14)-matrix with all technical input coefficients, i.e. the both domestic and imported input coefficients. In turn, $\mathbf{D}^{\mathbf{A}}$ represents the share of the technical input coefficients that are produced domestically. In similar fashion, we can write the final demand vector **f** as the sum of domestic consumption, domestic investment, and export demand, so that $\mathbf{f} = \mathbf{c} + \mathbf{v} + \mathbf{e}$. In line with Feng et al. (2015), we can also decompose the domestic final demands (which we call F) $F = (\mathbf{c_p} + \mathbf{v_p})F_pP$. Here P is a scalar that represents the total population, F_p is a scalar that represents total final demands per capita, and $\mathbf{c_p}$ and $\mathbf{v_p}$ are (14x1)-vectors that provide the shares of each industry in 1 average unit of domestic final demand[4]. In similar fashion, we can write $\mathbf{e} = \mathbf{e_p}E$, where E represents the total export volume and $\mathbf{e_p}$ the industry composition of

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[4] All elements of $\mathbf{c_p}$ and $\mathbf{v_p}$ sum up to 1, as they represent the shares of domestic demand for (domestic) production for each industry. For instance, c_2 represents domestic consumption demand for manufacturing output. If $c_2 = 0.2$, it means that for each dollar of final demand, the value of final demand for manufacturing output is 0.20 dollars.

one average unit of export demand. This decomposition allows us to capture the effects of population growth, consumption growth and changes in consumption patterns on the changes in total CO_2 emissions. Combining these definitions of **f**, we can rewrite $\mathbf{f} = (\mathbf{c}_s + \mathbf{v}_s)F_pP + \mathbf{e}_\mathbf{p}E$.. Consequently, we can write equation (1) as:

(2) $CO_2 = P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}E)$

Structural decomposition analysis allows us to find the contribution of each of these seven terms to the change in emissions between 2000 and 2007. Since equation (2) contains six multiplicative terms, there are 6! = 720 possible decomposition equations, which are all equally valid but yield different results (Dietzenbacher & Los, 1998). Therefore, we follow De Haan (2001, in Dietzenbacher et al., 2007), who suggests that the average of a decomposition equation and its mirror image closely approximates the average over all 720 possible decomposition equations. A multiplicative decomposition of equation 2 would look as follows:

(1) $\Delta CO_2 = \Delta P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}E) * P\Delta\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}E) * P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \Delta\mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}E) * P\mathbf{k}((\mathbf{I} - \Delta\mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}E) * P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)\Delta F_p + \mathbf{e}_\mathbf{p}E) * P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\Delta\mathbf{c}_s + \mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}E) * P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \Delta\mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}E) * P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)F_p + \Delta\mathbf{e}_\mathbf{p}E) * P\mathbf{k}((\mathbf{I} - \mathbf{D}^\mathbf{A} \circ \mathbf{A}^\mathbf{T})(\mathbf{c}_s + \mathbf{v}_s)F_p + \mathbf{e}_\mathbf{p}\Delta E)$

(2) $= (4.1) * (4.2) * (4.3) * (4.4) * (4.5) * (4.6) * (4.7) * (4.8) * (4.9)$

Therefore, the change in emissions can be expressed as the product of eight equations. The ratio between carbon dioxide emissions in 2007, call them M_1, and carbon dioxide emissions in 2000, M_0, can then be expressed as:

$$\text{(4.1)}\quad \frac{M_1}{M_0} = \frac{P_1\boldsymbol{k}_1((\mathbf{I}-\boldsymbol{D}_1^A \circ \boldsymbol{A}_1^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}{P_0\boldsymbol{k}_1((\mathbf{I}-\boldsymbol{D}_1^A \circ \boldsymbol{A}_1^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}$$

$$\text{(4.2)}\quad = \frac{P_0\boldsymbol{k}_1((\mathbf{I}-\boldsymbol{D}_1^A \circ \boldsymbol{A}_1^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_1^A \circ \boldsymbol{A}_1^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}$$

$$\text{(4.3)}\quad = \frac{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_1^A \circ \boldsymbol{A}_1^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_1^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}$$

$$\text{(4.4)}\quad = \frac{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_1^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}$$

$$\text{(4.5)}\quad = \frac{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_1+(\boldsymbol{e}_iE_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_0+(\boldsymbol{e}_iE_1))}$$

$$\text{(4.6)}\quad = \frac{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_1+\boldsymbol{v}_1)F_0+(\boldsymbol{e}_iE_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_1)F_0+(\boldsymbol{e}_iE_1))}$$

$$\text{(4.7)}\quad = \frac{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_1)F_0+(\boldsymbol{e}_iE_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_iE_1))}$$

$$(4.8) \quad = \frac{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_i E_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_0 E_1))}$$

$$(4.9) \quad = \frac{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_0 E_1))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_0 E_0))}$$

In any of the above equations, the subscript 1 refers to the year 2007 and the subscript 0 to the year 2000. In the mirror image of the first of these nine equations all subscripts are set to 0, except for the term that varies. The mirror images for equation (4.1) and (4.2) are given in equations (4.1a) and (4.2a), the other mirror images can be derived by the same method.

$$(4.1\text{a}) \quad = \frac{P_1\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_0 E_0))}{P_0\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_0 E_0))}$$

$$(4.2\text{a}) \quad = \frac{P_1\boldsymbol{k}_1((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_0 E_0))}{P_1\boldsymbol{k}_0((\mathbf{I}-\boldsymbol{D}_0^A \circ \boldsymbol{A}_0^T)^{-1}(\boldsymbol{c}_0+\boldsymbol{v}_0)F_0+(\boldsymbol{e}_0 E_0))}$$

In the decomposition equations (4.1) through (4.9), each equation captures the effect of the term that varies. Equation (4.1) captures the effect of population growth on emission changes, while equation (4.2) looks at changes in emissions per unit of output: this effect can be considered a technology effect, in the sense that it captures the emissions associated with the production of one unit of output. However, interpretation of this emission coefficient vector should take place with caution. After all, the emission coefficients are emissions associated with one *monetary* unit of output. While the use of a GDP deflator ensures that prices are constant for the year 2000, this is an economy-wide deflator. An economy-wide deflator is unable to account for heterogeneity in price increases. The consequence is that, when prices of manufacturing output in Greece decrease strongly between 2000 and 2007, while the prices of other outputs in Greece increase, the use of a common deflator is unable to correctly deflate the prices of manufacturing goods. In this case, one unit of monetary output of 2007 is not comparable to one unit of monetary output of 2000, when the former may represent 4 products and the latter only 2 products. So, even when increased technology allows for lower emissions for the production of one product, emissions per monetary unit of output may increase even in the context of better technology. While this issue is endemic to input-output analysis and to the use of GDP deflators in general, it should be stressed that economy-wide deflators are by definition unable to account for idiosyncrasies.

Moving on, term (4.3) accounts for changes in the extent to which inputs are produced domestically (i.e., within one of the three super-regions) or imported, while term (4.4) captures changes in intermediate input coefficients. The terms (4.5) through (4.9) account for changes in final demand: equation (4.5) looks at changes in the per capita volume of domestic final demand. Equations (4.6) and (4.7) capture what Dietzenbacher et al (2007) call the *taste effect*, i.e. changes in the composition of domestic consumption and investment demand. Equations (4.8) and (4.9) captures changes in export demand, where (4.8) looks at changes in the composition of an average unit of export demand and (4.9) accounts for changes in the total export volume.

4. RESULTS

The previous section outlined the structure of the available data, and explained the methods that we have used in order to find out whether the growth in the rural and intermediate regions has been associated with a strong increase in emissions. This section provides the results of the analysis. Firstly, section 4.1 provides results on the catching-up process: how strong has the increase in production been in the rural, intermediate and urban areas during the period 2000-2007? And has there been a concomitant increase in consumption? Section 4.2 looks at the PB emission measures: to which extent have PB emissions increased in each of the three super-regions? Finally, section 4.3 discusses the emission trade balance. In order to establish a region's emission trade balance, we calculate a region's CB emissions, and subtract them from the region's PB emissions.

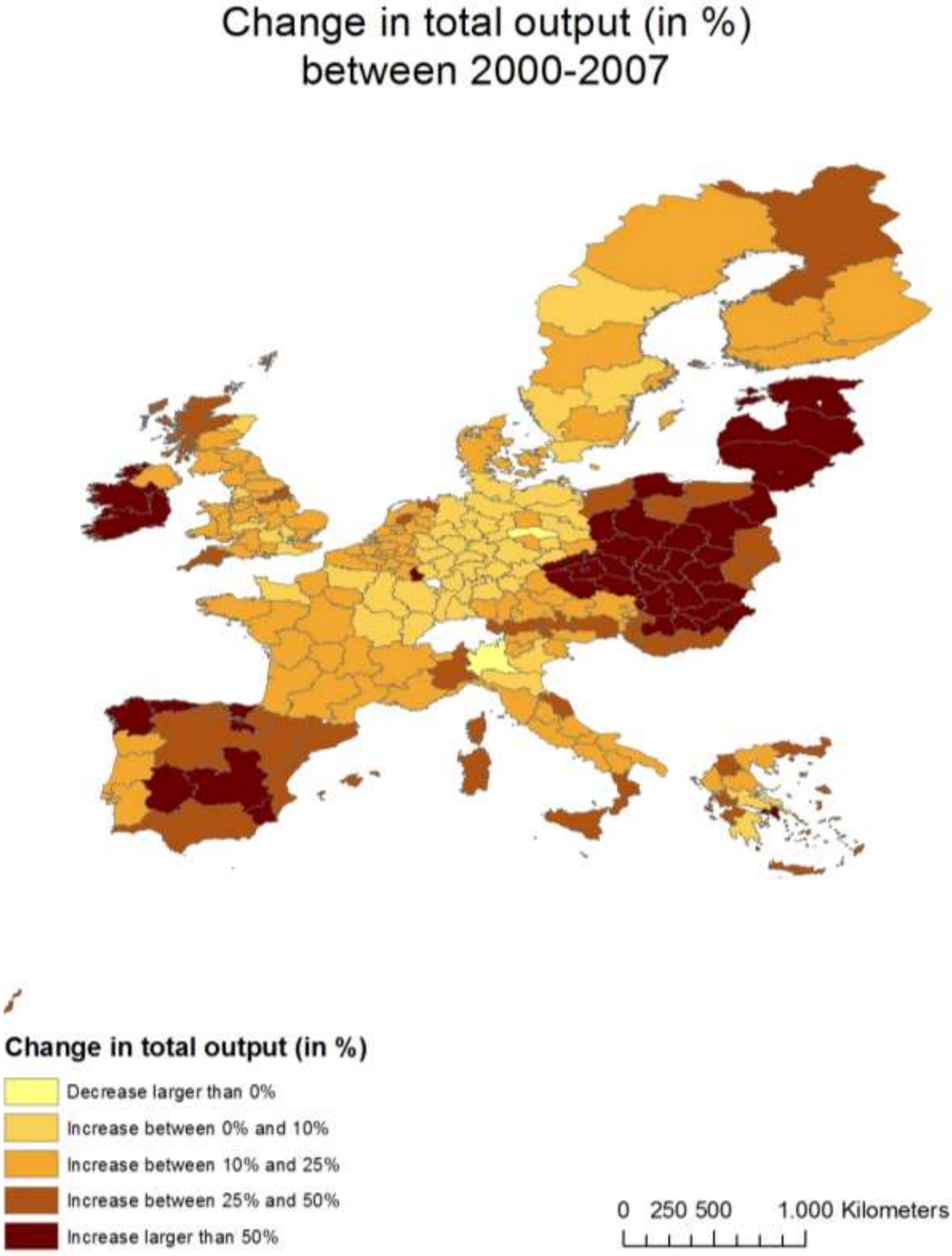
4.1 Catching-up of rural consumption and production.

Many authors and reports have emphasized the increasing importance of the rural and intermediate regions as drivers of economic growth, as we have discussed in section 2.1. Nonetheless, it is important to check whether our results reaffirm these findings. Since our input-output data relies on national accounts, as do most reports and authors, it would be remarkable when we could not reaffirm their findings, and indeed, we do. As table 3 demonstrates, the relative growth of total output **x** has increased more strongly in the primarily rural and intermediate regions. While absolute growth has been the strongest in the primarily urban NUTS-2 regions, the larger relative increase in the rural and intermediate regions indicates a catching-up process. The results for domestic consumption show a similar pattern: while the absolute increases were much higher in the primarily urban areas, the relative increase in domestic consumption has been slightly higher in the primarily rural areas.

Our results therefore confirm that growth in relative terms, both with regards to production and consumption has mainly occurred outside the urban regions. Map 2 shows the increase in output across the regions in the EU. The map clearly shows that output growth has mainly occurred in the new member states, as well as in Ireland and Spain. The most remarkable increases have occurred in the Slovakian regions: according to our data, total output of the Slovakian regions have nearly doubled in the period 2000-2007. While this increase may seem erroneous, OECD data (2018) confirms that Slovakian GDP has at least doubled in the first decade of the 21st century. The increase has also been strong in the Baltic States and Czech regions.

Changes in:	Total output (millions of €)	Total output (%)	Total domestic consumption (millions of €)	Total domestic consumption (%)
Primarily Rural	619 740	22.4%	299 317	20.6%
Intermediate	971 970	21.7%	302 120	16.4%
Primarily Urban	1 894 303	19.4%	806 986	16.9%

Table 3 - Changes in output and consumption for the primarily rural, intermediate and primarily urban regions in the period 2000-2007. Source: author's calculations.



Map 2 - Shows the percentage of increase of total output between 2000 and 2007 per NUTS-2 region. Source: Regional Input Output Database, author's calculations.

At the top of the relative output growth rankings, however, is the Spanish region ES21. The region ES21 reflects *Pais Vasco*, or the Basque country. The region's remarkable economic performance of the Basque region persisted even when the rest of Spain fell into economic downfall as the Financial Crisis struck. Cooper (2008) suggests that the Basque economic success is due to the fact that its economy is based on manufacturing, rather than the property and tourism industries that had fuelled growth in the other Spanish regions. This focus on manufacturing is also reflected in our data, as output growth largely occurred in *industry 8*, which represents the *other manufacturing* industry. Similarly, Martinez-Granado et al. (2012) demonstrate that the Basque region has a GDP/capita that is higher than the Spanish or EU average, and that this gap has increased during 2000 and 2010. They suggest that this is due to the region's specialization in those manufacturing sectors that are technologically intensive and therefore have a high productivity. The major player in this manufacturing industry is the Mondragon co-operative. For its business model and its resilience in the Financial Crisis Mondragon has received much praise in the press (Burridge, 2012; Rowe et al., 2017) and in academia (Errasti et al., 2003), although Cheney et al. (2013) argue that Mondragon experienced some financial distress after 2013. Since 2013 falls outside our sample period, this would not influence the Basque performance in our research anyway.

Conversely, we find that output growth has been the weakest in regions in Germany and the UK. One explanation might be that the use of a Eurozone deflator might have deflated the 2007 data too strongly, more than for any other region: the trajectory of the consumer price index (CPI) for the UK and Germany suggests that the (unavoidable) use of a Eurozone deflator has indeed understated British and German growth (World Bank, 2018). Nevertheless, data from OECD (2018) confirm that GDP growth in Germany and the UK has been lower than in most other European countries, such as Poland, Spain, Ireland and Greece. In absolute sense, productivity growth has been the strongest in the Southern European member states.

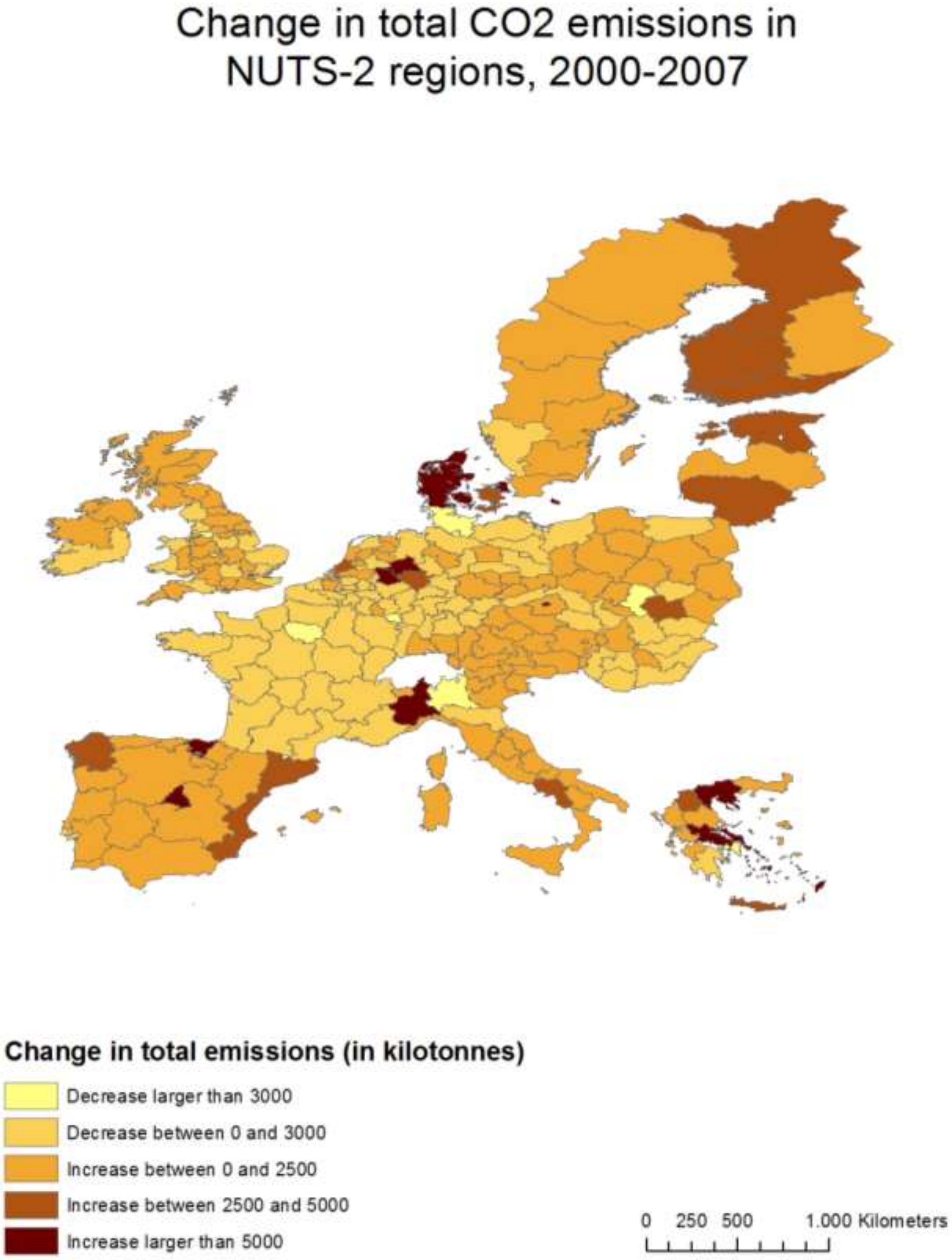
4.2 Changes in production-based emissions

The previous section demonstrates that growth has mainly occurred in the rural, and also in the intermediate, regions, rather than in the urban areas. Yet, so far, emissions that are part of the changes in production have been left out of the discussion. We can look at changes in emissions from a PB and a CB point of view. Looking at the former, we measure clean growth at the location where it has been emitted. Map 3 and 4 show the increase in total PB-emissions across NUTS-2 regions. In general, table 4 indicates that emissions have increased, regardless of whether a region is primarily rural or urban. Yet, the increase in total emissions has been the most pronounced in the primarily rural areas. While emissions have changed across the whole range of the three super-regions, map 3 clearly demonstrates that large differences between regions and countries.

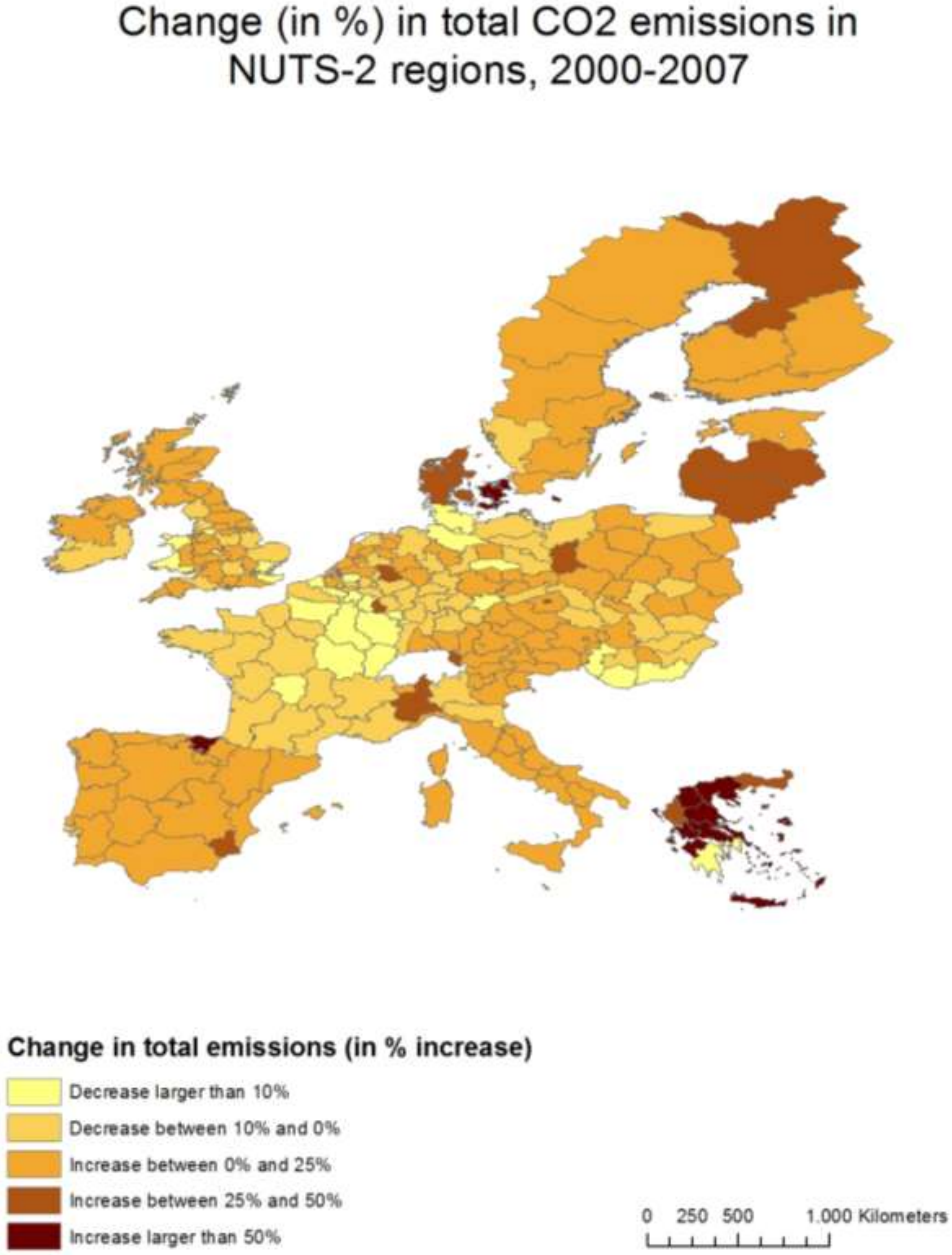
Change in:	Total emissions in production (kilotons)	Total emissions in production (relative)	Emissions in consumption (kilotons)	Emissions in consumption (relative)
Primarily Rural	57 886	10.20%	154 213	23.80%
Intermediate	39 200	4.65%	185 135	18.02%
Primarily Urban	58 320	3.20%	298 506	14.56%

Table 4 - Changes in total emissions between 2000 and 2007. The first two columns relate to PB emissions, the last two columns to CB emissions. Source: author's calculations.

In general, PB emissions have increased the strongest in Greek non-capital regions, and in Danish regions as well. The latter is remarkable, since Denmark has often received praise as a country that managed to reduce its per capita emissions (Danish Energy Agency, 2017; European Environmental Agency, 2017; Gerdes, 2015). A report by Nordic Energy Research (2012) suggests that the high Danish emissions are due to relatively carbon-intensive production of electricity, and the cold climate that increases the need for energy. However, absolute changes can only be interpreted sensibly in the context of the magnitude of total emissions: therefore, map 4 provides the relative changes. This map shows a more nuanced perspective. It also demonstrates that the large increase in production in the Basque country has been accompanied by a large increase in emissions: this had been expected, as Basque growth has been driven by the manufacturing and construction sector. It also demonstrates that PB emissions have increased in most regions in the EU.



Map 3 - Shows the change of PB-emissions in **kilotons** between 2000 and 2007 per NUTS-2 region. Source: Regional Input Output Database, author's calculations.



Map 4 - Shows the change of PB-emissions in **percentages** between 2000 and 2007 per NUTS-2 region. Source: Regional Input Output Database, author's calculations.

4.3 Emission-growth accounting

The previous section demonstrates that total PB emissions have increased in all three types of regions, but that this increase has been more pronounced in the rural areas. In similar fashion, an in-depth inspection of some regions learns that the increases in total emissions have been most severe in the Greek and Danish regions, as well as in Latvia and Lithuania. However, structural decomposition analysis is a more formal way to find the sources of the changes in emissions. More specifically, it allows us to disentangle the contribution of population, technology, trade patterns and the volume and composition of final demand to the increase in PB emissions[5].

Tables 5A through 5C in appendix 3 show the determinants of emission growth for the three super-regions, which have been calculated as the geometric averages of the two polar decomposition equations. Table 5, on the next page, displays the Fisher indices from tables 5A through 5C for an easier comparison: the rest of this section will discuss table 5. We find that the direction of the effects are similar across the three regions: if only population growth had occurred, and all other factors would have remained similar, emissions in the three regions would have increased slightly, although the magnitude of that increase would have been smaller in the rural than in the intermediate and urban areas. In similar fashion, the volume of exports has increased between 2000 and 2007, which has exerted an upward pressure on the total PB emissions. This effect is the strongest effect in all three super-regions, but has the largest effect in the primarily urban areas.

In fact, the contribution of the export volume for the urban areas is remarkably high: keeping the other parameters constant, the increase alone would have increased urban PB emissions by 53%. When we look at the data, we see that the export value for some industries in the urban areas has more than doubled, mostly in the construction and services industries, but in industry 2 – which contains, among others, the energy supply sector – as well. However, the increase in emissions that the export volume would have brought about in urban areas, is countered by the $\mathbf{A}^{\mathbf{T}}$ and **k**-effects. The former indicates that urban areas have changed the composition of their intermediate inputs. Since the $\mathbf{A}^{\mathbf{T}}$ effect has exerted a downward pressure on urban emissions, this implies that production of output in urban areas has relied increasingly on inputs from those sectors that are relatively non-polluting. To illustrate: industry 2, that contains the energy supply sector, is a relatively polluting industry. It might be that production in urban areas has become more energy efficient, thereby requiring less inputs from industry 2 and, as a result, the $\mathbf{A}^{\mathbf{T}}$ effect exerts a stronger, downward pressure on PB emissions. The **k**-effect, with a magnitude below 1, suggests that production overall has become cleaner. While the $\mathbf{A}^{\mathbf{T}}$**-**effect might represent a decrease in energy consumption in the urban production process, the **k**-effect might point towards cleaner energy production in general, which leads to a further decrease in PB emissions.

The effect of emissions per unit (**k**-effect) has been similar in the rural and intermediate areas. However, the upward pressure on PB-emissions by an increase in the export volume and the downward pressure by the $\mathbf{A}^{\mathbf{T}}$-effect have been much less pronounced in the rural, and especially in the intermediate areas. In rural areas, export volume alone would have increased emissions by 18% and export composition adds another 2.5%. Furthermore, the per capita final demand volume increased relatively strongly in rural areas compared to the other areas, which increased PB-emissions for rural areas even further. The composition of final demand did not have any substantial effect on rural emissions. For intermediate areas similar effects can be found, but the magnitude of these effects is lower.

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[5] While it is possible to decompose the CB emissions as well, the large number of negative values in the IO table with regards to direct imports to satisfy final demand renders the decomposition equation from this paper invalid. While there are algebraic techniques to work around this issue, these would go beyond my capabilities.

Finally, there seems to be no substantial *taste effect* for any of the three types of regions. Here we define the taste effect as the change in the composition of average units of consumption, investment or export. Only changes in the export patterns from rural areas and urban areas have exerted a somewhat substantial, positive effect of the total emissions of approximately 2.5%. Indeed, the share of exports from the rural areas has increased slightly for industries 2, 3, 5, 11 and 13[6], and industries 2, 5 and 11 are the three most polluting industries in the dataset for the rural areas. A weak *taste effect* compared to a *quantity effect* means that the effects of an increase in export volume are much larger than the effects of changes in the export composition, and that the effects of an increased final demand volume are much larger than the effects of changes in the composition of consumption and investment demand.

It is not possible to study the drivers of emission growth in the rural, intermediate and urban areas in any more detail by using this method. The results indicate that emission growth in the rural areas has been driven by increases in quantities, i.e. increases in the output volume and final demand volume, rather than the composition of export or final demand, or emissions per unit of output. For the intermediate areas all determinants contribute relatively little to the increase in total emissions, except the emissions per unit of output that have decreased substantially. For urban areas, the results indicate that the strong surge in emissions that has been brought about by an increase of the export volume has been counteracted by cleaner production and changing patterns of intermediate inputs.

Effect	**Notation**	**Primarily Rural**	**Intermediate**	**Primarily Urban**
Population size	P – effect	1.004	1.013	1.012
Emissions per unit	$\mathbf{k}$ - effect	0.842	0.824	0.825
Domestic share of production	$\mathbf{D^A}$ - effect	1.049	1.054	1.035
Intermediate input composition	$\mathbf{A^t}$ - effect	0.976	0.999	0.730
Per capita final demand volume	F - effect	1.048	1.036	1.035
Consumption shares	$\mathbf{c}$ – effect	1.006	1.001	1.005
Investment shares	$\mathbf{i}$ – effect	1.003	1.002	0.998
Export composition	$\mathbf{e}$ – effect	1.023	1.008	1.028
Export volume	E - effect	1.177	1.034	1.532
Product (1) – (9)		1.102	1.047	1.032

Table 5 – An overview of the Fisher indices from tables A-C in Appendix 3. Tables A-C provide the results from the Structural Decomposition Analysis for the primarily rural (table A), intermediate (table B) and primarily urban regions (table C). The Fisher index is the geometric average of the result from each equation (4.1)-(4.9) and the result from the corresponding mirror decompositions (4.1a)-(4.9a).

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[6] Industry 2 : mining, quarrying, energy supply
Industry 3 : food, beverages and tobacco
Industry 5 : coke, refined petroleum, nuclear fuel, chemicals, etc.
Industry 11 : transport, storage and communication
Industry 13 : real estate renting and business activities

	PB Emissions in 2000 (million tons)	PB Emissions in 2007 (million tons)	CB Emissions in 2000 (million tons)	CB Emissions in 2007 (million tons)
Primarily Rural	567.23	625.11	647.89	802.11
Intermediate	842.67	881.87	1027.25	1212.39
Primarily Urban	1821.12	1879.44	2050.21	2348.82

Table 6 - The magnitudes of PB and CB emissions in 2000 and 2007 for all here types of super-regions. For all three types of regions the CB emissions are higher than the PB emissions in both years. Source: RIOT, author's calculations.

4.4 Emission trade balance

Table 6 provides the magnitude of the PB and CB emissions in 2000 and 2007 for the super-regions. We have already discussed the PB emissions in the previous sections. This section will discuss the CB emissions, as well as the emission trade balance that can be calculated by means of these PB and CB emissions.

The last two columns of table 6 show that CB emissions have been somewhat higher in all three types of regions. This means that the trade balance for all three regions will be negative. Table 4 demonstrates that both PB emissions and CB emissions have generally increased in all regions. We have also seen that both PB and CB emissions have increased much stronger in the rural than in the urban regions in relative sense: therefore, if the magnitudes of consumption growth and production growth are relatively similar within a super-region, the emission trade balance should not change that much across rural, intermediate and urban regions. However, we have seen that production increase has been approximately three times as large as consumption terms when expressed in money terms. This would hint towards an increase in the trade balance: after all, production increased stronger than consumption. Yet, as table 7 demonstrates, the reverse is true. While the output growth has been stronger in all three super-regions, this did not lead to a very strong increase in the region's emissions. Tables 3 and 4 show that rural regions managed a 22% increase in the value of their output, while their PB emissions only increased by 10%. Conversely, the value of rural consumption increased by 20% while CB emissions increased by 22%. This might be because rural output growth may have been driven by sectors that are relatively non-polluting. Alternatively, it could be that rural, European regions consume products that are produced in areas where production is somehow more polluting.

At any rate, the emission trade balance has decreased for all three super-regions. Table 7 provides the magnitudes of this decrease: it shows that the magnitude of change is the smallest for rural areas and the largest for urban areas. While the trade balance has decreased strongly in relative terms, this is mainly due to the fact that the magnitude of the trade balance was very small in 2000, so that even a small increase would seem very high in relative terms. Therefore, expressing the change in percentages does not necessarily provide fruitful insights in the change in regional emission trade balances. However, we can put the numbers in perspective in other ways. Firstly, we can look in the per capita change in the emission trade balance. It turns out, that the per capita decrease in the trade balance is nearly identical across the three super-regions[7]. Secondly, we can assess the magnitude and change of the trade balance relative to the volume of CB and PB emissions. It turns out that, for 2007, the magnitude of the trade balance is approximately 25%-30% of the magnitude of the PB emissions for every type of region, and between 20%-25% of the CB emissions. In 2000, this was between 15%-20% of PB emissions and between 10% and 17% for CB emissions.

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[7] Using the population size at 1 January 2007, the per capita change in the emission trade balance in rural regions stood at -10 tons, in intermediate regions at -11 tons, and also at -10 tons/capita for urban regions.

	Emission trade balance 2000 (kilotons)	Emission trade balance 2007 (kilotons)	Emission trade balance (kilotons)	Emission trade balance (%)
Primarily Rural	- 80 666	- 176 994	- 96 327	- 119.4%
Intermediate	- 184 579	- 330 514	- 145 936	- 79.1%
Primarily Urban	- 229 185	- 469 372	- 240 187	- 104.8%

Table 7 - Emission trade balance for the rural, intermediate and urban areas. Note the minus signs in front of all values. Source: RIOT, author's calculations.

What do these results tell us? Firstly, the results show that CB emissions are higher than PB emissions in all super-regions in 2000 and in 2007. In other words, the footprint of these regions is slightly negative as they consume more than they produce. This finding was expected: after all, international production fragmentation dictates that an increasing amount of economic activities moves to non-European production locations, and that these activities are often the more polluting ones. This is in line with findings by Dietzenbacher et al. (2012), who find that Chinese emissions (i.e. non-European PB emissions) increasingly serve the purpose to satisfy non-Chinese final demand (i.e. also European final demand). Similarly, Mózner (2013) finds that CB emissions are higher than PB emissions for a selection of European countries. Our results show that this also holds for rural, intermediate ánd urban regions.

Secondly, we have found that relative consumption in rural regions has increased more strongly than in other regions (see table 3). This resulted in a concomitant increase in relative, rural CB emissions. In fact, the increase in CB emissions for rural regions is so strong that the change in the rural emission trade balance is the most negative of all, despite the fact that rural regions also managed to maintain the strongest output growth (and high output growth exerts a positive pressure on the trade balance). Heinonen & Junnila (2011) have demonstrated that urban residents have higher per capita consumption volumes than rural residents for Finland. While the stronger increase in rural relative consumption might imply that rural residents are somehow catching-up when it comes to the volume of their consumption, it does not necessarily do so. Rather, since population growth has been stronger in rural areas compared to urban areas, *per capita* consumption volumes have actually increased more strongly in urban areas, even when the relative increase in *total consumption volume* has been higher in rural areas[8]. There is no catching-up when it comes to per capita consumption. Conversely, while per capita consumption increases were higher in urban regions, per capita CB emissions increased more strongly in rural areas[9].

Now we have arrived at the situation that per capita consumption increased more strongly in urban areas, but per capita CB emissions increased more strongly in rural areas. One explanation may be that urban residents somehow consume more services than rural residents: however, for residents in both types of areas service consumption constitutes approximately 52% of their total consumption volume. A more compelling explanation may rest from the finding that regions tend to derive their consumption mostly from *domestic* producers, in the sense that rural regions tend to mainly consume rurally produced products. In more technical terms, the diagonal sub-matrices within the **Z**-matrix contains much larger values than the other sub-matrices in the same row. Therefore, rural manufacturing demand is mostly satisfied by

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[8] Expressed in euros from the year 2000, per capita consumption in rural regions rose with 2500 euros, while consumption expenditure for both the urban areas and intermediate areas increased with 3000 euros per capita per year between 2000 and 2007.

[9] For rural regions CB emissions increased from 6.8 tons per capita per year to 8.5 tons. Conversely, for urban regions per capita CB emissions increased from 9.2 to 9.9 tons.

rural manufacturing production. We have demonstrated in section 4.3 that emissions per unit of output have remained somewhat higher in rural areas compared to intermediate and urban areas. Similarly, the decomposition demonstrated that urban PB emissions decreased because of the $\mathbf{A}^{\mathrm{T}}$ effect, which implies a shift towards less-polluting intermediate inputs. Urban residents tend to consume goods and services from urban areas, where production has become cleaner between 2000 and 2007. In rural regions, emissions per unit of output have remained somewhat higher. The preference of rural residents to consume rurally produced goods means that each unit of per capita consumption increase will lead to a stronger increase in CB emissions than for urban residents, who prefer the overall cleaner urban products. A decomposition analysis could show this more substantially, but this is not possible with the available data, at least not without the creation of many hypothetical coefficients in the analysis.

5. CONCLUDING REMARKS

This paper has demonstrated that most regions have experienced output growth and consumption growth in the observed period, albeit at a different speed. Generally, consumption growth has outpaced output growth. With regards to output growth, we have seen that newer member states have realized stronger output growth than older member states, and that the same is true for rural regions compared to urban regions. However, the difference in output growth between rural and urban regions is relatively small at 3%. PB emissions, on the other hand, increased much more strongly in rural areas compared to urban areas at 10% versus 3%. The decomposition analysis has shown that the main driver of the low increase of urban emissions is a change in the inputs that are required for urban production, and that change has been favourable in terms of the emissions associated with the production.

Rural consumption did not grow as fast as rural output, especially in relative terms. However, the increase in rural CB emissions have been stronger than the increases in PB emissions (the same is true for intermediate and urban areas). As a result, we find that between 2000 and 2007 the emission trade balance has deteriorated for all three types of regions, but mostly for rural regions. It is this change, rather than the magnitude of the trade balance, that is interesting to policy makers who are often more interested in changes rather than magnitudes (Edens et al., 2011). The findings suggest that European regions, whether they are rural or urban, increasingly export clean products: this is supported by the finding that output growth has been higher than PB emission increases. On the other hand, regions have started to import more *dirty* products, and this is especially true for rural regions. Within the realm of environmental justice, this implies that policy arrangements that target PB emissions will increasingly shift their focus on non-European areas, even if the deteriorating trade balance suggests that European consumption should be equally central in these policy considerations (Afionis et al., 2017).

Furthermore, our findings do not indicate that rural growth and emission reduction are fully reconcilable at the moment. While improved production efficiency has mediated the effect of output growth on the total emission growth, the total level of emissions did increase in the rural areas, and more strongly than in intermediate or urban areas. Indeed, a recent report by the European Court of Auditors (2018) suggests that the EU rural development policy could more explicitly take renewable energy initiatives into account. Furthermore, the Court also criticizes the EU energy policy agenda on the grounds that it does not sufficiently nurture the links between rural development on the one hand and renewable energy on the other hand. These findings are in line with our results.

This research is the first to use an input-output framework to assess sustainability in rural growth at the supra-national scale[10]. However, the large geographical coverage of this research comes at the price of high aggregation. Firstly, ideally, data would have been available at the NUTS-3 rather than NUTS-2 level. However, this will probably not happen in the next decade or so, since the availability of data at the NUTS-2 level has only recently become available. Furthermore, the number of industries in the RIOT is 14, which induces a measure of unreliability in the outcomes due to the high level of aggregation (even though a certain extent of aggregation is endemic to IO-analysis). Future RIOTs might distinguish between more industries, reducing the aggregation errors.

Additionally, in future research we can also use regional data to discuss questions that are more profoundly regional than the one in this thesis: data at the NUTS-3 level would help us to distinguish between rural areas that are close to urban areas and remote rural areas. NUTS-

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[10] Heinonen & Junnila (2011) do the same thing for Finnish rural and urban regions, but lack (compatible) data for other countries.

3 data would also allow us to investigate the ties and complementarities that exist between urban areas and its surrounding rural areas. This would allow us to calculate the strength of economic ties, but also the emissions that are embodied in these inter-regional ties. Finally, we have not incorporated direct household emissions from heating, cooking and other non-economic activities, because there is no such data available at the regional level. This data would allow an expansion of this research because future research could then incorporate the effects of lifestyles and house types on CB emissions, rather than merely looking at economic activities. The omission of these elements of consumption is unfortunate, since they constitute an important source of carbon consumption, and an important difference between rural and urban emissions (Heinonen & Junnila, 2011).

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APPENDIX 1

RIOT (14 industries)	**WIOT (35 industries)**
1. Agriculture	1. Agriculture, Hunting, Forestry and Fishing
2. Mining, Quarrying, Energy Supply	2. Mining and Quarrying
	17. Electrical, Gas and Water Supply
3. Food, Beverages and Tobacco	3. Food, Beverages and Tobacco
4. Textiles, Leather etc.	4. Textile and Textile Products
	5. Leather, Leather and Footwear
5. Coke, Refined Petroleum, Nuclear Fuel, Chemicals, etc.	8. Coke, Refined Petroleum, and Nuclear Fuel
	9. Chemicals and Chemical Products
	10. Rubber and Plastics
6. Electrical & Optical Equipment and Transport Equipment	14. Electrical and Optical Equipment
	15. Transport Equipment
7. Other Manufacturing	6. Wood and Products of Wood and Cork
	7. Pulp, Paper, Paper, Printing and Publishing
	11. Other Non-Metallic Mineral
	12. Basic Metals and Fabricated Metal
	13. Machinery, Not Elsewhere Classified
	16. Manufacturing, Not Elsewhere Classified; Recycling
8. Construction	18. Construction
9. Distribution	19. Sale, Maintenance & Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
	20. Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
	21. Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
10. Hotel and Restaurant	22. Hotel and Restaurant
11. Transport, Storage & Communication	23. Inland Transport
	24. Water Transport
	25. Air Transport
	26. Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
	27. Post and Telecommunications
12. Financial Intermediation	28. Financial Intermediation
13. Real Estate Renting and Business Activities	29. Real Estate Activities
	30. Renting of M&Eq and Other Business Activities
14. Non-Market Services	31. Public Administration and Defense; Compulsory Social Security
	32. Education
	33. Health and Social Work
	34. Other Community, Social and Personal Services
	35. Private Households with Employed Persons

APPENDIX 2

Industry	Luxembourg		Malta	
	WIOD	RIOD	WIOD	RIOD
1. Agriculture	270	270	170,08	170,08
2. Mining, qua..	474	474	348,65	348,65
3. Food, beve..	577	577,30	365,86	365,86
4. Textiles and ..	464	464,2	247,94	247,94
5. Coke, refine..	1.222	1222,1	169,65	169,65
6. Electrical …	239	238,7	1.995,02	1.995,02
7. Other manuf..	4.402	4402,2	477,40	477,40
8. Construction	2.810	2809,9	339,30	339,30
9. Distribution	3.150	3150,1	681,05	681,05
10. Hotels and ..	823	822,7	550,49	550,49
11. Transport..	3.489	3488,9	846,65	846,65
12. Financial..	24.784	24783,7	363,63	363,63
13. Real Estate..	5.236	5235,7	631,72	631,72
14. Non-market..	4.734	4734,4	1.054,24	1.054,24

APPENDIX 3

	Equations	Mirror images	Fisher Index
Population size	1.004	1.004	1.004
Emissions per unit	0.839	0.845	0.842
$\mathbf{D}^{\mathbf{A}}$ effect	1.050	1.048	1.049
$\mathbf{A}^{\mathbf{t}}$ effect	0.978	0.974	0.976
Per capita consumption volume	1.044	1.053	1.048
Consumption shares	1.006	1.007	1.006
Investment shares	1.003	1.004	1.003
Export composition	1.025	1.021	1.023
Export volume	1.180	1.174	1.177
Product (1) – (9)	1.102	1.102	1.102

Table 5A – Results from the Structural Decomposition Analysis for the primarily rural regions.

	Equations	Mirror images	Fisher Index
Population size	1.013	1.014	1.013
Emissions per unit	0.822	0.826	0.824
$\mathbf{D}^{\mathbf{A}}$ effect	1.054	1.054	1.054
$\mathbf{A}^{\mathbf{t}}$ effect	1.000	0.998	0.999
Per capita consumption volume	1.033	1.039	1.036
Consumption shares	1.002	1.001	1.001
Investment shares	1.002	1.002	1.002
Export composition	1.010	1.007	1.008
Export volume	1.138	1.130	1.034
Product (1) – (9)	1.047	1.047	1.047

Table 5B – Results from the Structural Decomposition Analysis for the intermediate regions.

	Equations	Mirror images	Fisher Index
Population size	1.010	1.014	1.012
Emissions per unit	0.822	0.829	0.825
$\mathbf{D}^{\mathbf{A}}$ effect	1.012	1.058	1.035
$\mathbf{A}^{\mathbf{t}}$ effect	0.754	0.706	0.730
Per capita consumption volume	1.028	1.042	1.035
Consumption shares	1.004	1.007	1.005
Investment shares	0.999	0.998	0.998
Export composition	1.030	1.027	1.028
Export volume	1.537	1.527	1.532
Product (1) – (9)	1.032	1.032	1.032

Table 5C – Results from the Structural Decomposition Analysis for the primarily urban regions.