Ref. Ares(2018)2303963 - 30/04/2018

EUCALC

Explore sustainable European futures

Decoupling typologies in European economies.

D1.4

April/2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730459.

Project Acronym and Name	EU Calculator: trade-offs and pathways towards sustainable and low-carbon European Societies - EUCalc
Grant Agreement Number	730459
Document Type	Deliverable
Work Package	WP1
Document Title	Decoupling typologies in European economies.
Main authors	Moreau V., Neves. C., Costa, L.
Partner in charge	PIK
Contributing partners	EPFL
Release date	April 2018
Distribution	*All involved authors and co-authors agreed on the publication.*

Short Description
This deliverable analyses contemporary factors underlying the energy consumption and territorial CO_2 emissions in European member states by economic sector, and relates them to structural changes like deindustrialisation, tertiarisation and efficiency gains. It exposes time persistent patterns of structural and intensity changes in the secondary sector of Europe, and identifies countries for which increases in territorial emissions brought about by demographic and economic growth are outpaced by reductions caused by structural change and efficiency gains.

Quality check	
Name of reviewer	**Date**
Steffania Tron	**27-04-2018**
Giuseppe Forino	**27-04-2018**

Statement of originality:

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Table of Contents

List of Figures

List of abbreviations

IDA – Index decomposition analysis
LMDI – Log mean divisia index
Mtoe – Million tonnes of oil equivalent.
NUTS – Nomenclature of territorial units for statistics

1 Executive Summary

This deliverable analyses contemporary factors underlying the energy consumption and territorial CO_2 emissions in European member states and economic sectors, and relate them to structural changes like deindustrialisation, tertiarisation and technological innovations. The factors underlying energy consumption were decomposed by the means of and Index Decomposition Analysis (IDA) technique (Ang & Zhang 2000) which allows to link the variation of final energy consumption and CO_2 emissions of a country to changes in the level of ***activity*** or ***scale*** of the economy (effect of the economic growth); changes in the ***structure*** of the economy (shifts of economic activity from one sector to another, typical agriculture to industry to services and outsourcing); and changes in ***energy intensity*** which primarily is due to improved energy efficiency measures. The IDA analysis for the case of energy is done for the years 1995 to 2014 and sectioned into five time-intervals. The IDA for the case of territorial CO_2 emissions is done for the years running from 2010 to 2015. For the case of the IDA analysis of energy consumption this deliverable engages on identifying patterns of structure and intensity changes by sector and across sector that are persistent in time, that is, that occurred more often than not during the five time periods evaluated.

While results of the IDA on energy varied greatly among countries, negative structural effects in the secondary sector played a role in all countries. These effects were predominant in the 1990s and early 2000s, after which they mostly subsided and gave way to larger intensity effects. This supports the hypothesis that a significant portion of the drop in energy consumption in European countries is due to deindustrialization rather than to energy efficiency. In regard to the IDA made for territorial emissions of CO_2 the results are in line with those obtained for the case of energy. We found that for the majority of the countries, the negative effect (decrease) in emissions brought about improvements in efficiently and structural changes outpace the positive (increase) effect on emissions brought about economic growth. For the time period evaluated (2010-2015) this has been particularly true to the tertiary and primary sectors. For the secondary (by far the most energy intensity sector) such apparent decoupling is also observed among countries but to lesser extent.

When IDA results for energy and emissions are compared for the matching time period, preliminary results point for the existence of a considerable lag between decreases in energy consumption and drop in territorial emissions in Europe. We have determined that the percent reduction of final energy consumption in the secondary sector is circa two times larger than the corresponding savings in territorial CO_2 emissions. This highlights that in general the reduction of emissions will be felt much slower that the achievements in energy savings.

2 Introduction

Decoupling energy consumption from economic growth is broadly accepted as a strategy to reduce energy consumption and achieve emissions targets (EEA, 2016). The ratio between energy use and economic output, also known as "energy intensity", is the indicator used to assess the depth and rate of decoupling of final energy consumption and economic growth. Decoupling of any natural resource, such as energy, and economic output can be (i) relative, when the growth rate of energy consumption is positive but less than that of economic growth, or (ii) absolute, when energy consumption is stable or declining while the economy is growing (UNEP, 2011). In the particular case of the EU-28, data from the European Environment Agency (EEA) shows that this decoupling was been relative until approximately 2005, after which it became absolute (EEA, 2016).

However, this decoupling can also be distinguished between real and virtual (Moreau & Vuille, 2018). Real decoupling occurs due to actual energy consumption reduction measures in economic activities. Virtual decoupling, on the other hand, is an apparent reduction in energy intensity due to changes in economic structure, such as increased reliance on imports, which reduce domestic energy consumption by exporting it abroad. Understanding what are the drivers of decoupling helps to evaluate the effectiveness of different policies. It allows, for example, to quantify how much of the decoupling can be attributed to global, regional or national changes in economic structure, especially at the level of industrial activities; and how much can be credited to energy efficiency measures and innovations.

The case made for the decoupling of energy consumption and economic growth is equally valid for the case of the decoupling between territorial CO_2 emissions and economic growth. The latter has been investigated in the context of human development and fairness approaches to global mitigation (Costa et al 2011, Steinberger et al 2012). These studies noted that the decoupling of territorial emissions and human development has been underway for advanced economies and that in the process less developed economies are benefiting (in terms of human development) by a rise in their territorial emissions. Nevertheless, accounting for emissions embodied in consumption (those attributable to the manufacturing of materials and products imported by a country) reveals that further socio-economic benefits are accruing to carbon-importing (high developed countries) rather than carbon-exporting countries (mostly developing or emerging economies).

This deliverable aims at gaining a deeper understanding of the driving forces behind in final energy consumption and territorial CO_2 emissions in Europe. We do so by undertaking a decomposition analysis in which the effects of activity/scale (population & economic growth), structure (deindustrialization & tertiarization) and intensity (energy/CO_2 efficiency) are isolated across country and sector. Once the effects are isolated we conduct an exploratory analysis in the search of typologies (classification of observations in terms of their attributes on multiple variables) across countries. For the case of energy, typologies indicate the countries for which the structure of the secondary sector has had a persistent negative evolution in time, from those where the structural effect oscillated between positive and negative. A further typology sections the countries for which the effect of intensity has been persistently decreasing, at the same time, for the primary and secondary sectors. In regard to emissions, the typologies indicate the countries for which the increase of emissions brought about by economic growth has been outpaced by efficiency gains and structural change. The analysis is conducted for the primary, secondary and tertiary sectors.

3 Methods and data

3.1 Index Decomposition analysis

Decomposing the factors underlying energy consumption can be achieved in two ways, namely Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA). Aside from their mathematical foundations, a key difference between these methods is the data sources. SDA uses Input-Output Tables, while IDA uses sector level data. As such, IDA requires less data, but also outputs less detailed results when decomposing the economic structure of a country. Additionally, SDA can account for indirect demand effects, which are ignored in IDA (Hoekstra et al., 2003). However, from an applied perspective, five times more analyses in energy and environment used IDA over SDA between 2000 and 2010, in part because IDA has seen more systematic developments (Su and Ang, 2012). The choice between SDA and IDA is not only based on the complexity of the desired investigation and output, but also on data availability.

IDA was applied in this case. Based on index number theory, it encompasses several methods, all falling within two categories: Laspeyres Index and Divisia Index. The log mean Divisia index (LMDI) is widely used among Divisia index methods, while the modified Fisher index is recommended among the Laspeyres index methods (Ang, 2004). In addition, decomposition can be additive (studying the difference in an indicator between two periods), or multiplicative (studying the ratio between two periods). IDA was conducted using additive LMDI, with the following problem formulation. The identity equation is:

$$E = \sum_i E_i = \sum_i Q \frac{Q_i E_i}{Q Q_i} = \sum_i Q S_i I_i$$

Where *E* is the total final energy consumption of the country, E_i is the energy consumption of the *i*th sector, *Q* is the total economic output (GDP) of the country, and Q_i is the value added of the *i*th sector. As such, *Q* is the *activity* effect (or the effect of economic growth), *S* is the *structure* effect, or the share of value added of a sector over GDP (Q_i/Q), while *I* is the *intensity* effect, or the energy consumption per unit of economic output (E_i/Q_i).

A few caveats must be included here: because both residential and transport sector data are included in the IDA, a few adaptations were made in the equation when calculating their effects. For services and industry, value added is used. However, this is not how transport and residential effects were measured. In lieu of value added, average floor area of dwellings was used for the residential sector and passenger-km was used for passenger transport and tone-km for freight.

The effects of each of these drivers (activity, structure and intensity) on the overall changes in energy consumption are measured through the equation:

$$\Delta E = \Delta Q + \Delta S + \Delta I$$

Where

$$\Delta Q = \sum_i \frac{E_i^T - E_i^0}{lnE_i^T - lnE_i^0} ln\left(\frac{Q^T}{Q^0}\right)$$

$$\Delta S = \sum_i \frac{E_i^T - E_i^0}{lnE_i^T - lnE_i^0} ln\left(\frac{S_i^T}{S_i^0}\right)$$

and

$$\Delta I = \sum_i \frac{E_i^T - E_i^0}{lnE_i^T - lnE_i^0} ln\left(\frac{I_i^T}{I_i^0}\right)$$

The application of LMDI for the IDA case is much simpler, as the IDA only uses sector level data. Additionally, as it can be seen from this formulation, the IDA requires significantly less data (GDP, added value and energy consumption are the only requirements in this case. Thanks to the flexible nature of IDA, residential energy consumption and transportation are included both in the structural and energy intensity effects given the availability of sector level data.

In regard to the IDA for the case of territorial emissions, the approach followed is identical to the one described for energy consumption. The effects of each of activity, structure and intensity on the overall changes in territorial CO_2 emissions (ΔC) are measured through the equation:

$$\Delta C = \Delta Q + \Delta S + \Delta I$$

Where

$$\Delta Q = \sum_i \frac{C_i^T - C_i^0}{lnE_i^T - lnE_i^0} ln\left(\frac{Q^T}{Q^0}\right)$$

$$\Delta S = \sum_i \frac{C_i^T - C_i^0}{lnE_i^T - lnE_i^0} ln\left(\frac{S_i^T}{S_i^0}\right)$$

and

$$\Delta I = \sum_i \frac{C_i^T - C_i^0}{lnC_i^T - lnC_i^0} ln\left(\frac{I_i^T}{I_i^0}\right)$$

3.2 Data

The data for the IDA analysis regarding energy consumption primarily came from the ODYSSEE-MURE database[1], with detailed data available from 1990 to present for most EU countries. Time series were divided into five periods, 1990-1995, 1995-2000, 2000-2005, 2005-2010, 2010-2014. This division simplified the observation of long term trends given the inertia in the industrial system. However, the database is incomplete, and for several countries and/or periods, part of the data had to be complemented with data from the World Input Output Database (WIOD) which also covers the EU. All monetary values were adjusted to constant euros 2005.

Emissions data for the IDA analysis regarding CO_2 emissions were taken primarily from EUROSTAT air emissions account database[2] broken down by economic activities classification in the EU (abbreviated as NACE[3]). Information of value added of economic activities, for the matching time frame, was taken from the EUROSTAT regional economic accounts database[4]; which contains values of total gross value added at basic prices for NUTS3[5] regions broken down by NACE classification. In order to guarantee geographic consistency between emissions (national level) and added value (NUTS3), the latter values are summed, by economic activity, according to NUTS1 (country) classification. Complete information on emission values for the countries starts in year 2008

[1] http://www.odyssee-mure.eu/project.html

[2] http://ec.europa.eu/eurostat/cache/metadata/en/env_ac_ainah_r2_esms.htm

[3] The Statistical classification of economic activities in the European Community, abbreviated as NACE, is the classification of economic activities in the EU; the term NACE is derived from the French Nomenclature statistique des activités économiques dans la Communauté européenne. Various NACE versions have been developed since 1970.

[4] http://ec.europa.eu/eurostat/cache/metadata/en/reg_eco10_esms.htm

[5] Nomenclature of territorial units for statistics.

and runs until 2015. Given the shorter time series on emissions (with complete data) than that available for energy, we conduct the analysis only for the time period 2010-2015. The analysis is made at the member state level and is available for all of the EU28 member states.

4 Energy

4.1 Activity, Structure and intensity effects in energy consumption

The results of the IDA indicate that the EU saw a period of growing deindustrialization throughout the 1990s, as evidenced by the large negative structural effects in Figure 1 during the first two time periods analysed. From the year 2000 until 2014 the effect of structure in lowering energy consumption has been progressively decreasing and substituted by increasingly negative intensity effects. Throughout the investigated time-periods the effect of activity (economic growth) has contributed to an increase of energy consumption. When all effects are summed up (black line in Figure 1), the changes taking place in Europe resulted in a decrease of energy consumption for the time periods 2005-2010 and 2010-2014 of approximately 50 Mtoe.

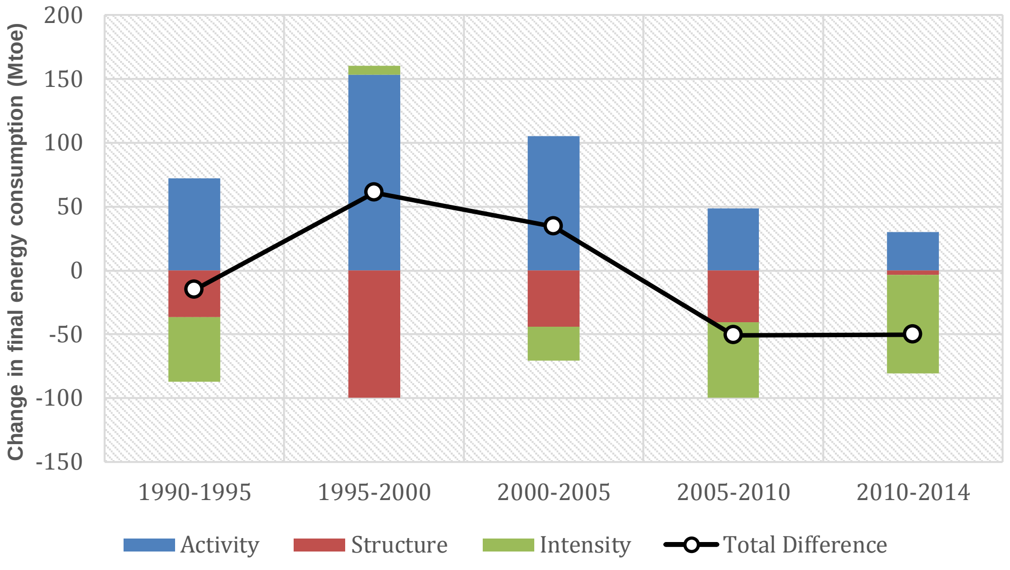

Figure 1 - Decomposition of final energy consumption in Activity, Structural and Intensity effects in the EU (Luxembourg and Malta excluded).

Structural changes are essentially represented by changes in the share of value added by each sector over the sum of added values or GDP. We can assume that part of the negative structural effects was compensated by imports of equivalent products at least in the manufacturing sector. This highlights the more important role of energy efficiency in the last decade. It is also important to note that many of the effects are relatively small (less than 5% of final energy consumption). This can either be because Europe as a whole saw small homogeneous effects, or because the varying effects between countries average each other out on a regional level, which is what we observe from detailed study of individual member states.

4.1.1 Geographic

Across the EU, member states differ significantly in terms of climate, energy policies, industrialization and other factors. These groups can be clustered based on broad regional lines, with Eastern Europe coming later among the trading partners of the EU, the South having milder climates, or the West being more industrialized, for instance. As such, we expected that decomposition would yield different results across these broad geographic regions. We show that in energy terms there are indeed differences, which make it worthwhile to investigate member states individually or as clusters more in depth to understand the political, economic, and historical drivers behind these differences. The figures shown exclude Luxembourg and Malta for lack of data, as well as Cyprus. The results for Cyprus are outliers which, if included, would significantly skew results for Eastern Europe. Additionally, information on total goods transport is not included in the secondary sector for some countries due to data unavailability; these countries are: Belgium, Bulgaria, Estonia, Hungary, Lithuania, and Slovakia.

The results in Figure 2and Figure 3 illustrate the evolution of structural and energy intensity effects for the industry sector in four European regions. The results indicate that most regions in Europe have deindustrialized albeit at different paces. Northern countries have experienced strong negative structural effect, in particular from the year 2000 onwards. For Eastern economies the relative pace of deindustrialization has been less pronounced and even exhibiting a shy positive effect (leading to more consumption of energy) in the last time-period evaluated.

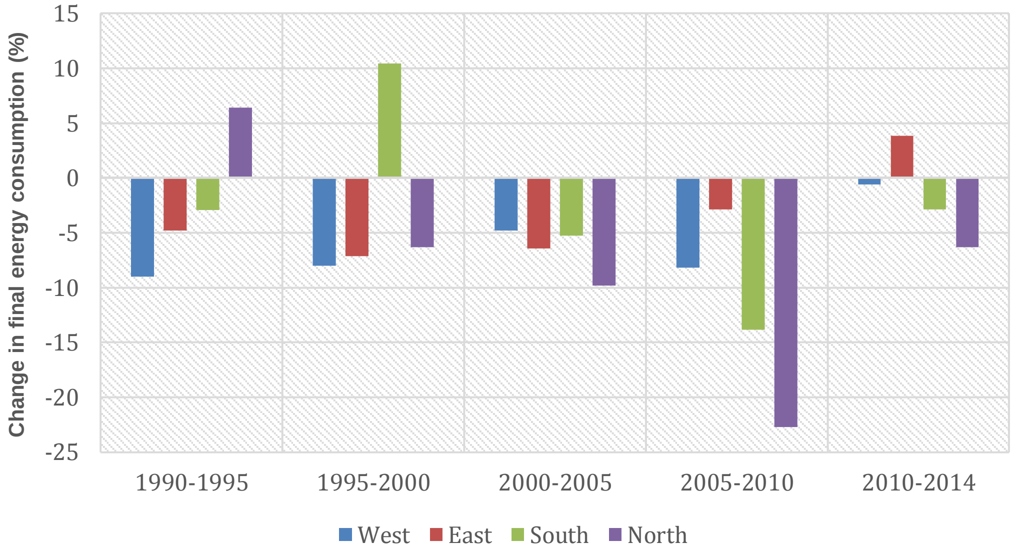

Figure 2 - Structural effects in the secondary (industry) sector broken down by regional cluster.

The smaller pace of deindustrialization in Eastern countries has co-evolved with generous gains in energy efficiency. This is highlighted in Figure 3 in which the IDA values for the intensity effect are reported. Throughout the entire time frame evaluated, the intensity effect in Eastern countries has steadily been responsible for savings between 25 and 10% in energy consumption in the secondary sector for the time-periods evaluated (approximately 4.1 to 1.6 % on an annual basis).

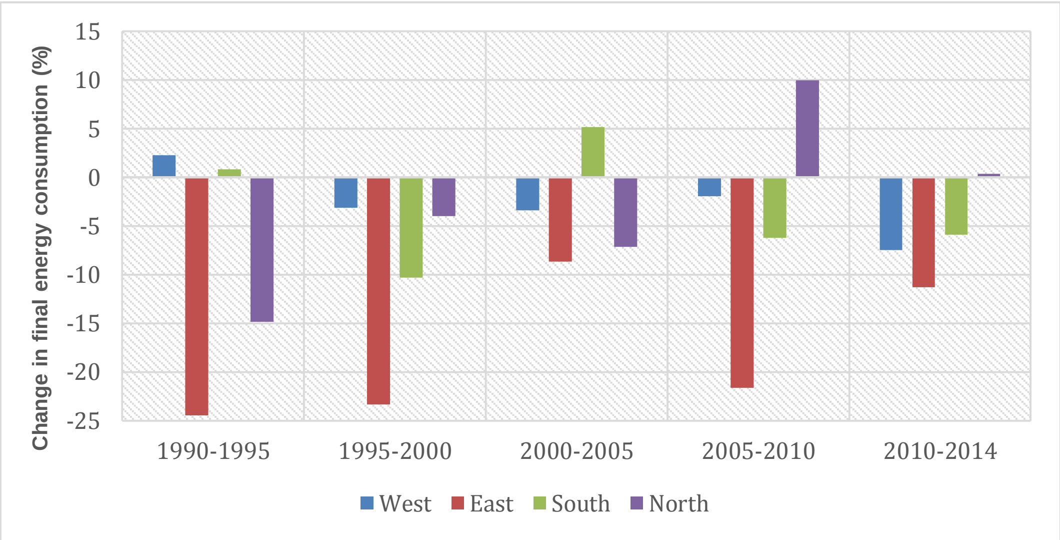

Figure 3 - Energy intensity changes in the secondary (industry) sector broken down by regional cluster.

In Northern member states, as mostly lead to reductions in intensity except in the time period 2005-2010. Indeed, in the absence of large and energy intensive industries, small structural changes can lead to relatively large changes in energy consumption. This was somewhat the case in Western European member states over previous periods of time.

4.1.2 Sectoral

Across all three sectors, the results show that the 1990s and 2000s saw significant negative structural effects in both the primary and secondary sectors. These effects were more prominent in the 1990s, suggesting that most of the deindustrialization observed in the past 27 years occurred early on. This narrative is only partially in line with evidence from global trade balances, which worsened (deficit) after 2000, but a relatively stable ratio of exports to imports throughout. This is because European trade is largely internal, and changes in one country are partially offset by another. As such, overall effects are smaller than many of the domestic level effects. In addition, while negative intensity effects were pervasive in the primary sector, they were much less noticeable in the secondary, suggesting a larger role in the modernization of agriculture than industrial activities. It is only in the latest period that intensity effects became dominant in the secondary sector.

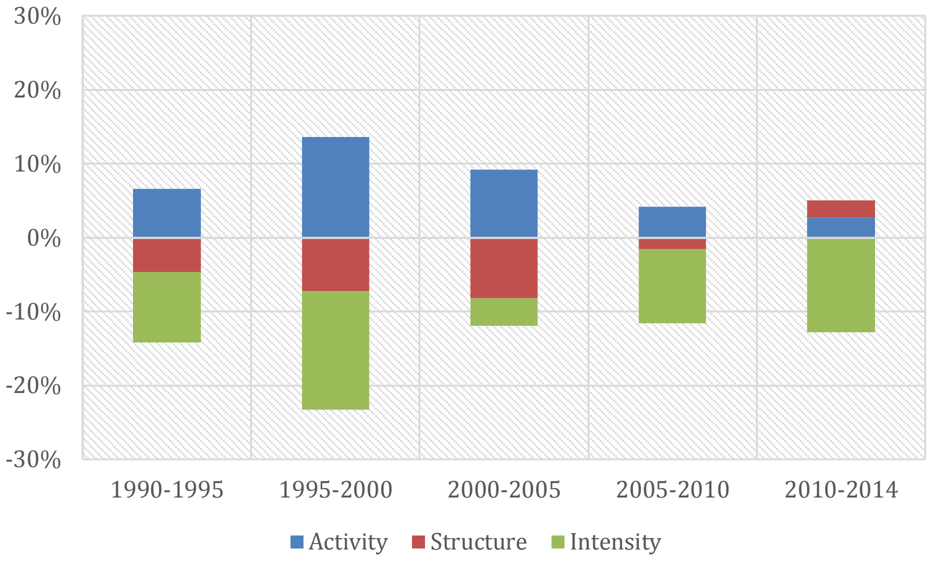

Figure 4 - Relative contribution of the activity, structural and intensity effects in the change of final energy consumption in the primary (agriculture, fisheries, forestry) sector in the EU.

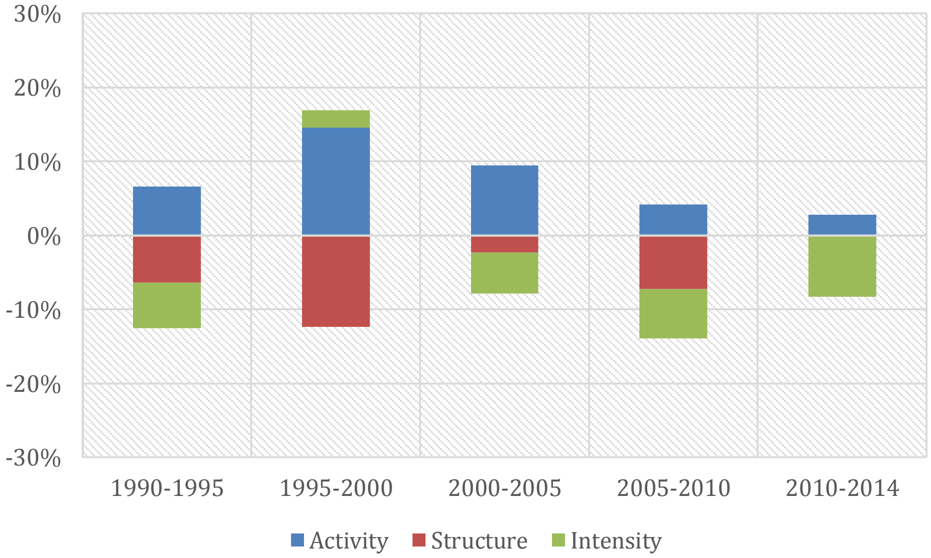

Figure 5 - Relative contribution of the activity, structural and intensity effects in the change of final energy consumption in the secondary (industry) sector in the EU

The services sector saw minimal structural effects and small negative intensity effects in most periods. Since intensity effects in these sectors are very large and negative is some countries, but small and sometimes positive in others, the EU as a whole sees the result of averaging out very energy efficient countries, such as Germany, and some which are not so, such as Spain (as can be seen in the geographical clustering above). One of the implications of this result is the uneven application or enforcement of EU directives and other policies regarding energy efficiency across member states and sectors. Support for implementing such policies may also be unevenly distributed leaving it up to the highest value added activities and wealthiest member states to achieve the necessary changes.

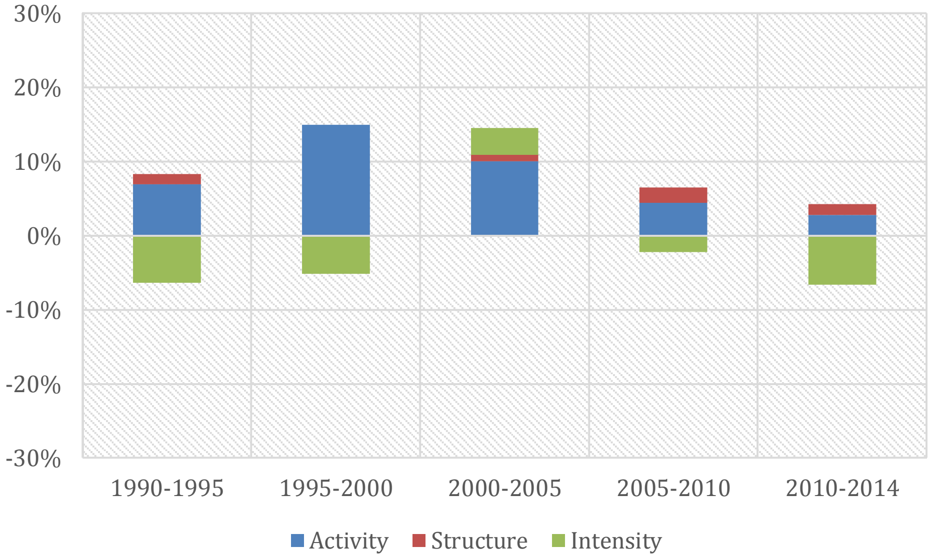

Figure 6 - Relative contribution of the activity, structural and intensity effects in the change of final energy consumption in the tertiary (services) sector in the EU

5 Emissions

5.1 Activity, structural and intensity effects in CO_2 emissions

5.1.1 Sectoral

The analysis of IDA for the case of emissions does not enjoy from the same length in time series as the one for energy and hence represents more of a snapshot of changes taking place in recent years (2010-2015) than a statement on how scale, structure and intensity has been influencing the territorial CO_2 emissions of a country. It also helps to reference the change IDA components obtained for a country with the average change observed across Europe.

Following the results are presented for the case of intensity of the primary sector, structure of the secondary sector, and Activity of the tertiary sector for the time period 2010-2015. The complete results for all the IDA components can be consulted in section 8.1 of the Annex.

Figure 7 shows European countries ranked by their change (from most negative to positive) in intensity of the primary sector. A negative value of the intensity component of IDA contributed to a decrease in territorial emissions associated with the primary sector. The more negative the stronger (in relative terms) has been the contribution in reducing emissions. It should be noted that a negative value in one component of the IDA analysis does not mean *per se* that emission have fallen; it only indicates that *that* particular component contributed to lower the emissions. The "savings" in emissions from a negative value of intensity can be offset by for example, increasing values of scale and structure.

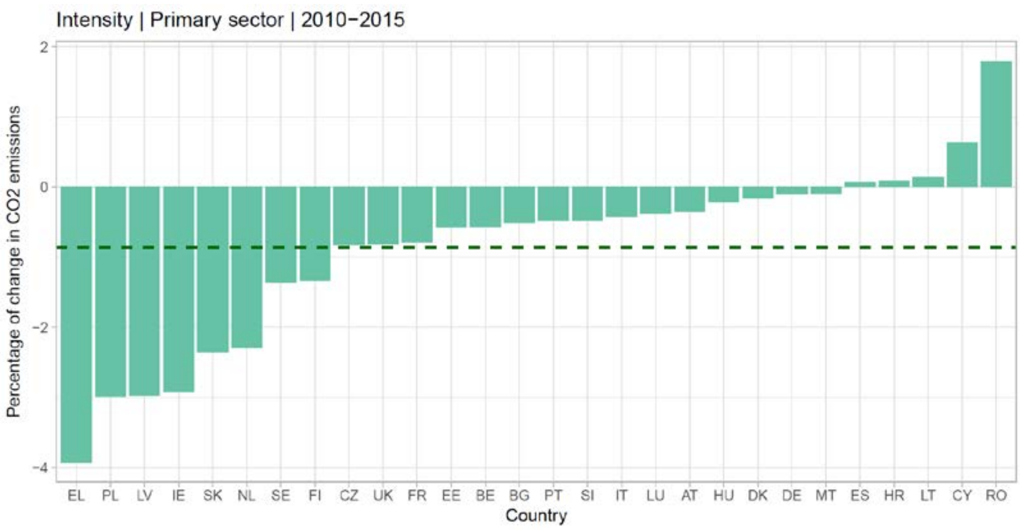

Figure 7 - Ranking of countries according to changes intensity of the primary sector.

For the particular case of intensity in the primary sector the majority of the countries evaluated returned a negative value. This indicated that the production of goods from the primary sector has become more efficient within their territory and over the time period considered. Decrease in intensities have been observed to rank between -2.5[6] to nearly + 2%.

The European average change in intensity of the primary sector (dashed line) was close to -1%. Most of the countries trail behind the European average, highlighting the disproportional territorial evolution of intensity change in the primary sector. Positive changes in intensity (meaning a positive contribution to emissions increase in the primary sector) are constrained to only five of the evaluate countries. These are Cyprus (CY), Lithuania (LT), Hungary (HR), Spain (ES) and Romania (RO); only for the latter has the change in intensity been greater than 1%.

In Figure 8 countries are ranked according to their IDA values of structure in the secondary (industry) sector. Very much in line with results of section 4.1.1 for the case of energy, deindustrialization has been associated with relative savings (negative structural effect) in territorial CO_2 emissions across the majority of the member states for the time period 2000-2015. This effect, when averaged across all member states, contributed -2.1% to the difference in CO_2 emissions between 2010 and 2015 (dashed line). The exception to this “general” rule has been a cluster of Eastern economies composed notably by Slovenia (SI) Hungary (HU), Czech Republic (CZ), Lithuania (LT), Poland (PL) and Estonia (EE). The above average negative effect (less relative emissions) of structural changes in Latvia (LV) and Romania (RO), see Figure 8, highlight the heterogeneity of emissions saving taking place in Eastern Europe. For the secondary sector, the average contribution of activity and intensity effects has been of +12 and -12.7% respectively. In total, a drop of final emissions of circa 2.9% for the time period (~0.5% annually) considered has taken place in the secondary sector. Over a comparable time period (2010-2014), the combined effect of activity, structure and intensity in energy consumption (see section 4.1.2) has led to about 5.4% drop in energy consumption (~ 1.1% annually). Accordingly, and in rough terms, the percent reduction in final energy consumption in the secondary sector is circa two times larger than the corresponding savings in territorial CO_2 emissions. This highlights that in general the reduction of emissions will be much slower that the achievements in energy savings.

[6] Given the economic turmoil that has taken place and the economic restructuring in the aftermath of the bailouts of 2010 and 2012, the results for Greece (EL) are to be taken with caution.

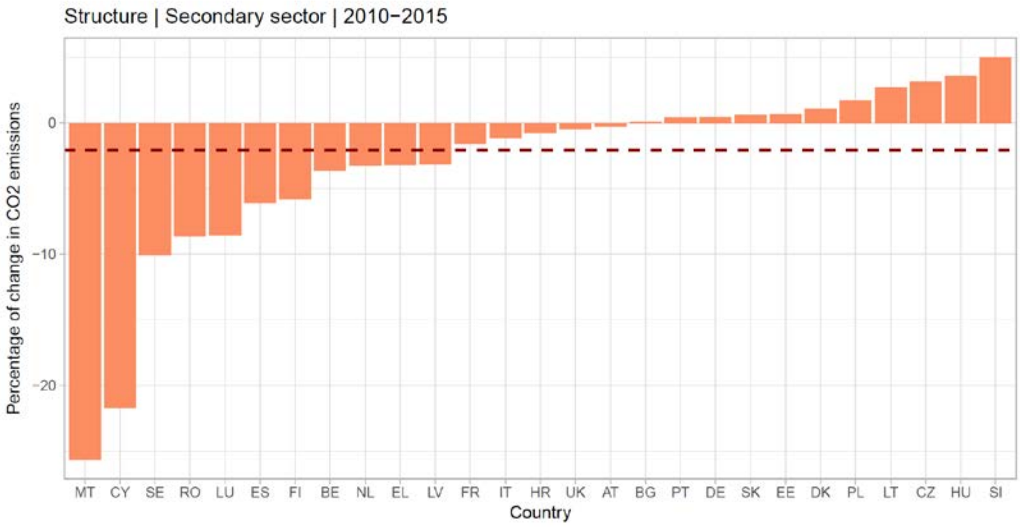

Figure 8 - Ranking of countries according to changes in structure of the secondary sector.

Lastly, Figure 9 presents the countries according to the change in activity in the tertiary (services) sector. The more positive the changes in the activity effect, the higher the effect of economic growth in the demand for services. The results indicate the across Europe the contribution of the tertiary sector to the change of emissions between 2010 and 2015 has been positive (~ 1%). Countries like Estonia (EE), Ireland (IE) and the United Kingdom (UK) have led the change, presenting activity effects well above the European average. These are countries well known for their bet in technological and financial services as engine of development. On the opposite side of the rank Greece (EL), Cyprus (CY), Croatia (HR), Portugal (PT) and Spain (ES) are the only countries in which the activity effect in the tertiary sector has been negative. This might indicate a decrease of activity in sectors like finance or public administration, which would be in line with the Cyprus financial crises of 2012-2013, and the austerity policies in public administrations of countries like Greece and Portugal due to the bailout programs installed after their financial crisis.

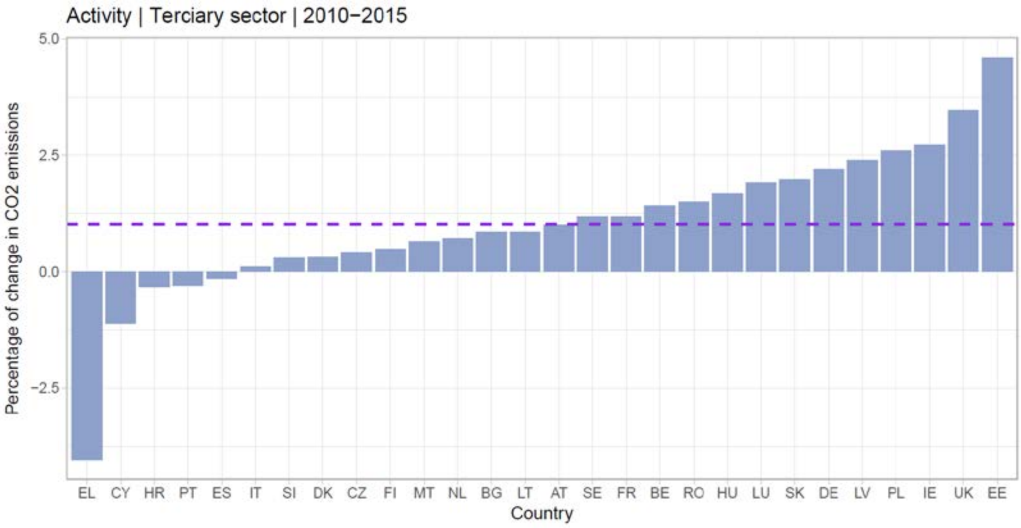

Figure 9 - Ranking of countries according to changes in activity of the tertiary sector.

6 Typologies of energy and emissions change in Europe

From a quantitative perspective a typology can be understood as composite measure that involves the classification of observations in terms of their attributes on multiple variables (Babbie, 1998). Classifying data according to key features is a useful strategy to reduce the complexity of observations into more traceable classes or objects. This allows establishing associations between objects and helps to outline structures which are not immediately apparent but gives much sense and meaning to the data when discovered (Kaufman & Rousseeuw, 2009). In the context of the work carried in this deliverable, a typology refers to the observation of typical patterns in the evolution of the activity, structure and intensity determined in sections 4 and 5 across time and across member states.

In order to achieve this we devise a simple procedure to identify typologies of IDA component's structure and intensity across time. The procedure is as follows. Using the results IDA analysis for energy consumption we determine in how many of the time periods evaluated the components of activity and intensity (in each sector) are below zero ($\Delta S < 0 \; or \; \Delta I < 0$). This denotes that the variation in energy consumption had a negative (reducing) influence from these factors. In total five time periods are evaluated; namely 1990-1995, 1995-2000, 2000-2005, 2005-2010, 2010-2014. A country that has experienced a consistent negative evolution of the structure or intensity components in IDA would have all or most of the time verifying the conditions $\Delta S<0$ or $\Delta I<0$. By contrast, a country for which only sporadically structure and intensity drove energy consumption down would not satisfy the conditions for most to the time periods.

6.1 Structural and intensity changes in the secondary sector

Figure 10 shows the results for the case of structure in the secondary sector of EU28 member states (except Luxembourg and Malta). The map highlights that deindustrialization ($\Delta S<0$) has been a consistent phenomenon in most of the member states. Romania, the United Kingdom, Ireland and Cyprus present a negative evolution of the structure of the secondary sector in all time periods. This highlights that the phenomenon of deindustrialization has been consistent across time in countries with very distinct economic, political and geographic considerations. The majority of countries evaluated (10 out of 26) have experience deindustrialization for the most part (4 out of 5) of the time periods considered. These include large economies like Germany, France and Spain, as well as the Northern member states of Denmark, Finland and Sweden. The evolution of structure in Eastern Europe presents us with a rather mixed picture.

On the one hand Poland has seen the structure of its secondary sector contributing positively to energy consumption in the large majority of the time periods evaluated. Meanwhile, Bulgaria, Romania and Hungary show a contrasting evolution with noticeable deindustrialization for most of the time periods.

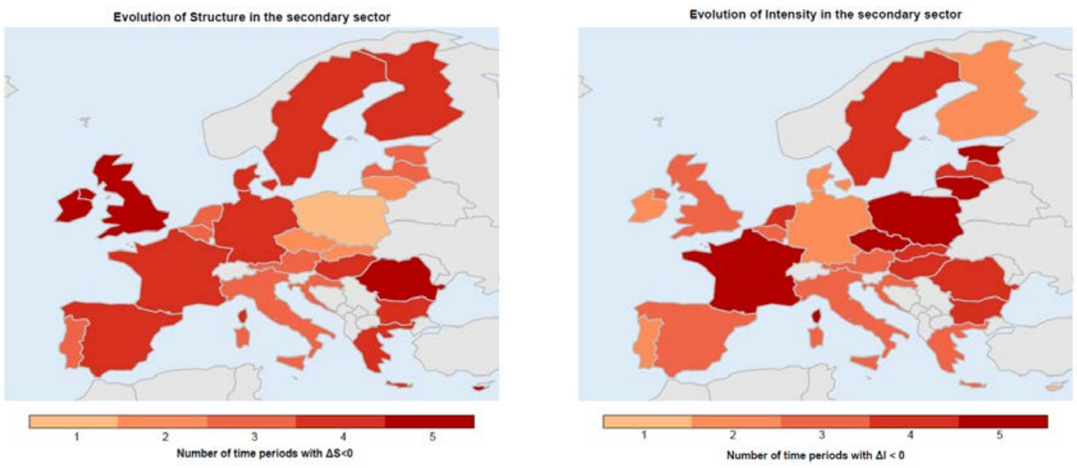

Figure 10 - Patterns of structure (left) and intensity (right) across time in the secondary sector.

On regard to the intensity component (right side of Figure 10), the analysis shows a fragmented picture across the evaluated countries. Countries that were identified as similar in regard to their structure evolution in Figure 10 present contrasting evolutions of intensity. This is particularly noticeable for the cases of Germany, France and Spain. Germany shows a decrease of intensity of the secondary sector only two out of the five time periods investigated while France exhibits a consistent decrease of the intensity component (5 out of 5 time periods). Spain ranks in between Germany and France. The picture is more homogenous in Eastern Europe. Consistent reduction on energy demand from intensity can be observed very much from the Baltic countries down to Bulgaria.

6.2 Cross sectoral changes of energy intensity

Although the examples provided beforehand give a glimpse on certain “groups” emerging; e.g., generalized deindustrialization in most of the EU member states vs holding of industry in particular Eastern economies (see Figure 10), or the consistent drop in intensity for industry in Eastern countries; it is only when we extend the analysis to account for the evolution of structure or intensity across all sectors at time periods that more traceable typologies emerge. Accordingly, we carry the same analysis for the primary, secondary and tertiary sectors. We then evaluate for which countries a decrease of intensity ($\Delta I<0$) has been consistent across all sectors and time periods. By consistent we mean that “more often than not” ΔI is <0 in all sectors. We take three (3) or more time periods as a threshold for this analysis (out of a total of five). In practice this procedure differentiates the countries for which a decrease in intensity has been observed for 60% or more of the time periods evaluated for all three sectors. Figure 11 illustrates the results obtained.

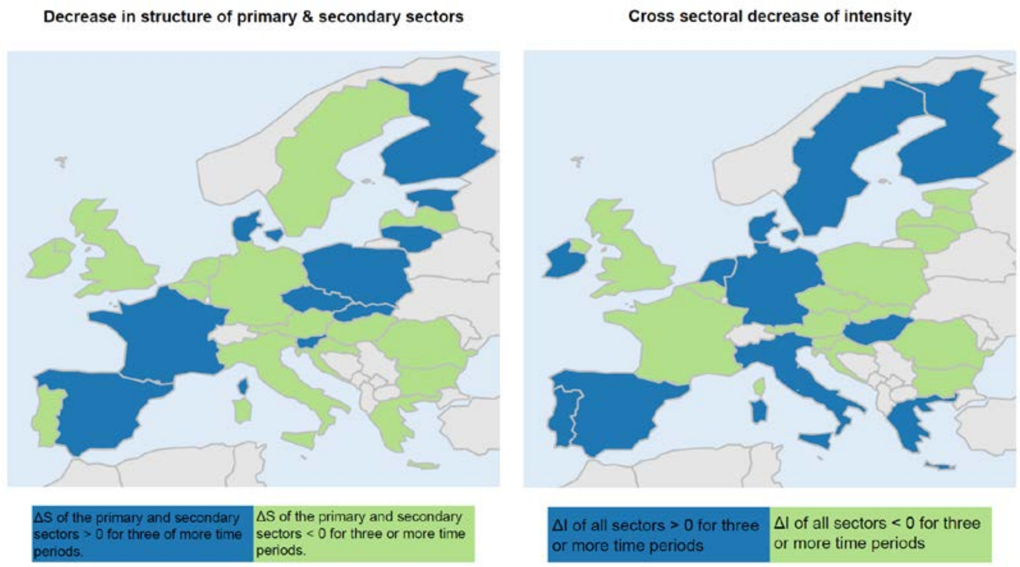

Figure 11 - Typologies of decrease of structure in the primary and secondary sectors (left); and cross sectional decrease of intensity (right).

Concerning the decrease of structure in both the primary and secondary sectors (Figure 11, left), we observed that this phenomenon has been most persistently taking place in persistent in South East Europe, UK and Ireland, parts of central Europe like Germany, Austria and Hungary, The Netherlands and Belgium, Portugal Finland and Latvia. Large economies such as France, Spain have more often than not experienced a rise in the structure of the primary and secondary sectors between 1995 and 2014. The same is observed in parts of Eastern Europe like Poland and Lithuania. In regard to the drop of intensity across all sectors (Figure 11, right), these have been taking place in most of Eastern Europe, Austria, Croatia and Slovenia, France and Belgium and the UK. In these countries all the sectors have experienced more often than not a decrease in intensity of energy consumption across all the sectors considered and time periods investigated.

6.3 Decoupling of territorial emissions

The results of section 5.1.1 pointed for a generalized gain in efficiency (emissions released per unit of economic output) regarding territorial emissions of CO_2 in the primary sector. At the same time, the additional demand generated by economic growth in the primary sector (the activity factor) has generally increased (see Figure 15 of the Annex) while the structural component of the IDA shows a mix of both positive and negative values. Hence the following question can be asked: what is rising faster? The gains in efficiency of a country (which lowers emissions) or the increase demand from economic growth (which generally leads to an increase in associated emissions). In order to shed light into this question Figure 12 shows a cross plot of the scale effect *versus* the combined effect of structure and intensity in countries[7]. The dashed line indicates the separation of two regions. In countries above the dashed line scale effect outpaces the combined effects of structure and intensity. For countries below the dashed line the increase of emissions caused by economic growth is outpaced by improvements in efficiency and changes in the economic structure of the country. For countries in the neighbourhood of the dashed line, increases in emissions brought about changes in scale and reductions from intensity improvements and structural changes mostly balance out.

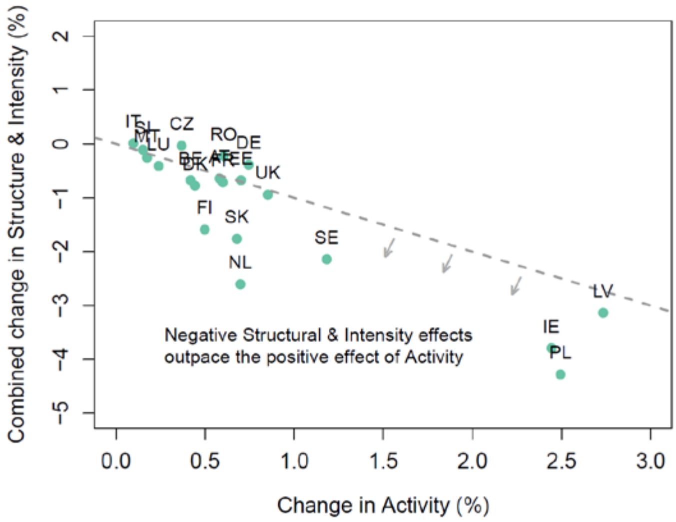

Figure 12 - Activity effect vs the combined effect of structure and intensity for the primary sector.

The same exercise presented in Figure 12 for the case of the primary sector was conducted for the secondary (industry), see Figure 13. As before, countries[8] below the 1:1 line (dashed) are those for which the positive (increasing) effect of activity in territorial emissions is outpaced by gains (reductions) of emissions brought about changes in the structure of the economy and efficiency (fewer emissions per economic output).

Most of the countries for which the activity effect was positive during the investigated time frame are located below the 1:1 line. This indicates that countries have decoupled their economic activity from territorial emissions of CO_2 between 2010 and 2015. The perpendicular distance of countries to the 1:1 line indicates how strong the decoupling has been. Accordingly, Italy (IT) and Finland (FI) are those for which the largest difference between the positive effect of activity and the compensating effects of structure and intensity have been

[7] Only countries with positive changes in the activity factor are shown.
[8] Only countries with positive changes in the activity factor are shown

observed. For Finland, the decrease in emissions brought about gains in efficiency and structural change were of about -20% while the effect of increase economic growth (activity) in emissions +10%. For the countries above the 1:1 line the opposite takes place. The most “extreme” case appears to be Estonia (EE) where although efficiency and structural change have contributed negatively (reduction) to CO_2 emissions (in the reason of about -8% during the time-period), the relative contribution of economic growth to emissions has been of more than 30%. Given the limited time series it is not possible at the moment to discern on how persistent in time the decoupling (and non-decoupling) has been. This would demand for a more comprehensive analysis including longer time series of CO_2 emissions broken down by sectoral activity and available for all member states.

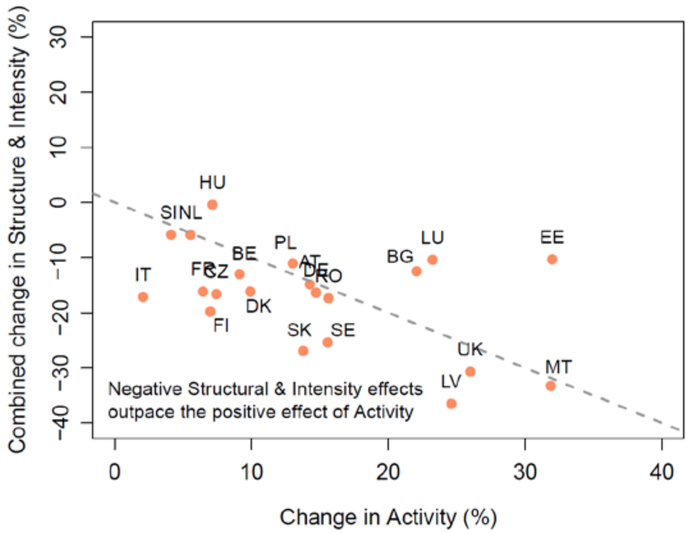

Figure 13 - Activity effect vs the combined effect of structure and intensity for the secondary sector

Unlike for the cases of the primary and secondary sectors, positive change in the activity of the tertiary sector (Figure 14) effect seem to be either outpaced, or compensated, by improvements in the intensity effect in nearly all the countries. The territorial decoupling of the tertiary sector appears therefore to be widespread across Europe, at least for the time-period evaluated. Although this constitutes good news, the fraction of green-house-gas emissions attributable to the service sector has been of about 10%[9] in 2015.

[9] http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics_-_air_emissions_accounts

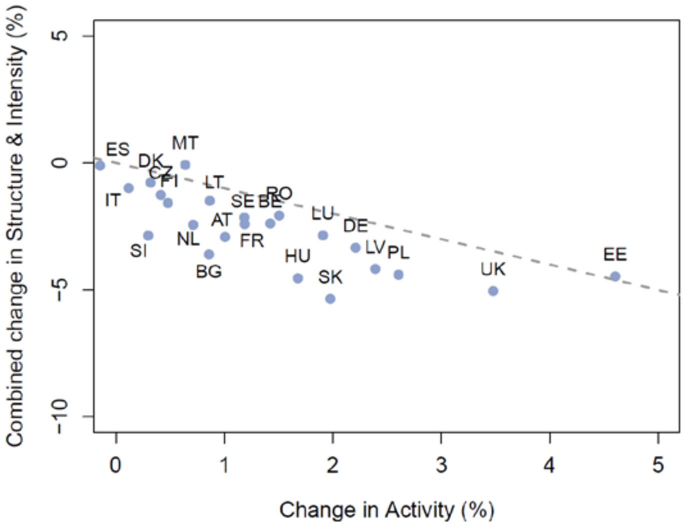

Figure 14 - Activity effect vs the combined effect of structure and intensity for the tertiary sector

7 Conclusions

While results of the IDA can vary greatly among countries, negative structural effects in the secondary sector played a role in all countries for at least one of the time periods, but often more. These effects were predominant in the 1990s and early 2000s, after which they mostly subsided and gave way to larger intensity effects. This seems to corroborate the hypothesis that a significant portion of the drop in energy consumption in European countries is due to deindustrialization rather than to energy efficiency. An equally significant portion can be attributed to energy efficiency. This points for much of the decoupling observed between economic growth and energy consumption to be virtual: it is largely due to the outsourcing of energy intensive activities. Accordingly, a shift in the dialogue of decoupling is necessary, and further emphasis put in devising effective energy efficiency policies for the key economic sectors of the EU.

In regard to the IDA made for territorial emissions of CO_2 the results are in line with those obtained for the case of energy. We found that for the majority of the countries the negative effect (decrease) in emissions brought about improvements in efficiency and structural changes outpace the positive (increase) effect on emissions brought about economic growth. For the time period evaluated (2010-2015) this has been particularly true to the tertiary and primary sectors. For the secondary (by far the most energy intensity sector) such apparent decoupling is also common among countries but to a larger extent that in the previous sectors. When IDA results for energy and emissions are compared for the matching time period, preliminary results point for the existence of a considerable lag between decreases in energy consumption of drop in territorial emissions in Europe. We have determined that the percentage reduction of final energy consumption in the secondary sector is circa two times larger than the corresponding savings in territorial CO_2 emissions. This highlights that in general the reduction of emissions will be felt much slower that the achievements in energy savings.

References

Ang, B.W. and Zhang, F.Q., 2000. A survey of index decomposition analysis in energy and environmental studies. *Energy*, *25*(12), pp.1149-1176.

Ang, B.W. "Decomposition analysis for policymaking in energy: which is the preferred method?" Energy Policy, 2004

Babbie, Earl R. (1998), *The practice of social research*. International Thomson Publishing Services, 1998.

Costa, L., Rybski, D., & Kropp, J. P. (2011). A human development framework for CO2 reductions. *PloS one*, *6*(12), e29262.

EEA (2016), Trends in energy intensity, gross domestic product and gross inland energy consumption." European Environmental Agency, December 2016.

Hoekstra et al. "Comparing structural and index decomposition analysis". Energy Economics, 2013

IEA (208), Worldwide trends in energy use and efficiency, International Energy Agency, 2008.

Kaufman, L. and Rousseeuw, P.J., (2009). *Finding groups in data: an introduction to cluster analysis* (Vol. 344). John Wiley & Sons, 2009

Moreau, V., & Vuille, F (2018). Decoupling Energy Use and Economic Growth: Counter Evidence from Structural Effects and Embodied Energy in Trade. Applied Energy, Elsevier, 20 Feb. 2018.

Steinberger, J. K., Roberts, J. T., Peters, G. P., & Baiocchi, G. (2012). Pathways of human development and carbon emissions embodied in trade. *Nature Climate Change*, *2*(2), 81.

UNEP (2011), M. Fischer-Kowalski, M. Swilling, E. von Weizs□acker, Y. Ren, Y. Moriguchi, W. Crane, F. Krausmann, N. Eisenmenger, S. Giljum, P. Hennicke, P. R. Lankao, A. S. Manalang, and S. Sewerin, Decoupling natural resource use and environmental impacts from economic growth, a report of the working group on decoupling to the international resource panel, UNEP, 2011.

8 Annex

8.1 Components of IDA analysis for territorial CO_2 Emissions

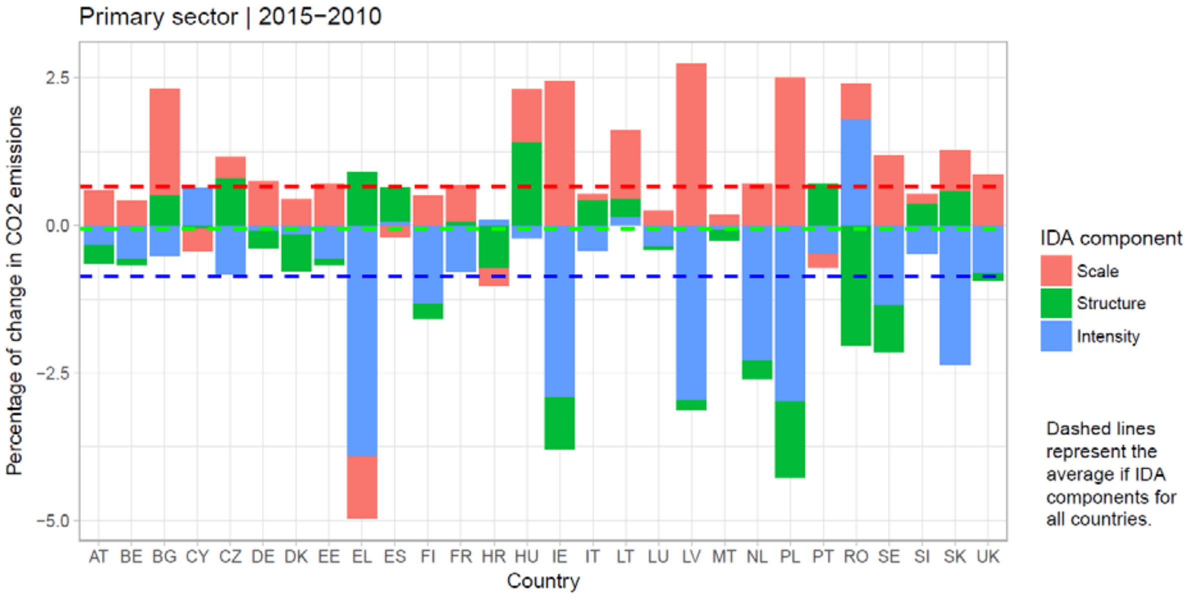

Figure 15 - IDA results for the primary sector, period 2015-2010

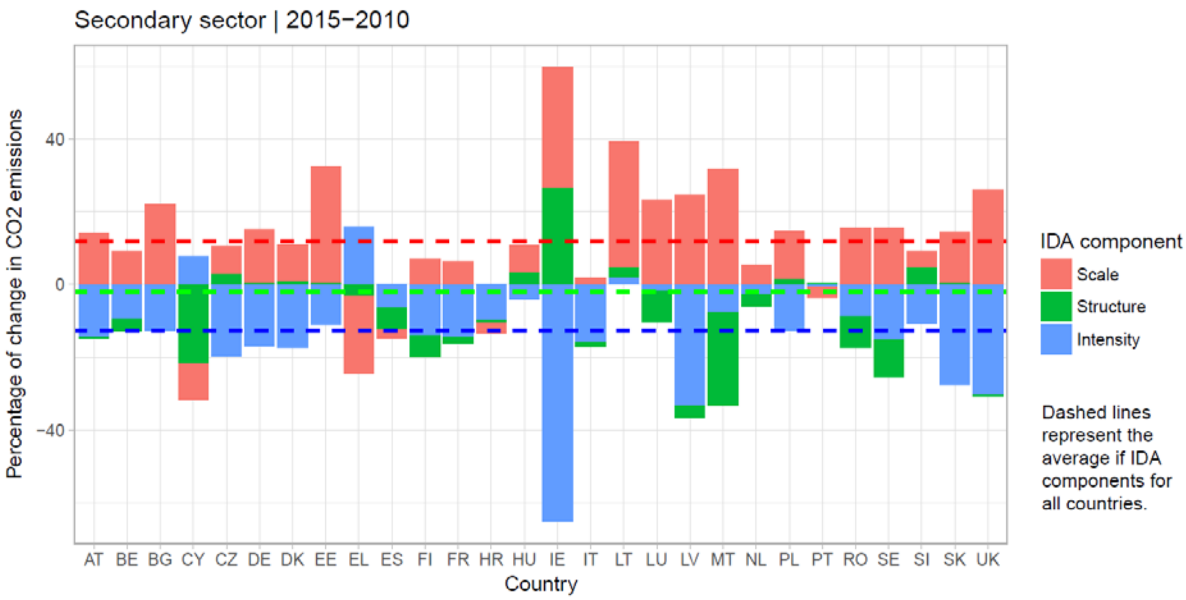

Figure 16 - IDA results for the secondary sector, period 2015-2010

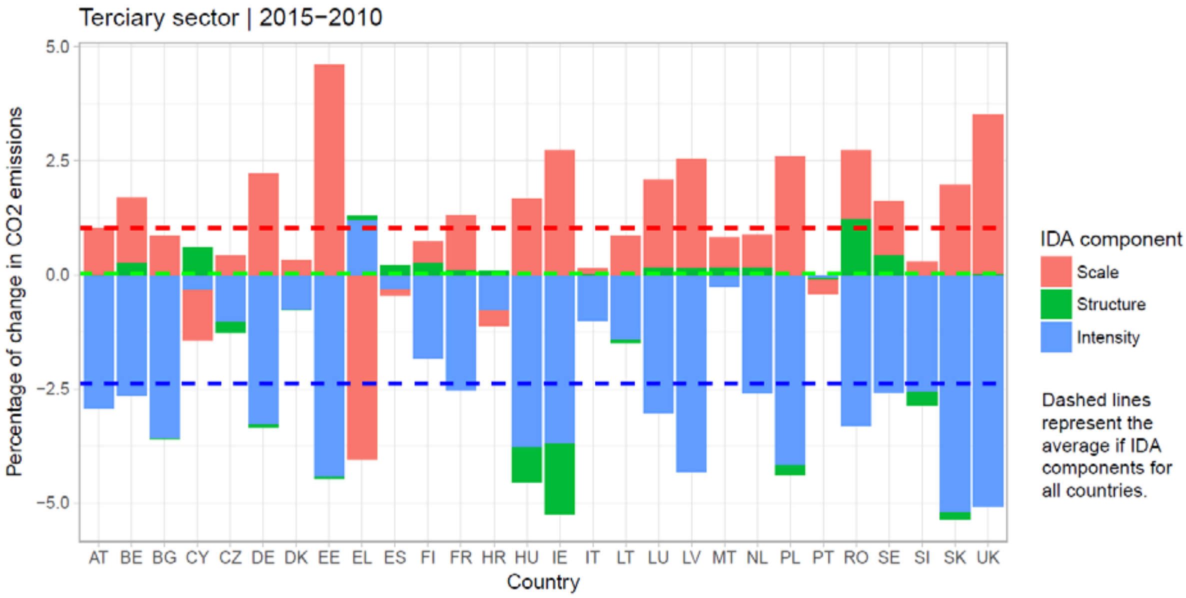

Figure 17 - IDA results for the tertiary sector, period 2015-2010