Decomposition Analysis of Greenhouse Gas Emissions in the European Union Based on Its Sectoral Structure

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Abstract

Climate change is a serious threat to sustainable development (SD). A Decomposition Analysis (DA) of the data on Greenhouse Gas (GHG) emissions in the European Union (EU) in 2008 – 2014 was carried out using the Log-Mean Divisia Index Method (LMDI). To detect the factors behind de/coupling of GHG emissions from Gross Value Added (GVA) in the EU-28, changes of GHG emissions were divided into three effects. The negative intensity effect showed the highest absolute magnitude in the overall period 2008 – 2014 and the two partial periods 2008 – 2011 and 2011 – 2014. The composition effect also helped reduce GHG emissions, but to a lesser extent. The scale effect boosted increases of GHG emissions except for two years, 2009 and 2012, which was related to the effects of the economic crisis. Transportation and storage along with the Agriculture, forestry and fishing activities should be addressed more significantly in relation to GHG emissions.

Keywords: *Climate Change, Decomposition Analysis (DA), European Union (EU), Greenhouse Gas (GHG) Emissions, Gross Value Added (GVA), Kyoto Protocol, Log-Mean Divisia Index Method (LMDI), Sustainable Development (SD)*

JEL Classification: Q51, Q54, Q56, F64

Introduction

Climate change has become one of the most urgent global environmental problems (Brizga, Feng and Hubacek, 2013). Accordingly, it represents a significant threat to sustainable development (SD). The scientific community has agreed that man-made GHG emissions are the dominant cause of Earth's average temperature increases over the past 250 years (IPCC, 2014). In response to climate change, it is necessary to reduce GHG emissions. As it was indicated

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above, these issues are related to the concept of SD. SD is a global challenge which requires a progressive transformation of economies (Hediger, 2006). According to the most quoted definition of the World Commission on Environment and Development (WCED, 1987), SD is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. SD represents a vision of progress which integrates short-term and longer-term objectives, local and global action, and regards social, economic and environmental issues as inseparable and interdependent components of human progress (European Commission, 2015). At the EU level, the EU Sustainable Development Strategy (EU SDS) was launched in 2001 and renewed in 2006. The themes of the EU SDS cover the economic, social, environmental, global and institutional dimension of SD, but these dimensions also overlap in particular themes. In terms of the EU SDS, climate change is understood as an unsustainable trend (Commission of the European Communities, 2001). The sixth theme entitled Climate Change and Energy is directly related to the issue and challenges of climate change. Its aim is to limit climate change and its costs and negative effects to society and the environment (Eurostat, 2017a).

The concept of decoupling environmental pressure from economic development is the crucial form of putting the concept of SD into operation. This conception refers to breaking the links between two variables, often referred to as the driving force, particularly economic growth expressed in terms of GDP or GVA, and the environmental pressures, such as the use of natural resources and the generation of waste/pollutants. Absolute decoupling occurs when environmental variable is stable or decreasing while the economic one is growing. Decoupling is relative when the environmental variable is growing, but at a lower rate than the economic variable (OECD, 2002). To investigate the factors behind the development of GHG emissions in the EU economy, a Decomposition Analysis (DA) is used in this paper. The aim of the paper is to discover if decoupling of GHG emissions from Gross Value Added (GVA) in the EU-28 in the period 2008 – 2014 took place and to detect the extent of influence of the selected factors, i.e. drivers of the development. Accordingly, the analysis is based on an investigation of the development of GVA and GHG emissions of the main sectors and their activities in the EU-28.

1. Theoretical Background and Literature Review

This section introduces DA and its application with a more detailed focus on the area of GHG emissions. The literature review contains the relevant approaches applied in the analysis.

The two dominant methods used for DA are Structural Decomposition Analysis (SDA), which is based on Input-Output (I-O) models, and Index Decomposition Analysis (IDA). Hoekstra and van den Bergh (2003) presented a comparison between these two methods. IDA is based on the use of index number theory (concept) in decomposition. Although IDA model is not capable of capturing indirect demand effects, its advantage is that it can be used to analyse any available data at any level of aggregation (Ma and Stern, 2008; Zhang, Mu and Ning, 2009) and is less data intensive. However, it is also less detailed since indirect inter-industry effects are not reported (Wood and Lenzen, 2009). The Laspeyres index and the Divisia index are the most commonly applied methods in IDA (Wang, Chen and Zou, 2005).

Sun (1998), Ang and Zhang (2000) and Ang (2004) provided an overview of IDA methodologies. A literature survey of IDA studies is presented in Ang and Zhang (2000) and a comparison and evaluation of IDA methods in Ang (2004). DA, and particularly IDA, have become widely accepted analytical tools for policymaking on national energy and environmental issues (Ang, 2004). According to Ang and Zhang (2000), the survey in 1995 listed a total of 51 studies and since then, new studies and new decomposition methods have been reported. Ang along with other authors have produced a substantial amount of literature on IDA for energy use and environmental emissions (e.g. Ang and Liu, 2001; Ang and Zhang, 2000). Overall, IDA has also become a useful tool in energy and environmental analysis in general (Ang and Zhang, 2000) and as a part of such analysis also one of the common methods for analyses of the emissions trends (Ščasný and Tsuchimoto, 2011) including CO_2 emission topics. In particular, as climate change and GHG emissions became a global issue in the 1990s, IDA was first extended from energy consumption to energy-related CO_2 emission studies in 1991. Since then many studies have been carried out for various countries and emission sectors.

Xu and Ang (2013) conducted a comprehensive literature survey and revealed the relative contributions of the key effects on changes in aggregate carbon intensity by emission sector and by country. Concerning IDA methodology, decomposition models for analysing emission changes are slightly more complex than those for changes in energy consumption. More factors are normally included in the IDA identity and a larger dataset is generally required. Thus, IDA became a useful analytical tool for studying the drivers of changes in CO_2 emissions (Xu and Ang, 2013). Moreover, Xu and Ang (2013) concluded that changes in energy intensity were generally the key driver of changes in the aggregate carbon intensity in most sectors and countries. In most cases, they contributed to decreases in the aggregate carbon intensity. If energy intensity is taken as a proxy for energy efficiency, improvements in energy efficiency have been the main driver of decreases in the aggregate carbon intensity for most sectors in most countries. The contribution of changes in the activity structure and those in the carbon factor have been less significant. While there were some uniform patterns among countries with respect to the underlying development of the aggregate carbon intensity, there were also disparities, which led to differences in development among countries. This has implications for future development of CO_2 emissions, especially of the developing countries. These conclusions also indicate that to reduce growth in future CO_2 emissions, countries should focus more on the activity structure and carbon factor.

A number of studies have used IDA for analysing energy intensity and consumption (Ang, 2005; Cornillie and Fankhauser, 2004; Duro and Padilla, 2011; Hatzigeorgiou, Polatidis and Haralambopoulos, 2008; Mulder and de Groot, 2013; Shahiduzzaman and Alam, 2013; Zha, Zhou and Ding, 2009) and GHG emissions (Agnolucci et al., 2009; Brizga, Feng and Hubacek, 2013; Ang and Zhang, 1999; Diakoulaki and Mandaraka, 2007; Feng, Hubacek and Guan, 2009; Hubacek, Feng and Chen, 2012; Lee and Oh, 2006; Lise, 2006; Löfgren and Muller, 2010; Paul and Bhattacharya, 2004; Wang, Chen and Zou, 2005; Wu, Kaneko and Matsuoka, 2005; Zhang et al., 2013). A large number of the studies were focused on Asia, especially on China. It is important to introduce several of them in order to understand the factors behind changes of GHG emissions, including their effects in different stages of development. Feng, Hubacek and Guan (2009) used the IPAT model (*IPAT equation: Impact (I) =Population (P) × Affluence (A) × Technology (T)*) for China to analyse how these main drivers contributed to the growth of CO_2 emissions, representing *Impact*, over 1952 – 2002.[1] Affluence or lifestyle change has been variously recognized as one of the crucial factors contributing to CO_2 emissions. The main driving forces of changes in CO_2 emissions in the prereform period shifted between population growth, a growing level of affluence, and changes in industrial structure. At later stages, the improvement in the emission intensity started offsetting some of the increases in CO_2 emissions caused by the other drivers. Wang, Chen and Zou (2005) analysed the change in aggregated CO_2 emissions in China in the period 1957 – 2000 based on the LMDI method. They showed that China has achieved a considerable decrease in its CO_2 emissions mainly due to improved energy intensity. Fuel switching and renewable energy penetration also had positive effects on the decrease in CO_2 emissions. By means of IDA, Wu, Kaneko and Matsuoka (2005) revealed that trends in energy-related CO_2 emissions in China in the

[1] The IPAT identity based upon IDA allows identifying the relationship between the driving forces and environmental impacts (Hubacek, Feng and Chen, 2012; York, Rosa and Dietz, 2003).

1980s were driven by a trade-off between the positive sectoral-specific scale effects, including the activity intensity effect and activity size effect, and the negative energy intensity effects. Structural change accounted for only a small portion. Zhang et al. (2013) analysed the status of CO_2 emissions from electricity generation in China in 1991 – 2009. The authors applied the LMDI approach to find the essence of the factors influencing changes in CO_2 emissions. The economic activity effect was the most important contributor towards increasing CO_2 emissions from electricity generation.

Lee and Oh (2006) decomposed changes in CO_2 emissions in Asia Pacific Economic Cooperation (APEC) countries in 1980 – 1998 using the LMDI approach. They concluded that the growth in GDP per capita and population are the two dominant contributors to the increase in CO_2 emissions in most cases. Efficiency improvements in energy and fuel substitution contributed to decreases in CO_2 emissions in APEC. The complete DA as originally proposed by Sun (1998) was also carried out by Lise (2006) to detect which of the factors, i.e. scale, composition, energy and carbon intensity, explain the changes in CO_2 emissions in Turkey in 1980 – 2003. Pursuant to the scale effect, a decoupling of carbon emissions and economic growth did not take place in Turkey over this period. Accordingly, as is common to relatively fast growing economies, the biggest contributor to the rise in CO_2 emissions was the expansion of the economy, i.e. the scale effect. The energy intensity of the economy, which was decreasing, was responsible for a modest reduction in CO_2 emissions. The composition of the economy and the carbon intensity also contributed to the increase in CO_2 emissions. Paul and Bhattacharya (2004) referred to the major economic sectors of India in the period 1980 – 1996 and aimed at identifying the factors that have influenced changes in the level of energy-related CO_2 emissions. By means of DA, the observed changes are analysed in terms of four factors (effects), i.e. pollution coefficient, energy intensity, structural changes and economic activity. Economic growth had the largest positive effect on changes in CO_2 emissions in all the major economic sectors. Emissions of CO_2 in industrial and transport sectors showed a decreasing trend due to improved energy efficiency and fuel switching.

Brizga, Feng and Hubacek, (2013) provided detailed country-by-country analyses determining factors for changes of CO_2 emissions in post-Soviet republics by applying a disaggregated version of the commonly used IPAT IDA including energy intensity, affluence industrialization, energy mix, carbon intensity and population. According to the authors, these factors played different roles during different stages of economic development. During a period of economic growth, affluence boosts emissions that are only partly compensated by decreasing energy intensity. On the other hand, during an economic recession the emission decrease is predominantly driven by decrease of affluence as well as of the share of fossil fuels. Ang and Zhang (1999) described the use of the decomposition technique for comparing energy-related CO_2 emission levels in three OECD and three world regions. The LMDI approach was applied. The relative importance of contributions associated with fuel share, aggregate energy intensity, income, and population depends on the regions compared.

The last part of the literature review is focused on the EU and its countries to which DA was applied. Diakoulaki and Mandaraka (2007) examined energy related CO_2 emissions in the manufacturing sector in 14 EU countries. This paper comparatively evaluated the progress made in 14 EU countries in decoupling of emissions from industrial growth in the period 1990 – 2003. The refined Laspeyres model was used to detect the impact of five explanatory factors, i.e. output, energy intensity, structure, fuel mix, and utility mix. It is concluded that most EU countries made a considerable but not always sufficient decoupling effort, while no significant acceleration was observed in the period following the agreement on Kyoto Protocol. The actions to reduce CO_2 emissions were not always sufficient to decouple emissions from industrial growth. The authors also found out that the decrease in industrial energy intensity and the shift towards cleaner energy forms in electricity generation have the greatest beneficial impact on the decoupling process. A description and application of DA to CO_2 emissions in Germany can be found in Seibel (2003). Hatzigeorgiou, Polatidis and Haralambopoulos (2008) carried out a DA on energy-related CO_2 emissions in Greece from 1990 to 2002. The Arithmetic Mean Divisia Index (AMDI) and the LMDI techniques were applied and changes in CO_2 emissions were decomposed into four factors: income effect, energy intensity effect, fuel share effect, and population effect. The authors showed that the biggest contributor to the rise in CO_2 emissions in Greece is the income effect. On the contrary, the energy intensity effect is mainly responsible for the decrease in CO_2 emissions. Löfgren and Muller (2010) carried out a DA to identify the drivers of CO_2 emissions change in the Swedish business and industry sectors in the period 1993 – 2006. Overall, the energy intensity decreased, but this does not seem to have been very important for reducing emissions. Fuel substitution seems to have been more important. At the sectoral level, no clear pattern of the effect of fuel substitution and energy intensity on emissions was detected.

According to Agnolucci et al. (2009), the crucial aspect for a society that seeks to contribute to climate change mitigation is the difference between achieving reduced carbon emissions through higher energy prices, behaviour change involving energy conservation and lower economic growth, or through a higher growth society in which a significant part of this growth is required for investment in low-carbon energy supply. Finally, the results of the crucial study in this field cannot be left unmentioned (Kisielewicz et al., 2016). The authors applied two complementary analyses that decomposed the changes in GHG emissions to identify the relative significance of different drivers. The first method provided a detailed sectoral analysis, an examination of the relative significance of different types of renewable energy and the use of specific time frames to reflect the entry into force of specific policies. The second approach involved the use of an IDA and the World I-O Database to analyse a larger number of economic sectors and to investigate the role of structural changes in the economy in the evolution of the EU's GHG emissions. The same conclusion was drawn from the two analyses, i.e. there was a decoupling of economic growth from GHG emissions in the EU during the period 1995 – 2012, which was mainly driven by technological improvements. GHG emissions did not rise in line with the economic growth experienced during the period 1995 – 2008.

The results of the aforementioned papers inspired the analysis carried out in this paper, which is focused on the EU-28. Overall, it can be concluded that the output/income, emission intensity and the structure of the economy/sectors were in particular forms used in all the papers. Using these three factors in the DA in this work is thus justified. Finally, this work is based on two previous papers by the author applying an IDA and the LMDI (Drastichová, 2016; 2017), where a similar methodology was applied to the Domestic Material Consumption (DMC) and GHG emissions in the EU-28 respectively. However, the structure of the EU based on its countries, not NACE activities, was used to determine the composition effect. GVA is used in this paper instead of GDP, which was used in the previous one, to reflect the products of the analysed sectors and their activities.

2. Data and Methodology

In this section the source of data used, the indicators applied and the IDA methodology applied in this paper are introduced.

2.1. Foundation of the Data Used

The EU-28 as a whole and its sectoral structure is the subject of the analysis. All the data applied were extracted from Eurostat (2017b). NACE Rev. 2 classification of economic activities is used to define industry breakdowns for both the economic and the environmental variable, i.e. GVA and GHG emissions respectively.[2] As the detailed classification provided for these variables differs, 21 main activities A – U are used in the analysis. GHG emissions include CO_2, N_2O in CO_2 equivalent and CH_4 in CO_2 equivalent. The units used are tonnes.

GVA in chain linked volumes (reference years: 2005 and 2010) in million euro is used as the economic variable representing the economic activity. Chain-linked level series are obtained by successively applying previous year's price's growth rates to the current price figure of a specific reference year, particularly 2005 and 2010. The choice of appropriate indicator of economic activity is challenging. The problematic aspects that needs to be considered when using the variable of the economic activity in chain linked volumes is that chain-linking involves the loss of additivity for all years except the reference year and the directly following year, as these are the only periods expressed in prices of the reference year.

However, in percentage terms, the deviations between the provided aggregates for the EU-28 and the sums calculated for the included activities A – U are low. Therefore, the results of the analysis can still be regarded as reliable. In each monitored year, they are lower than 0.5%. The highest deviation was reached in 2013 for both GVA indicators (0.363% and 0.234% for the 2005 and 2010 reference year respectively). Both GVA indicators are applied in the DA, as the deviations for each of them differ in particular years. This is consistent with the definition of such a kind of indicator that is expressed in chain linked volumes.

2.2. Index Decomposition Analysis Methodology

DA explains the channels through which certain factors affect a variable (Ščasný and Tsuchimoto, 2011). Accordingly, the different factors need to be identified, whereas this is fully a case-specific issue (Vehmas, Luukkanen and Pihlajamäki, 2008). As it was already indicated, the simplicity and flexibility of IDA methodology make it easy to be adopted in comparison to the SDA where I-O tables are required (Ang, 2004). Any DA starts with the creation of an equation by means of which the relations between a dependent variable and several factors ("underlying causes") are defined. In this equation, the product of all the factors has to be equal to the variable, the change of which is analysed in the DA (see more in Drastichová, 2016).

[2] NACE (Statistical classification of economic activities in the European Communities) is the acronym used to designate the various statistical classifications of economic activities developed since 1970 in the EU. It provides the framework for collecting and presenting a large range of statistical data according to economic activity in the fields of economic statistics, e.g. production, employment, national accounts, and in other statistical domains (European Communities, 2008).

The factors choice should be determined by the conceptual model. In the analysis of this paper, the environmentally related variable represented by the GHG emissions is decomposed into three factors, which affect its development.

Firstly, the *scale*, or *activity factor* (Y), measures the change in the aggregate (GHG emissions) associated with a change in the overall extent of the activity, i.e. the GVA.

The second, *composition*, or *structure factor* (S), is related to changes in the structure of the economy, i.e. the change in the aggregate (GHG emissions) linked to the change in the mix of the activity by sub-category. The 21 NACE activities are used to determine the structure of the EU economy.

Thirdly, *intensity*, or *technique factor* (I) expresses the emissions intensity of a partial/sectoral production (based on the 21 activities) to produce a unit of an output. More generally, it is the change in the aggregate associated with changes of the environmental intensities in the sub-categories (Ščasný and Tsuchimoto, 2011).

To quantify the impacts of the changes of the factors on the aggregate, various decomposition methods can be formulated in the framework of an IDA (see also section 1). The two most important decomposition approaches include the methods based on the Divisia index including the LMDI and those based on the Laspeyres index. For both categories, a DA can be performed additively or multiplicatively and the choice between the two is arbitrary. In the multiplicative decomposition the *ratio* change of an aggregate and in the additive approach its *difference* change is decomposed (Ang, 2004). The differences lie in ease of result presentation and interpretation (Ang and Zhang, 2000). The multiplicative LMDI I also possesses the additive property in the log form. The LMDI I is recommended for general application (see more in (Drastichová, 2016; 2017) and it is applied in this paper. This approach has time-reversal and factor reversal properties, leaves no residuals (the property of perfect decomposition), and can address the zero values in the dataset (Ang, 2004). The logarithmic mean (*L*) of two positive numbers *x* and *y* is defined as:

$$L(x,y)=\frac{y-x}{ln\left(\frac{y}{x}\right)};\ If\ x\neq y,\ \ otherwise\,L(x,y)=x \tag{1}$$

Based on Ščasný and Tsuchimoto (2011) and Ang and Zhang (2000), the quantitative foundation of the applied IDA using the LMDI is presented by Equations (2) – (9). In general, the formulas for the multiplicative and the additive LMDI decomposition are expressed by Eq. (2) and (3) respectively:

$$E_{total} = \frac{E_T}{E_0} = E_{x1} \times E_{x2} \times E_{x3} x \ldots \times E_{xn} \quad (2)$$

$$\Delta E_{total} = E_T - E_0 = \Delta E_{x1} + \Delta E_{x2} + \Delta E_{x3} + \ldots + \Delta E_{xn} \quad (3)$$

Equations (2) and (3) show that the total environmental effect (E_{total}) from period 0 to period T is generally decomposed into n factors where E_{xk} denotes the contribution of k^{th} factor to the change in the total environmental effect from 0 to T. E_{total} indicates the change of the variable whose factors of change are analysed. E_T is the value of variable at time T and E_O is the value in time 0. The following methodology description is related to the additive LMDI decomposition because this is applied in the analysis due to its features and simple application and interpretation. Within the framework of the three-factor DA, E_{total} is divided into the activity effect (E_{act}), the structure effect (E_{str}) and the intensity effect (E_{int}) which is indicated by Eq. (4):

$$\Delta E_{total} = E_T - E_0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \quad (4)$$

Applying the three factor DA, the above explained three effects are calculated as follows:

$$\Delta E_{act} = \left(\sum_{i=1}^{n} L(E_i^0; E_i^T) * \ln\left(\frac{Y^T}{Y^0} \right) \right) \quad (5)$$

$$\Delta E_{str} = \left(\sum_{i=1}^{n} L(E_i^0; E_i^T) * \ln\left(\frac{S_i^T}{S_i^0} \right) \right) \quad (6)$$

$$\Delta E_{int} = \left(\sum_{i=1}^{n} L(E_i^0; E_i^T) * \ln\left(\frac{I_i^T}{I_i^0} \right) \right) \quad (7)$$

where symbols Y, S, I indicate the activity (scale), structure (composition) and intensity effect respectively. The form of the variables applied in the analysis, i.e. the meaning of Y, S, I in the second parts of the Eq. (5) – (7), is explained in Table 1.

The first part of these equations expresses the logarithmic mean according to the Eq. (1), particularly:

$$L(E_i^0; E_i^T) = \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \quad (8)$$

For applying the IDA to the relationships between GHG emissions and GVA, the variables and formulas are described in Table 1.

Table 1

Description of Variables and Formulas Used in the Decomposition Analysis

Formula	Indication	Description
$GHG = \sum_{i=1}^{n} GHG$	Greenhouse gases (CO_2, N_2O and CH_4 in CO_2 equiv.)	The total effect: the total change of GHGs in EU-28; GHG = the sum of GHG emissions in 21 NACE activities (in tonnes, in period *t*).
$GVA = \sum_{i=1}^{n} GVA$	Scale effect (Y)	The scale (activity) effect: the effect of changes in overall GVA (the sum of all activities) on the change in GHGs, GVA_i : GVA of the *i*-th activity (sector); GVA: overall GVA of the entire EU-28 economy.
$\Delta_t \frac{GVA_i}{GVA}$	Composition effect (S)	The composition (structure) effect: the effect of changes in the GVA structure according to the 21 NACE activities on the GHG.
$\Delta_t \frac{GHG_i}{GVA_i}$	Intensity effect (I)	The intensity effect: the effect of changes in GHG intensities in the 21 NACE activities on the GHGs.

Source: Own elaboration.

To sum up the previous findings, the additive IDA using the LMDI applied in this is based on the formula indicated by Eq. (9). The total GHG emissions in the EU in time period *t* are split into three components:

$$\Delta_t GHG = \sum_{i=1}^{n} Y + S_i + I_i = \sum_i \Delta_t GVA + \Delta_t \frac{GVA_i}{GVA} + \Delta_t \frac{GHG_i}{GVA_i} \qquad (9)$$

whereas all the components of Eq. (9) are described in Table 1 (*i* – the NACE activity (sector), *t* – the period). The formula was explained in Eq. (5) – (8) using the LMDI. The analysis is aimed at the EU and the structure effect is based on the structure of the activities (sectors) in the NACE classification.

3. Results of the Analysis

Firstly, the development of the overall GHG emissions and GVA, and in the particular NACE activities included are analysed. Subsequently, the results of the LMDI decomposition of GHG emissions in the EU are presented.

3.1. Development of GHG Emissions and GVA in the EU

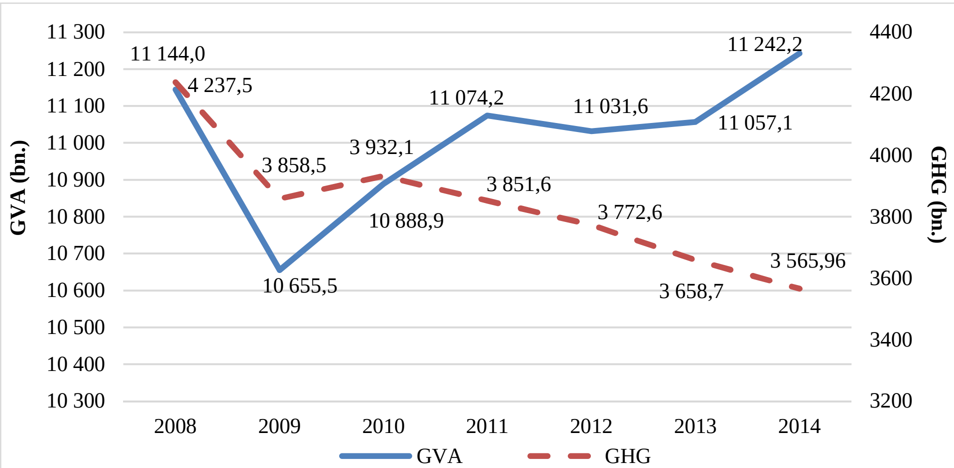
The development of total GVA and GHG emissions in the EU-28 is displayed in Figure 1. The GVA indicator based on the reference year 2005 is particularly used, however, the results are similar for both GVA indicators (the differences in growth rates are marginal). In the overall monitored period 2008 – 2014, absolute decoupling occurred, i.e. GVA increased (0.881%) and GHG emissions decreased (–15.847%).

However, the negative correlation in the overall period cannot be confirmed. The correlation coefficient (*r*) was low (–0.151). On the other hand, in period 2009 – 2014, the negative correlation is visible (r = –0.713) and it is even stronger in the period 2010 – 2014 (r = –0.861).

As regards particular years, both GVA and GHG decreased in 2009 and 2012, while the drop in GHG emissions surpassed that of GVA (decreases of –8.944% (2009) and –2.052% (2012) for GHG in relation to decreases of –4.384% (2009) and –0.385% (2012) for GVA)). In 2010, relative decoupling occurred when GVA increased by 2.190% and GHG emissions by 1.908%. Absolute decoupling took place in the remaining three years, i.e. 2011, 2013 and 2014, when GHG emissions dropped along with simultaneous increases in GVA. In 2013, the increase in GVA was very slight, i.e. 0.231% and the decline in GHGs was relatively high, i.e. –3.020%. In 2011 and 2014, GVA growth rates exceeded 1% (1.701% and 1.674% respectively) and they were accompanied with lower decreases in emissions (–2.046% and –2.534% respectively) than the decrease of 2013.

F i g u r e 1

GHG Emissions (bn. tonnes of CO_2 equivalent), GVA in Chain Linked Volumes (2005; bn. euro), EU-28, 2008 – 2014



Source: Eurostat (2017b); own elaboration.

The shares of particular activities in total GVA and GHG emissions showed different magnitudes. The activities with the lowest and highest shares in both of them are indicated in Table 2 using the percentage shares of the variables for particular activities in the sums of the variables. The manufacturing sector showed the highest share in GVA in all the monitored years (over 15% in all the years for both GVA variables, except for GVA (2010) in 2009, which showed 14.437%). Activities of extraterritorial organisations and bodies showed the shares very close to zero, while those of the remaining ones included in Table 2, representing the activities with the lowest shares in GVA, were below 1% in all the monitored years.

As regards the shares of the particular NACE activities in GHG emissions, all the activities included in Table 2 as those with the lowest shares, did not exceed 0.3% in each year of the monitored period. The shares of the first three sectors (Table 2) were even lower than 0.2% of the overall GHG emissions, while the very first of them, i.e. Activities of extraterritorial organisations and bodies, showed a value close to zero. Transportation and storage showed the fourth highest percentage share in GHG emissions in all the years except for the first monitored year, 2008, when the share of Agriculture, forestry and fishing was slightly lower (12.548%). In all the remaining years, the shares of both sectors surpassed 13% and the shares of Agriculture, forestry and fishing were even above 14% in the last two monitored years 2013 and 2014. Other activities with relatively high shares should also be mentioned. Water supply; sewerage, waste management and remediation activities had shares above 5% except for 2013 and 2014 when the shares decreased to just over 4.9%. Mining and quarrying along with Wholesale and retail trade; repair of motor vehicles and motorcycles showed shares above 2% in all the monitored years, except for the latter in 2008, when it achieved 1.977%. Construction showed shares above 1% in all the monitored years. All the remaining activities had shares in GHG emissions lower than 1%.

T a b l e 2

The NACE Activities with the Lowest and Highest Shares in GVA in Chain Linked Volumes (2005, 2010) and GHG Emissions, EU-28, 2008 – 2014

	GVA	**GHG**
Lowest shares	Activities of extraterritorial organisations and bodies Activities of households as employers; undifferentiated goods- and services--producing activities of households for own use Mining and quarrying Water supply; sewerage, waste management and remediation activities	Activities of extraterritorial organisations and bodies Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use; Arts, entertainment and recreation; Financial and insurance activities; Real estate activities; Information and communication; Other service activities
Highest shares	Real estate activities (above 10%) Wholesale and retail trade; repair of motor vehicles and motorcycles (above 11%) Manufacturing (above 14%)	Transportation and storage (above 13%) Agriculture, forestry and fishing (above 12%) Manufacturing (above 23%) Electricity, gas, steam and air conditioning supply (above 32%)

Note: The shares of activities in GVA and GHG emissions which were exceeded each year are indicated in parentheses.

Source: Eurostat (2017b); own elaboration.

It can also be concluded that while the Manufacturing sector showed the highest shares in both GVA and GHG, Real Estate Activities showed relatively high shares in GVA, but relatively low shares in GHG emissions. It is also important to note that GHG emissions of all examined activities decreased in period 2008 – 2014. The highest decreases occurred by Activities of extraterritorial organisations and bodies, whose overall GHG emissions are marginal, and by Public administration and defence; compulsory social security (both exceeding 27% in absolute values). Another three sectors reduced their emissions by more than 20%, particularly other service activities (–22.772%), Mining and quarrying (–21.426%) and Manufacturing (–20.562%). As Manufacturing is the sector that produced one of the highest amounts of GHG emissions, this decline is especially important. The decrease of emissions in Electricity, gas, steam and air conditioning supply was also relatively high, i.e. –18.260%. Relatively low decreases occurred in other two major GHG emitters, i.e. Transportation and storage (–12.066%) and Agriculture, forestry and fishing (–1.376%). Overall, the latter activity showed the lowest decrease as compared to others. In general, the transport sector, which is an important produced of GHGs, seems to be problematic with regard to the reduction of GHG emissions in the EU as well as in most of its countries (see more in Drastichová, 2014).

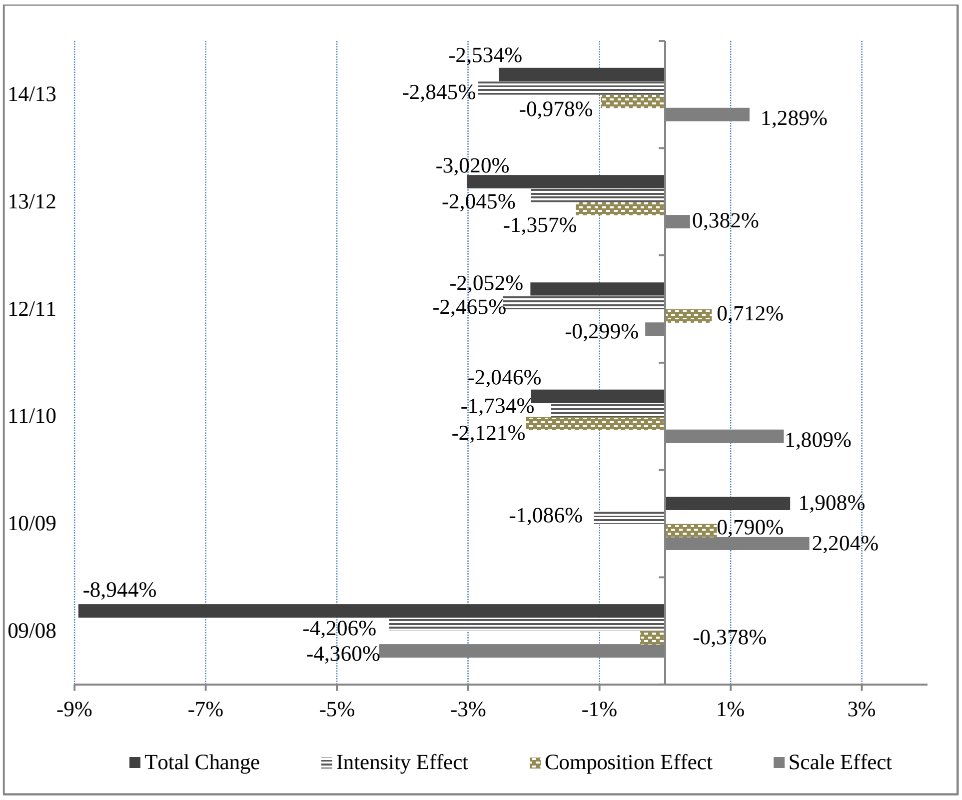
3.2. Results of the Index Decomposition Analysis

To detect the factors of changes in GHG emissions within the EU-28, an IDA of GHG emissions was carried out. The results of the IDA applying the additive form of LMDI to data of Eurostat (2017b) are presented in this subsection. The total effect reflects the percentage change of the GHG emission indicator and thus it showed the same magnitude for both GVA indicators used. The applied GVA indicator very slightly affected the division into three partial effects (the differences are marginal). Firstly, the results of the year-by-year DA are presented in Figures 2 and 3 applying GVA in chain linked volumes in 2005 and 2010 prices respectively. The total effect was negative in the five years and it was positive only in 2010, which is consistent with the annual GHG changes. However, in absolute values this change showed the lowest magnitude when compared with the extent of this effect in other years. In 2009, the highest annual decrease of GHG emissions occurred which is related to the economic crisis. In this year, not only the significant negative intensity effect, but also the high negative scale effect led to considerable drop in the GHG emissions. Moreover, the composition effect was negative as well, but it was relatively low.

The scale effect was negative only in 2009 and 2012 and the highest positive changes occurred in 2010 and 2011 respectively, which complies with annual changes in GVA (see subsection 3.1, Figure 1). As indicated above, the huge negative scale effect in 2009 significantly affected the annual fall in GHG emissions. The composition effect was positive only in 2010 and 2012 and the highest negative effect occurred only in 2011 (for both GVA indicators above 2% in absolute values). The intensity effect was negative in all the monitored years and highest in magnitude in 2009, followed by 2014.

F i g u r e 2

The Scale, Composition, Intensity and Total Effect in the Year-by-year DA of GHG Emissions, EU-28, 2008 – 2014, %; GVA in Chain Linked Volumes (2005) Used

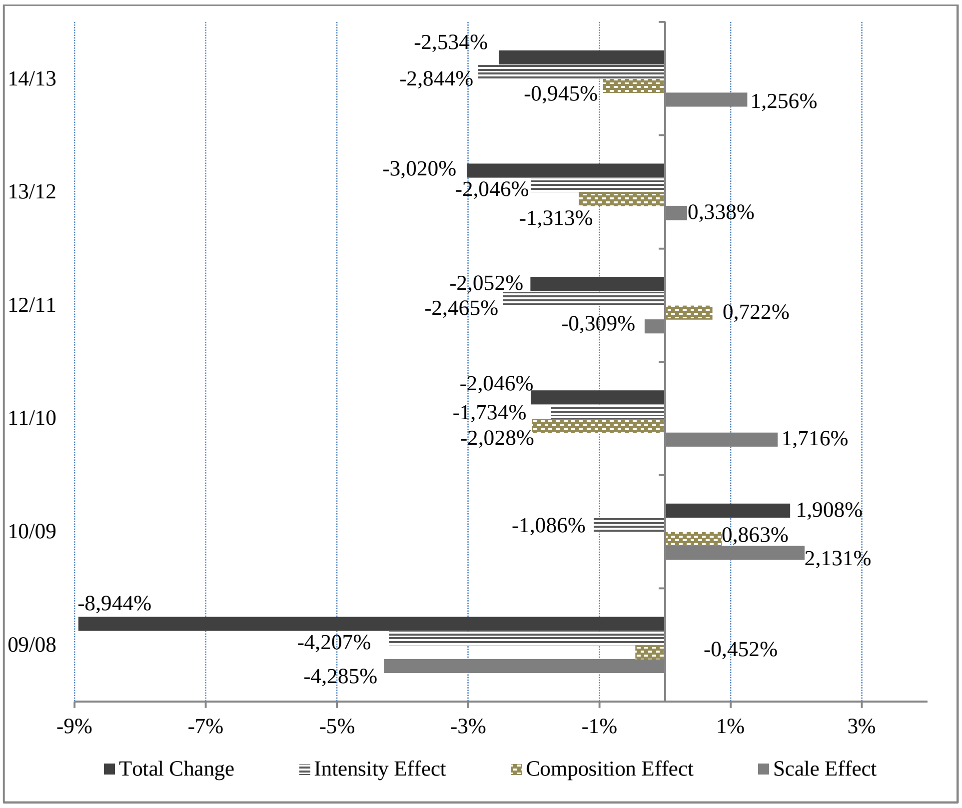


Source: Eurostat (2017b); own calculation.

For both GVA indicators, in the absolute values, the intensity effect surpassed the composition effect in each year except for 2011, and the composition effect exceeded the scale effect in three monitored years (2011, 2012, and 2013). Figure 3 presents the results of the DA using GVA in chain linked volumes (2010) as the indicator of economic activity. As compared to Figure 2, it can be seen that the differences in the extent of the partial effects in the year-by-year decomposition are only marginal.

Figure 3

The Scale, Composition, Intensity and Total Effect in the Year-by-year DA of GHG Emissions, EU-28, 2008 – 2014, %; GVA in Chain Linked Volumes (2010) Used



Source: Eurostat (2017b); own calculation.

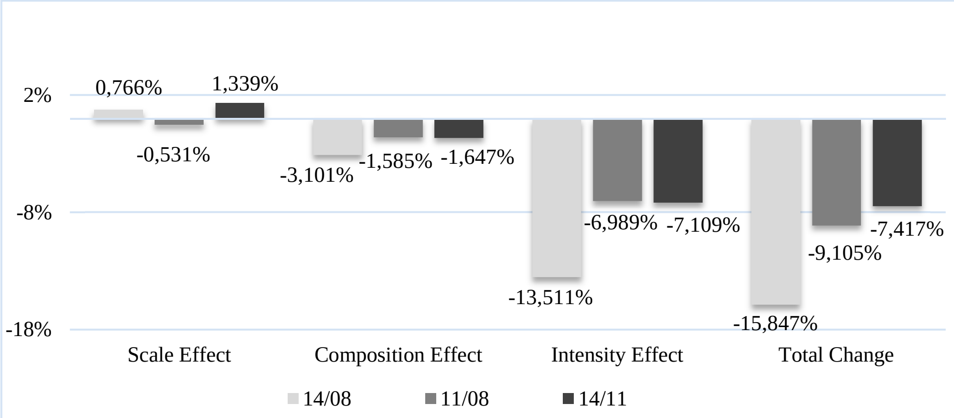
In the next step, the results of the DA in the overall monitored period 2008 – 2014 and the two partial periods 2008 – 2011 and 2011 – 2014 are presented in Figure 4 using GVA in chain linked volumes (2005) and in Figure 5 using GVA in chain linked volumes (2010).

In a similar way to the year-by-year decomposition, the differences between the results for the two GVA indicators applied are only marginal. For both GVA indicators and all three monitored periods, the absolute values of the composition and intensity effect surpassed those of the scale effect, while the intensity effect showed the highest absolute magnitude of all in all the periods.

Using GVA with the reference year 2005, slightly lower intensity effects in absolute values were obtained, but this is hardly visible in Figures 4 and 5 because the difference is minor. The other partial effects showed higher levels for GVA using the reference year 2005 except for the scale effect in the period 2008 – 2011.

F i g u r e 4

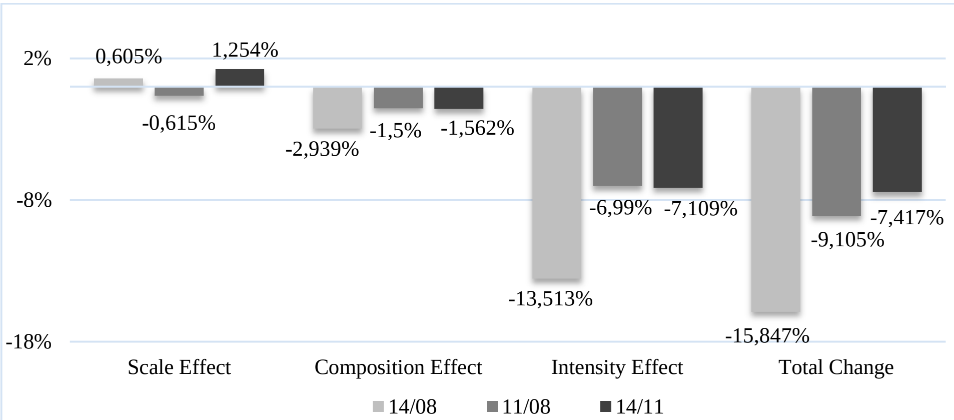
The Scale, Composition, Intensity and Total Effect in the DA of GHG Emissions in the Periods, EU-28, %; 2008 – 2014; 2008 – 2011, 2011 – 2014, GVA in Chain Linked Volumes (2005) Used



Source: Eurostat (2017b); own calculation.

F i g u r e 5

The Scale, Composition, Intensity and Total Effect in the DA of GHG Emissions in the Periods, EU-28, %; 2008 – 2014; 2008 – 2011, 2011 – 2014, GVA in Chain Linked Volumes (2010) Used



Source: Eurostat (2017b); own calculation.

It can be concluded that except for the period affected by the recession, the scale effect predominantly led to an increase in GHG emissions, while both the composition and especially the intensity effect led to their decrease. The relatively high magnitude of the intensity effect significantly encouraged decreases in GHG emissions. Thus, a negative total effect was achieved in the overall as well as in both partial monitored periods. Accordingly, absolute decoupling took place in the overall monitored period and in the second partial period when GVA increased and GHG emissions dropped. In the first partial period GVA decreased as well, due to a significant drop in GHG emissions in 2009, which was reinforced by the economic crisis and recession. The development trends comply with the studies introduced in the literature review.

Accordingly, it was also detected that in the time of economic problems or slow economic growth the GHG emissions decrease more significantly than in the time of rapid economic growth. These findings comply with Brizga, Feng and Hubacek (2013). These conclusions are also similar to Drastichová (2016; 2017), but they are deeper. Several recommendations can also be derived, i.e. the EU, national authorities and other authorities (at lower level as well) should develop and apply policies and strategies to further enhance the negative intensity effect. Moreover, it results from the analysis, contrary to the findings from Drastichová (2016; 2017) that the negative composition effect plays the important role as well and therefore, it should by appropriately advanced. It means that composition of the EU does not play a significant role regarding the structure based on the countries but the structure of economy based on the sectors and their activities plays an important role. The greater attention should be paid to the sectors generating high amount of emissions and especially to those, in which the GHG emissions decreases were relatively lower, particularly Transportation and storage and Agriculture, forestry and fishing.

These conclusions can also be linked to those of Kisielewicz et al. (2016). As indicated in section 1, they revealed that technological improvements and the deployment of low-carbon technologies were the main determinants behind the emissions reduction which has occurred since 1995. This study also indicated that the shift towards less carbon-intensive economic sectors, such as from industry to services, had in fact a limited impact on net emissions. There was a shift in the economy towards less carbon-intensive sectors within Member States. This means that, within a country, structural changes in the economy contribute to decreases in emissions. However, at the EU level, this effect was offset by a shift of output within the EU towards countries which have a higher emission-intensity. This reflects “between-country structural effects”. Nevertheless, the results of the IDA carried out in this paper in the monitored period 2008 – 2014 confirmed that at the EU level the negative composition (structural) effect contributed to decreases in GHG emissions, including both partial periods. Following the results of subsection 3.1, it must be emphasised that GVA decreased in the monitored period most significantly in Mining and quarrying (–23.361%), followed by Construction (–16.867%). GVAs of the other GHG-intensive sectors decreased as well. This is especially the case for Electricity, gas, steam and air conditioning supply (–2.749%), Manufacturing (–1.802%), Agriculture forestry and fishing (–0.434%), and Transportation and storage (–4.423%). Nevertheless, the GVA of Water supply; sewerage, waste management and remediation activities, which is the sector with the fifth highest GHG emissions in 2014, slightly increased (3.488%). On the other hand, GVAs of the various services predominantly increased. The highest increases occurred in Information and communication (14.099%), Human health and social work activities (9.781%), Real estate activities (6.976%) and Administrative and support service activities (4.309%). Thus, it can be concluded that the composition effect at the EU level played its role in the process of decoupling.

At the EU level, the key strategies should be supported and further enhanced. These especially include the long-term EU SDS that has provided the groundwork for achieving SD, the shorter-term and dynamic Europe 2020 Strategy, as well as the 7^{th} Environment Action Programme, for which the Europe 2020 Strategy created the basis. The other two strategies related to the previous ones are of crucial importance for the effort of the EU to mitigate climate change. The 2020 package, i.e. a set of binding legislation to ensure the EU meets its climate and energy targets for the year 2020, provided the background for the Europe 2020 Strategy and the EU's climate commitments generally. The 2030 climate and energy framework sets three key targets in the same areas for the year 2030. Both of them address three key areas while setting particular targets for them: at least 20% and 40% cuts in GHG emissions; 20% and 27% shares for renewable energy; and 20% and 27% improvements in energy efficiency respectively. Accordingly, it is likely that decoupling and decreases in GHG emissions have been affected significantly by these strategies and the other strategies and activities mentioned above. This also includes the encouragement of the negative intensity and composition effect (European Commission, 2018). Moreover, a huge number of interconnected and interrelated strategies focused on particular sectors and their emissions have been developed, which are often based on the above-mentioned strategies. Absolute decoupling needs to be further encouraged by the introduction of appropriate technologies, structural reforms and other activities. However, an additional area that is a challenge for further research is an estimation of emissions embodied in final demand and trade (export). In such a way, the impact of developed countries, such as those composing the EU, on developing countries, should be particularly investigated. Finding solutions to these problems requires a long time and a properly designed international regime in the field of climate change should be developed and enhanced in terms of the framework of the 2015 Paris Agreement.

Conclusions

The aim of the Paper was to discover if decoupling of GHG emissions from GVA in the EU-28 in the period 2008 – 2014 took place and to detect the extent of the influence of the three selected factors of development. An IDA and a LMDI were applied to detect the role of these three factors and their effects on the development of GHG emissions in the EU-28.

In the overall monitored period 2008 – 2014, absolute decoupling took place in the EU-28, when GVA increased by 0.881% and GHG emissions decreased by 15.847%. Manufacturing showed the highest shares in both GVA and in GHG, Real estate activities showed a relatively high share in GVA but a relatively low share in GHG emissions. The GHG emissions of all the examined activities decreased in the period 2008 – 2014. As regards the year-by-year DA, the total effect, i.e. changes in GHG emissions, is negative for five of the years and positive only in 2010. In absolute values, this change showed the lowest magnitude when compared with the extent of this effect in other years. On the other hand, the highest annual drop in GHG emissions occurred in 2009, which is connected with the economic crisis and recession. Accordingly, the significant negative intensity effect in this year was enhanced by the even higher negative scale effect and the slight negative composition effect. The scale effect (GVA annual changes) was negative only in 2009 and 2012 and the highest positive increases occurred in 2010 and 2011 respectively. The composition effect was positive only in 2010 and 2012 and it showed the highest absolute extent in 2011 (below –2%). The intensity effect was negative in all the monitored years and highest in magnitude in 2009, followed by 2014. The relatively high extent of the negative intensity effect in the most recent year is of great importance for further reductions in GHG emissions. Nevertheless, the composition effect at the EU level played its role in the process of decoupling as well.

In the IDA of GHG emissions in the overall monitored period 2008 – 2014 and the two partial periods 2008 – 2011 and 2011 – 2014, the absolute values of the composition and the intensity effect surpassed those of the scale effect, while the intensity effect showed the highest absolute magnitude of all in all the periods. In both of the partial periods and the overall period, all the effects were negative, except for the scale effect in 2008 – 2014 and 2011 – 2014. This means that, apart from the period affected by the recession, the scale effect predominantly led to increases in GHG emissions, while both the composition and especially the intensity effect led to their decreases. Accordingly, the negative total effect was achieved in the overall period as well as in both partial periods, which was considerably augmented by the negative intensity effect.

Resulting from the analysis, significant attention should be paid to those sectors generating high amounts of GHG emissions, such as Manufacturing and Electricity, gas, steam and air conditioning supply and especially to those whose decrease was relatively lower, i.e. Transportation and storage, and Agriculture, forestry and fishing. Nevertheless, further support for the negative intensity effect should be crucial for further reductions in GHG emissions. To achieve them, crucial EU actions have to be properly implemented at national level as well. Moreover, it is crucial to address GHG emissions embodied in domestic final demand and international trade. Therefore, applying SDA and I-O tables for a more detailed analysis is a challenge for further research.

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