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Decomposition Analysis of the Greenhouse Gas Emissions in the European Union

Analiza rozkładu emisji gazów cieplarnianych w krajach Unii Europejskiej

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Abstract
Climate change is a significant threat to sustainable development (SD). Using the Log-Mean Divisia Index Method (LMDI) a decomposition of the data on the greenhouse gas (GHG) emissions in the European Union (EU) in 2000 -2013 is carried out. To detect if decoupling of the environmental variable represented by the GHG emissions from the economic variable represented by the GDP was taking place in the EU economy, the changes of the GHG emissions were divided into three effects. These factors include the economic activity (scale), the composition or structure of the EU economy with respect to the countries, and GHG intensity of the countries. The aim of the paper is to detect if decoupling of the GHG emissions from the GDP development in the EU took place and to detect the factors of this development. The intensity effect was mainly responsible for the reduction of the GHG emissions in the EU while the scale effect contributed to their increase. The role of the composition effect was only marginal; however, it was positive. As the intensity effect often showed the high negative values, the total effect was often negative as well, which means that decoupling of GHG emissions from GDP took place.

Key words: decomposition, climate change, European Union (EU), Greenhouse Gas Emissions (GHGs), Log-Mean Divisia Index Method (LMDI), Kyoto Protocol, sustainable development
JEL Classification: Q51, Q54, Q56, F64

Streszczenie
Zmiany klimatyczne stanowią istotne zagrożenie dla zrównoważonego rozwoju (ZR). Przy pomocy metody LMDI przeprowadzono analizę rozkładu emisji gazów cieplarnianych w krajach Unii Europejskiej (UE) w okresie lat 2010-2013. Aby sprawdzić, czy decoupling zmiennej środowiskowej reprezentowanej przez emisję gazów cieplarnianych od zmiennej ekonomicznej reprezentowanej przez PKB w kontekście zmian emisji gazów cieplarnianych zachodzi we Wspólnocie, uwzględniono następujące efekty: aktywność ekonomiczną (skalę), skład i strukturę europejskiej ekonomii z uwzględnieniem różnic charakterystycznych dla poszczególnych krajów i poziomu ich emisji gazów cieplarnianych. Celem artykułu jest potwierdzenie, czy decoupling emisji gazów cieplarnianych od wzrostu PKB faktycznie zachodzi i jakie czynniki na niego wpływają. Efekt intensywności okazał się być odpowiedzialny głównie za zmniejszenie emisji gazów cieplarnianych w Europie, podczas gdy efekt skali przyczyniał się do wzrostu tej emisji. Efekt struktury odgrywał rolę marginalną, choć pozytywną. Efekt intensywności zwykle charakteryzował się wysokimi wartościami ujemnymi, to samo odnosiło się do efektu całkowitego, co oznacza, że decoupling emisji gazów cieplarnianych od PKB faktycznie zachodzi.

Słowa kluczowe: dekompozycja, zmiany klimatyczne, Unia Europejska, emisja gazów cieplarnianych, metoda LMDI, Protokół z Kioto, rozwój zrównoważony

1. Introduction

Climate change is a significant threat to sustainable development (SD). The scientific community agrees that man-made GHG emissions are the dominant cause of Earth's average temperature increases over the past 250 years (IPCC, 2014). This has, among others, led to extreme weather conditions worldwide (Eurostat, 2016c). At the international level, the commitments related to the greenhouse gas (GHG) emission limitation / reduction are included in the *Kyoto Protocol* (KP) *to the United Nations Framework Convention on Climate Change* (UNFCCC) which is an international agreement linked to the UNFCCC. The KP commits its Parties by setting internationally binding emission reduction targets. It was adopted at the Conference of the Parties (COP) 7 in Kyoto / Japan, on 11th December 1997 and entered into force on 16th February 2005. Its first commitment period started in 2008 and ended in 2012. At the COP 18 in Doha / Qatar, on 8th December 2012, the *Doha Amendment to the Kyoto Protocol* was adopted which includes new commitments for Annex I Parties to the KP who agreed to take on commitments in a second commitment period from 1st January 2013 to 31st December 2020. During the first commitment period, 37 industrialized countries and the European Community (EC) committed to reduce GHG emissions to an average of 5% against 1990 levels. During the second commitment period, Parties (different composition) committed to reduce GHG emissions by at least 18% below 1990 levels in the eight-year period from 2013 to 2020. The EC / EU's commitments go beyond these basic commitments and the EU and its countries committed themselves to reduce the GHGs by 8% on average in the first period and by 20% on average in the second period (UNFCCC, 2015). However, the countries are provided with flexibility via the flexible mechanisms due to the different structures of their economies and therefore differences in the GHGs' reduction costs exist. Thus, the possibilities of the countries to reduce the GHG emissions also vary.

Sustainable development (SD) is a global challenge which requires a progressive transformation of economies (Hediger, 2006). The most quoted definition of the SD is that of the World Commission on Environment and Development (WCED, 1987) which claims that SD is *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. Although the term of SD is still vague there is a political consensus on its desirability (Daly, 1996). SD is amongst the top policy priorities worldwide (FEEM, 2011) and an overarching objective of the EU policies enshrined in its primary law. SD became a fundamental objective of the EU in 1997 when it was included in the *Treaty of Amsterdam*. Subsequently, the *EU Sustainable Development Strategy* (EU SDS) was launched in 2001 and renewed in 2006. The 2001 strategy is composed of two main parts. The first proposed objectives and policy measures to tackle the key unsustainable trends while the second part called for a new approach to policy-making that ensures the EU's economic, social and environmental policies mutually reinforce each other. Climate change is one of the results of the unsustainable trends, which are GHG emissions from human activity.

The aim of the paper is to detect if decoupling of the GHG emissions from the GDP development in the EU took place and to detect the factors, i.e. drivers of the development. The concept of decoupling environmental pressure from economic development is a useful tool of operationalizing SD concept. Decomposition analysis (DA) can subsequently reveal the factors behind de/coupling.

2. Theoretical Background

This section presents the introduction of the DA, its application with the more detailed focus on the emission issues, as well as the decoupling definitions. Particularly, the literature review with the relevant approaches applied in the analysis is presented.

2.1. Decomposition and Decoupling Analysis (Literature Review)

The DA and specifically the Index Decomposition Analysis (IDA) has become a widely accepted analytical tool for policymaking on national energy and environmental issues (Ang, 2004). Literature survey of IDA studies can be found in Ang and Zhang (2000) and a comparison and evaluation of IDA methods in Ang (2004). Ang and Zhang (2000) indicate that a survey in 1995 listed a total of 51 studies. Since then, new studies and new decomposition methods have been reported and the methodology has been increasingly used in energy-related environmental analysis. Decomposition methodology has traditionally been applied to decompose changes in an aggregate indicator over time in a country. Proops et al. (1993), Chung (1998), and Ang and Zhang (1999) used this methodology for cross-country comparisons.

The decomposition studies, and particularly the IDA, have been mostly applied in the former EU-15 countries and Asia, mainly in China, with some applications in the USA and Canada, and the OECD countries. Very few applications of the DA have been carried out for African countries, which is likely due to the insufficient availability of data. There are few applications in the region of Central and Eastern Europe (Tsuchimoto and Ščasný, 2011). Viquier (1999) and Cherp et al. (2003) decompose air emissions for several Central and Eastern European countries, while Brůha and Ščasný (2006) or Tsuchimoto and Ščasný (2011) decompose changes in emissions year-by-year for the Czech Republic. Vehmas et al. (2008) apply the DA to examine changes in several

indicators. Their analysis is mainly focused on the indicators in the EU SDIs set and the DA carried out is based on the Advanced Sustainability Analysis (ASA) approach and a revised Sun/Shapley decomposition technique.
Overall, the 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 of the emissions trends analysis (Tsuchimoto and Ščasný, 2011) including CO_2 emission topics. As climate change and GHG emissions became a global issue in 1990s, IDA was first extended from energy consumption to energy-related CO_2 emission studies in 1991. Since then many studies have been reported for various countries and emission sectors. Xu and Ang (2013) elaborated a comprehensive literature survey and revealed the relative contributions of key effects on changes in the aggregate carbon intensity by emission sector and by country. Concerning IDA methodology, decomposition models for analyzing emission changes are slightly more complex than those for energy consumption changes. More factors are normally included in the IDA identity and a larger dataset is generally needed. Thus, IDA is a useful analytical tool for studying the drivers of changes in CO_2 emissions. In energy-related CO_2 emission studies, more effects are included as the aggregate emissions depend on the fuel mix in energy consumption (Xu and Ang, 2013). Xu and Ang (2013) also concluded that that energy intensity change was generally the key driver of changes in the aggregate carbon intensity in most sectors and countries. In most cases, it 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 activity structure change and that of carbon factor change have been less significant. While there were some uniform patterns among countries with respect to the underlying developments of the aggregate carbon intensity, there were also diversities, which led to differences in development among countries. This has implications on future development of CO_2 emissions, especially of the developing countries. This also indicates that to reduce growth in future CO_2 emissions, countries should focus more on activity structure and carbon factor. Description and application of the DA to CO_2 emissions in Germany can be found in Seibel (2003).

2.2. Decoupling Definition and Indicators
The aim of the Paper is to detect if decoupling of GHG emissions from GDP development took place. The decoupling concept refers to breaking the link between two variables, often referred to as the driving force, mainly economic growth expressed in terms of GDP, and the environmental pressures, such as the use of natural resources (materials, energy, land, etc.), the generation of waste, and the emission of pollutants to air or water, etc. Thus, decoupling indicates breaking the link between environmental bads and economic goods (OECD, 2002). It points out the relative growth rates of a direct pressure on the environment and of an economically relevant variable to which it is causally linked. The purpose of decoupling indicators is to monitor the interdependence between these two different spheres and they usually measure the decoupling of the environmental pressure from the economic growth over a given period (OECD, 2003). Decoupling occurs when the growth rate of the economic driving force exceeds the growth rate of the environmental pressure over a given period. It can be either absolute or relative. The first takes place 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). Generally, decoupling is the process that is inevitable to draw closer and achieve the SD path. Therefore, decoupling is also applied in the monitoring of the SD in the EU using the decoupling indicators (Drastichová, 2014).

3. Data and Methodology

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

3.1. Data
The used indicators related to the climate change are included in the Sustainable Development Indicators (SDIs) set for monitoring of the EU SDS which are presented in ten themes. They include more than 130 indicators, while ten of them were identified as headline indicators (Eurostat, 2016b).
The annual GHG emissions are estimated and reported under the UNFCCC, the KP and the Decision 280/2004/EC. The EU as a party to the UNFCCC reports annually its GHG inventory for the year t-2 and within the area covered by its Member States. The inventory also constitutes the EU-15 submission under the KP while the Kyoto basket includes six gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6). The impact of land use, land use changes and forestry (LULUCF) on the GHG inventories is excluded. International aviation is included. Emissions are weighted according to the global warming potential of each gas. Emissions in CO_2-equivalents are obtained using their global warming potential (GWP) where the following weighting factors are used: CO_2=1, CH_4=21 and N_2O=310, SF_6=23900. HFCs and PFCs comprise a large number of different gases that have different GWPs (Eurostat, 2016c). The GHG (in CO_2 equivalent) indexed to 1990 indicator shows trends in total man-made emissions of the

Kyoto basket of GHGs. The indicator does not include emissions and removals related to LULUCF, nor does it include emissions from international maritime transport. GHG emissions from international aviation are included (not included in the data, which is indexed to the Kyoto base year because these emissions are not covered by the KP).

The GHG emissions indicators are included in the EU SDI used for the assessment of the progress towards the objectives and targets of the EU SDS. The latter indicator, i.e. indexed to 1990, serves as a headline indicator for the whole *Climate Change and Energy* theme and the former, i.e. in million tonnes, as one of the operational indicators for the *Climate Change* subtheme in this theme.

It is important to choose the appropriate GDP indicator for this analysis. As the EU-28 is analysed, data of Eurostat (Eurostat, 2016a) are used. Firstly, GDP in chain linked volumes (CLV) (2010), million euro, and secondly, GDP in current prices, million Purchasing Power Standards (PPS) are used. When PPS series are used, different price levels between countries are removed and they should be used for cross-country comparisons in a specific year but they do not constitute time series. Chain-linked level series are created by successively applying previous year's price's growth rates to the current price figure of a specific reference year, in this case 2010. On the other hand, 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. For other years, chain-linked components of GDP will not sum to chain-linked GDP, and chain-linked Member States' GDP will not sum to chain-linked EU GDP. However, there are no GDP figures, which allow for comparisons in two dimensions, both time and geographic area. GDP in CLV PPS to a reference year should be used to compare countries over time, but it does not exist (Eurostat, 2014). Thus, both above-mentioned GDP indicators are applied in the DA to better estimate the effect of the factors.

As it was explained above, chain-linking involves the loss of additivity and the sum of EU countries GDP figures in chain-linked volumes does not exactly equal to the EU-28's aggregate level. For GDP in CLV the highest deviation reached 0.199% (2000). In the case of GDP in PPS, the deviations are only marginal while the highest reached only 0.012 % (2013). As the EU economy is the subject of the analysis and its structure is bases on the countries, it would be difficult to redistribute these deviations among the countries. However, in percentage terms, these deviations are relatively low and therefore, the results of the analysis can still be regarded as reliable.

3.2. Methodology

The DA is aimed at explaining the channels through which certain factors affect a variable (Tsuchimoto and Ščasný, 2011). Thus, the different factors need to be identified whereas this is fully a case-specific issue (Vehmas et al., 2008). There are two basic streams of DA, concretely the SDA, which is based on input-output (IO) models, and the IDA founded on index theory. While the SDA can distinguish between a variety of technological and final demand effects which IDA is not able to detect and can also capture the indirect effects, i.e. the effect of a direct change in demand of one sector on the inputs of other sectors, the IDA merely considers the direct effects, but requires less data. However, the simplicity and flexibility of the IDA methodology make it easy to be adopted in comparison to the SDA where IO tables are required (Ang, 2004). The starting point of any DA is to create an equation by means of which the relations between a dependent variable and several *underlying causes*, i.e. factors, are defined. In that equation, the product of all the factors has to be equal to the variable, the change of which is analyzed in this DA. The selected factors are often the ratios where the denominator of one factor is equal to the numerator of the next one. As regards the DA in the environmental field, the environmentally-related variable is often decomposed into three factors which affect its development. The first, *scale*, or *activity factor*, measures the change in the aggregate associated with a change in the overall level of the activity. The second, *composition*, or *structural factor*, is related to changes in the structure of the economy, i.e. the change in the aggregate linked to the change in the mix of the activity by sub-category. It is usually measured via the share of partial, often sectoral, production in overall production assuming the constant scale of economy and technologies. Thirdly, *intensity*, or *technique factor*, expresses the input intensity of a partial / sectoral production, such as the material, or emission intensity to produce a unit of an output. More generally, it is the change in the aggregate associated with changes in the sub-category *environmental* intensities (Tsuchimoto and Ščasný, 2011).

For the IDA various decomposition methods can be formulated to quantify the impacts of the factors changes on the aggregate. The two most important decomposition approaches are the methods based on the Divisia Index including the LMDI and those based on the Laspeyres Index (Ang, 2004). For both categories, the decomposition can be performed additively or multiplicatively and the choice between the two is arbitrary (Ang, 2004). In 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). For the Divisia index based methods, Ang and Choi (1997) proposed a refined Divisia method based on the multiplicative form using a logarithmic mean weight function instead of the arithmetic mean weight function.

Table 1. Formulas for Multiplicative and Additive LMDI Decomposition, source: Ščasný and Tsuchimoto (2011), Ang and Zhang (2000), own elaboration

Multiplicative LMDI	Additive LMDI
$E_{total} = \frac{E_T}{E_0} = E_{x1} \times E_{x2} \times E_{x3}x \ldots \times E_{xn}$ (2)	$\Delta E_{total} = E_T - E_0 = \Delta E_{x1} + \Delta E_{x2} + \Delta E_{x3} + \cdots + \Delta E_{xn}$ (3)
$E_{total} = \frac{E_T}{E_0} = E_{act} \times E_{str} \times E_{int}$ (4)	$\Delta E_{total} = E_T - E_0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int}$ (5)
$E_{xk} = exp\left(\sum_i \frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} x \; ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right)\right)$ (6)	$E_{xk} = \sum_i L(E_i^T, E_i^0) \times ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right)$ (7)

Table 2. Description of Variables and Formulas used in the Analysis, source: Ščasný and Tsuchimoto (2011), Ang and Zhang (2000), author's elaboration

Formula	Indication	Description
$GHG = \sum_i GHG_i$	Greenhouse Gas Emissions	*GHG_i: GHG emissions in country i; GHG: total GHG emissions in the EU; (in tonnes, in period t)*
Δ_tGDP; $GDP = \sum_i GDP$	Scale effect	*The scale (activity) effect: the effect of change in performance of whole economy on the GHG change, i.e. the effect of the economic growth; GDP_i: GDP in country i; GDP: overall GDP of the whole EU economy (in period t).*
$\Delta_t \frac{GDP_i}{GDP} \; (S_i)$	Composition effect	*The composition (structural) effect: the effect of changes in countries' GDP on the change in GHG emissions levels.*
$\Delta_t \frac{GHG_i}{GDP_i} \; (I_i)$	Intensity effect	*The intensity effect: the effect of changes in GHG emissions intensity across countries. The GHG intensities in country i in period t: the ratio between the GHG and the production in GDP terms in the EU countries: $Ii = GHGi/GDPi$.*

The logarithmic mean of two positive numbers *x* and *y* is defined as:

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

From the theoretical foundation viewpoint, the LMDI I methods seem to be the most appropriate ones. They comply with basic tests for a good index number, i.e. the factor-reversal test as well the time-reversal test. It is a perfect, i.e. no residual decomposition. Multiplicative and additive DA results are linked by a simple formula. The multiplicative LMDI I also possesses the additive property in the log form. Next, the quantitative foundation of the applied DA using the LMDI is presented by Eq. 2 – 12. This method is used because it complies with the property of perfect decomposition, i.e. no residuals are generated and there is a clear linkage between the additive and the multiplicative decomposition. The general formulas are included in Tab. 1. For the multiplicative LMDI decomposition, the formulas are presented in the first column, expressed by Eq. 2, 4, 6 and for the additive LMDI in the second column by Eq. 3, 5, 7. 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 total environmental effect from *0* to *T* (Eq. 2 and 3). In terms of three-factor DA E_{total} is divided into an activity effect (E_{act}), a structural effect (E_{str}) and an intensity effect (E_{int}) (Eq. 4 and 5). Applying the LMDI methodology, the three effects are calculated from Eq. 6 and 7, using the logarithmic weights for the corresponding effects, where *i* denotes countries.

Regarding the appropriate properties of the additive form of LMDI decomposition, it is described in detail. Resulting from Eq. 7, the three effects are calculated:

$$\Delta E_{act} = \left(\sum_{i=1}^n L(E_i^0; E_i^T) * \ln\left(\frac{Y^T}{Y^0}\right)\right), \quad (8)$$

$$\Delta E_{str} = \left(\sum_{i=1}^n L(E_i^0; E_i^T) * \ln\left(\frac{S_i^T}{S_i^0}\right)\right), \quad (9)$$

$$\Delta E_{int} = \left(\sum_{i=1}^n L(E_i^0; E_i^T) * \ln\left(\frac{I_i^T}{I_i^0}\right)\right), \quad (10)$$

where symbols *Y*, *S*, *I* indicate the scale, structure and intensity effect respectively and according to the Eq. 1 we obtain:

$$L(E_i^0; E_i^T) = \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0}. \quad (11)$$

Applying the IDA to the relation of GHG emissions and GDP development, the variables and formulas are described in Tab. 2. As the analysis is aimed at the EU and its countries, the structural effect is based on the *structure of the EU*, i.e. its countries. This kind of analysis is crucial to examine the SD path in the EU, because this methodology is applied to the issue of decoupling, i.e. the one operationalizing SD, putting this concept into practise. Moreover, this analysis is applied to the EU SDIs that are the main indicators for monitoring the EU SDS. These indicators are organized in a theme-oriented framework and thus the concrete interlinks among the SD issues are less visible. So, they can be clearly detected using the DA.

Using the additive decomposition, the total GHG emissions in the EU in period *t* is split into three components:

Figure 1. GHG emissions (in CO_2 equivalent) indexed to 1990 (base year = 100) Source: Eurostat (2016c)

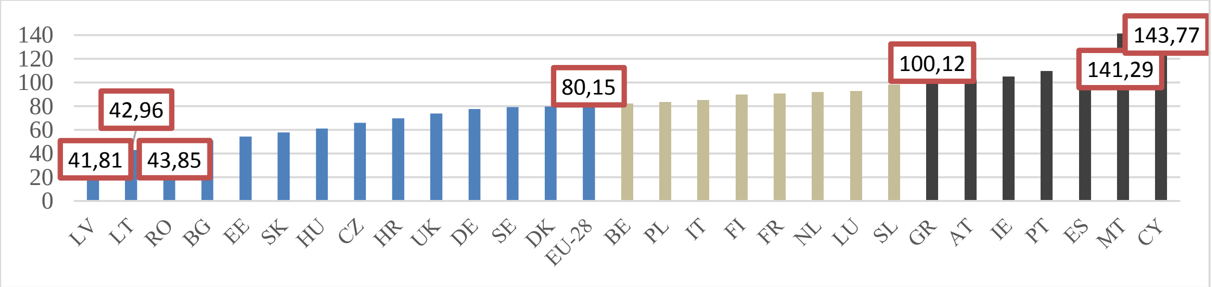


Table 3. Results of the year-by-year DA using GDP in CVL (2010) Source: author's calculations

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
S	2.221	1.336	1.317	2.529	2.065	3.328	3.053	0.496	-4.326	2.081	1.720	-0.475	0.186
C	0.160	0.308	0.442	0.382	0.332	0.438	0.485	0.463	0.191	-0.066	0.096	0.061	0.080
I	-1.482	-2.466	-0.025	-2.864	-3.059	-3.828	-4.594	-3.067	-3.068	0.220	-4.902	-1.041	-2.097
T	0.900	-0.823	1.734	0.048	-0.662	-0.062	-1.055	-2.108	-7.203	2.235	-3.086	-1.455	-1.832

Note: S – scale effect; C - Composition Effect; I – Intensity Effect; T – Total Change (Effect)

$$\Delta_t GHG = \sum_i \Delta_t GDP + \Delta_t \frac{GDP_i}{GDP} + \Delta_t \frac{GHG_i}{GDP_i} = \sum_{i=1}^{n} Y + S_i + I_i, \quad (12)$$

where all the components are described in Tab. 2 (*i* – the country, *t* – the period).

4. Results of Analysis

Firstly, the EU countries' results of meeting the KP commitments and subsequently the results of LMDI decomposition of GHG emissions are presented in this section.

4.1. The GHG emissions development in the EU

Many of the EU countries achieved significant progress towards meeting the commitments of the KP in the first and also in the second period while some countries have already met the commitments of the second one (see Fig. 1). Nine transition economies, except for Cyprus, Malta, Slovenia and Poland, achieved the GHG emissions reduction by more than 30% in 2013 compared to 1990, while three of them, i.e. Lithuania, Latvia and Romania, even more than 50%. The emissions increased only in seven countries including Cyprus and Malta showing the highest growth (more than 40%), three Southern countries, Ireland and Austria. Twelve countries already achieved the higher reduction than 20% in 2012 and thirteen in 2013. The EU as a whole showed the reduction of 19.85% in 2013 and thus significant progress has been made towards meeting the Kyoto commitments.

The development of the GHG emissions can be assessed as quite positive, when significant reduction was achieved. The only two cases of significant increase occurred in small island states, Malta and Cyprus, both with low level of the overall GHG emissions (3.125 and 9.045 mill. tonnes in 2013 respectively). The transitive economies have had great potential to reduce GHG emissions due to the inefficient resource use in the former regime and the majority of them showed the highest drops (Fig. 1). The countries with the highest total emissions, Germany and the United Kingdom (604.272 and 976.326 mill. tonnes in 2013 respectively), also showed significant drop of emissions compared to 1990. The progress of other major producers of GHGs, such as France, Italy, Poland, Spain and Netherlands, was slower. The varied progress is the result of differences in the structures of economies, their resource base and a range of other factors affecting their possibilities to reduce GHG emissions.

4.2. Decomposition Analysis of GHG emissions in the EU

The results of the year-by-year DA are presented in Tab. 3 using GDP in CVL (2010) and in Tab. 4 using GDP in PPS as indicators of economic activity. Before the results of the DA are assessed, the annual changes of GDP and GHG emissions are investigated to detect if decoupling took place. For GDP this results from the first line of Tab. 3 for GDP in CLV[1] and Tab. 4 for GDP in PPS while the last lines of these Tables show the GHG emissions changes.

There is only one year in the monitored period with no decoupling at all, i.e. 2003. The absolute decoupling took place in 2002, in every year from 2005 to

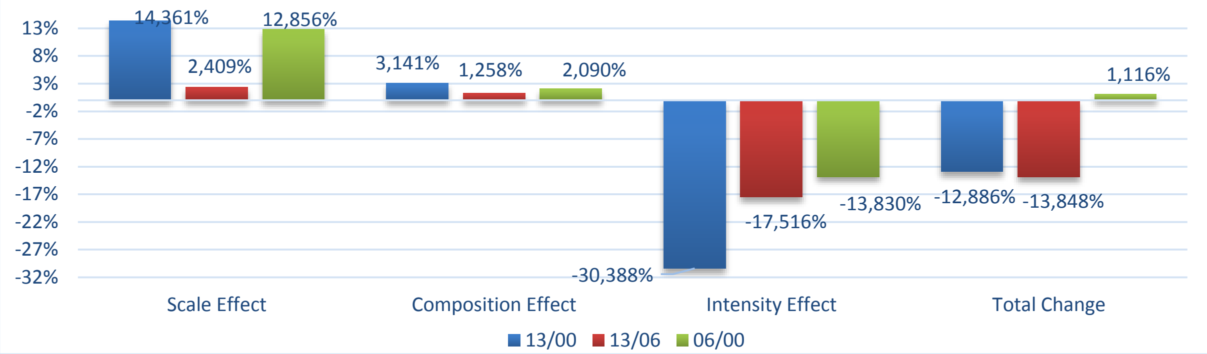
[1] As it was mentioned in Section 2.1., chain-linking involves the loss of additivity and thus the growth rates of the aggregate slightly differ from the growth of the sum of the GPDs of the EU countries. However, the direction remains the same and the differences are quite marginal.

Table 4. Results of the year-by-year DA using GDP in PPS, source: author's calculations

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
S	4.092	3.616	1.620	4.922	4.362	5.611	5.810	0.614	- 5.650	4.350	2.923	1.881	0.846
C	0.114	0.295	0.352	0.350	0.143	0.254	0.390	0.277	0.267	0.188	0.122	0.145	0.032
I	-3.306	- 4.734	- 0.238	- 5,223	- 5.167	- 5.927	- 7.255	- 2.998	- 1.820	- 2.303	- 6.131	- 3.481	- 2.711
T	0.900	- 0.823	1.734	0.048	- 0.662	- 0,062	- 1.055	- 2.108	- 7.203	2.235	- 3.086	- 1.455	- 1.832

Note: S – scale effect; C - Composition Effect; I – Intensity Effect; T – Total Change (Effect)

Figure 2. Results of DA using GDP in CVL (2010) in the overall and two partial periods, source: author's calculations



2008, in 2011 and 2013. In 2001 and 2004, the relative decoupling occurred as the GHG emissions annually increased but as slower rate than GDP. In 2009, the most significant effects of the economic crisis became evident as both GDP and GHG emissions dropped, but the emissions decreased more significantly. The results for 2010 and 2012 are not clear. In 2010, there is no decoupling when GDP in CLV is used and the relative decoupling when GDP in PPS is used due to the fact that emissions annually increased, but the GDP in PPS increased more and GDP in CLV less than GHG emissions. Emissions dropped in 2012, similarly GDP in CLV, but at lower rate. On the other hand, GDP in PPS slightly increased. It is obvious that the results in more recent period, since 2009, have significantly been affected by the effects of the economic crisis.

As regards the overall / average change, the scale and composition effects are positive and the intensity and total effects are negative for both indicators. The intensity effect followed by the scale effect reached the highest levels when GDP in PPS is used. For GDP in CVL these numbers are relatively lower. On the other hand, the composition effect showed the lowest absolute value; lower when GDP in PPS is used. Concerning the annual changes, the scale and composition effects are predominantly positive. The scale effect was only negative in 2009 for both and in 2012 when GDP in CVL is used. The composition effect is only negative in 2010 when GDP in CVL is used and still positive when GDP in PPS is used as the indicator of economic activity. The intensity effect is still negative except for 2010 when GDP in CLV is used. Thus in 2010 the results diverge concerning the direction of the composition and intensity effect. The results correspond with the kind of decoupling indicated above and those of the more recent period can still be affected by the economic crisis. Although the intensity effect in 2013 helped reduce the overall GHG, the scale effect was low due to the very slow economic growth.

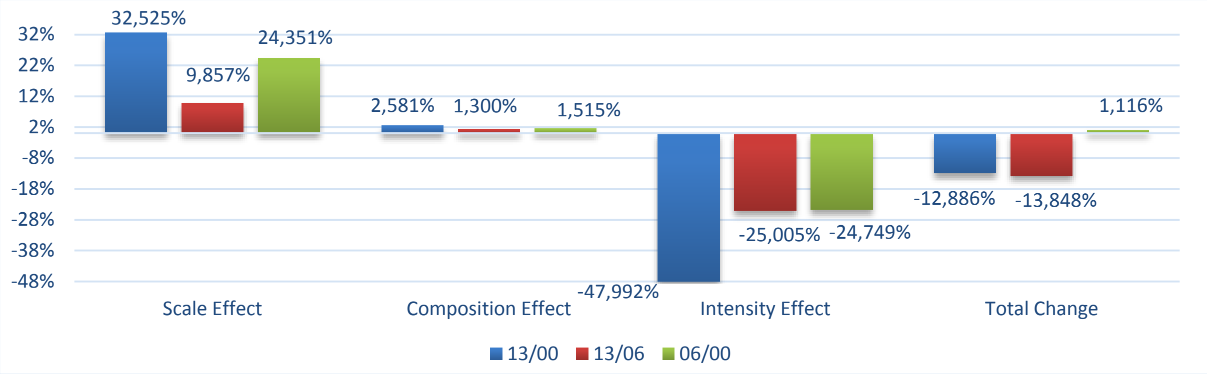
The changes for the overall and two partial periods are depicted in Fig. 2 and 3. These results confirm those of the year-by-year DA. The intensity effect showed the highest extent, but it is negative. This also affected the total effect, which is negative as well (except for period 2000-2006), but lower in absolute values, because it is also affected by other two effects, which were positive in overall as well as in both partial periods. While the scale effect also showed the relative higher absolute values, the composition effect was only marginal.

Comparing Fig. 2 and 3, it can be seen that the extent of the scale and intensity effect is relatively higher when GDP in PPS is used, but the application of this indicator led to the lower extent of the composition effect, except for period 2006-2013.

It can be concluded that the intensity effect has mainly been responsible for the reduction of the GHG emissions in the EU while the scale effect has contributed to their increase. However, in the overall and both partial periods the intensity effect showed the higher absolute value. The role of composition effect was only marginal, however, it was positive and in period 2000–2006, the positive effects outweighed the negative intensity effect and the GHG emissions increased. In the second partial period 2006-2013 and the overall period 2000-2013, the GHG emissions dropped due to the significant contribution of the negative intensity effect.

This results from the effort of the EU and its countries to meet the international commitments, particu-

Figure 3. Results of DA using GDP in PPS in the overall and two partial periods, source: author's calculations



larly those of the KP, and of a large number of corresponding laws, strategies to reduce GHG emissions, such as the long term EU SDS and Europe 2020 strategy, many initiatives, mitigation and adaptation measures. These activities also respond to the commitments included in the primary law of the EU, where in the wording of the Lisbon Treaty, *Union policy on the environment shall contribute to the objectives of promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combating climate change* (EU, 2012). The structure of the EU institutions has also been adapted to better meet the objectives related to combating climate change (e.g. establishment of the Directorate-General for Climate Action in the European Commission). The significant effort to reduce GHG emissions and the impacts of climate change still needs to be deepened not only in the EU, but also worldwide, as the effects are still more visible. Although some flexibility in commitments of the countries is inevitable due to their different conditions, the major producers should take responsibility and apply appropriate structural reforms. As it results from the analysis, the role of the composition effect in the EU has been marginal. The EU is composed of the countries with significant differences in the overall GHG emissions and successful reduction mainly depends on the major producers. On the other hand, the international aspects of this issue should also be considered.

5. Conclusions

The aim of the paper was to detect if decoupling of the GHG emissions from the GDP development in the EU took place and to detect the factors of the development. The IDA and the LMDI method were applied to examine the GHG emissions development in the EU. The EU as a whole showed significant reduction of GHG emissions and thus the steady progress has been made towards meeting the Kyoto commitments. However, the progress varied among the countries. This is the result of distinction between the structures of their economies, their resource base and other factors affecting their reduction possibilities.

In the monitored period 2000-2013 and the second partial period 2006-2013, the GHG emissions dropped in the EU due to the significant contribution of the negative intensity effect. The intensity effect was mainly responsible for the reduction of the GHG emissions in the EU while the scale effect contributed to their increase. The role of composition effect was only marginal; however, it was positive. In the overall period 2000-2013 and both partial periods, the intensity effect showed the higher absolute value. Only in the first partial period 2000-2006, the positive scale and composition effects together outweighed the negative intensity effect and the GHG emissions increased. However, this trend was already reversed. As regards the year-by-year DA, the results are similar; the major exception is the year 2009 with the negative scale effect caused by the economic recession. The total change of GHG emissions was negative in the majority of the years and decoupling took place, often its absolute alternative. No decoupling was typical only of 2003, but the more recent years were affected by the economic crisis and the results are ambiguous. The economic problems, such as the most recent economic crisis, can significantly affect the results. In 2009, the GDP as well as GHG emissions dropped while the emissions dropped more significantly. This is not the result of structural reforms, but economic problems and recession. While the absolute decoupling occurred in the last monitored year 2013, it was also not only affected by the negative intensity effect, but also by very small scale effect.

Thus, the appropriate structural reforms are needed to further reduce the GHG intensity of the GDP, i.e. to strengthen the negative intensity effect, which can lead to the reduction of the GHG emissions also by stronger economic growth. The EU should continue in institutional improvements, adopting appropriate legislation and strategies to combat climate change. The major producers should intensify their efforts and the international aspects of the problem should be taken into account.

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