Decomposition Analysis of the Material Consumption in the European Union

*Magdaléna DRASTICHOVÁ**

Abstract

The decomposition analysis (DA) has become a widely accepted analytical tool for policymaking on environmental issues. By means of the Log-Mean Divisia Index Method (LMDI) a decomposition of the data on the Domestic Material Consumption (DMC) in the European Union (EU) in 2002 – 2014 is carried out. To detect the factors of de/coupling of the environmental variable, represented by the DMC, from the economic variable, represented by the GDP, in the EU economy, the changes of DMC 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 material intensity of the countries. The results indicate that the intensity effect showed the highest magnitude in the longer-term periods 2002 – 2014 and 2004 – 2014, but overall and in the majority of years, this effect was negative. The scale effect showed the second highest extent, whereas the composition effect was only slight. Both of them were positive in the majority of the years as well as in total.

Keywords: *Decomposition Analysis (DA), Sustainable Development (SD), Log-Mean Divisia Index Method (LMDI), European Union (EU), Domestic Material Consumption (DMC)*

JEL Classification: Q32, Q51, Q56, F64

Introduction

The combination of resource depletion and growing international competition brings distributional issues of natural resources on the top of the agenda (Teixidó-Figueras et al., 2016). This issues are related to the sustainable development (SD) concept. Sustainable development is a global challenge which requires a progressive transformation of economies (Hediger, 2006), i.e. the substantial

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changes in production processes and lifestyles taking into account the fact that the global development cannot only be understood from the economic point of view (FEEM, 2011). According to the most quoted definition of the World Commission on Environment and Development (UN, 1987) the SD is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development 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). The rational usage of the scarce natural resources is a prerequisite and condition of such development, i.e. to meet the needs of the present as well as those of future generation or, in other words, the continuous increase in human well-being. 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 (Ang, 2004).

At the EU level, the EU Sustainable Development Strategy (EU SDS) was launched in 2001 and renewed in 2006. The Sustainable Development Indicators (SDIs), reflecting the key challenges of the EU SDS are used to monitor the EU SDS and presented in ten themes. The themes cover the economic, social, environmental, global and institutional dimension of SD, but these dimensions also overlap in particular themes.

The second theme entitled Sustainable Consumption and Production is directly related to the requirement of decoupling environmental pressure, such as natural resource use, from the economic growth. As regards this theme, the EU SDS sets out the objective of promoting sustainable consumption and production patterns. It is emphasised that addressing social and economic development within the carrying capacity of ecosystems and decoupling economic growth from environmental degradation is an essential requirement for SD (Eurostat, 2015c).

The aim of the Paper is to detect if decoupling of the Domestic Material Consumption (DMC) from the GDP in the EU took place and to detect the factors, i.e. drivers of the actual development.

1. Theoretical Background

This section introduces the DA, its application as to the usage of the scarce resources and the undesirable by-products of the production process. The section also provides definitions of decoupling. It is especially focused on the literature review containing the relevant approaches applied in the analysis.

1.1. Decomposition and Resource 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). A 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 and 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. On the other hand, Proops, Faber and Wagenhals (1993), Chung (1998), and Ang and Zhang (1999) used this methodology for cross-country comparisons.

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. Rogan, Cahill and Gallachóir (2012) used the Log-Mean Divisia Index I (LMDI-I) methodology to decompose gas consumption trends in the gas-connected residential sector in Ireland in period 1990 – 2008. In the most recent period, some studies can also be found in the field of waste generation and management. In this field, Brix and Bentzen (2008) applied the LMDI analysis to examine waste generation in Denmark to explain why the amount of business waste is increasing. The sector-specific waste intensities are defined in their study as the ratio between the waste volumes and value added produced.

The decomposition studies, and particularly the IDA, have been applied mostly in the former EU-15 countries and Asia, mainly in China, with some applications in the USA and Canada, and the OECD countries. On the other hand, 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). Viguier (1999) and Cherp, Kopteva and Mnatsakanian (2003) decompose air emissions for several Central and Eastern European countries (CEEC), while Brůha and Ščasný (2005) or Ščasný and Tsuchimoto (2011) decompose changes in emissions year-by-year for the Czech Republic. Vehmas, Luukkanen and Pihlajamäki (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 approach and a revised Sun/Shapley decomposition technique.

It results from the review above that the DA can be applied to the field of any environmental pressure at the input as well as output side, including the material inputs analysed in this Paper. Teixidó-Figueras et al. (2016) presented an international distributional analysis of natural resource use indicators. They showed that international trade worsens environmental equity for energy and material use. Measuring the resource use on a territorial basis, the environmental inequality tends to be lower and more linked to geographic endowments and demographic characteristics. As the resource use indicator is trade-corrected, i.e. measured as a footprint including elements embodied in goods, its international inequality tends to be higher and more related to economic factors. This is the case of material and fossil energy (carbon emissions) indicators. They concluded that the international distribution of material consumption is mainly a result of economic drivers, but, on the other hand, demographic drivers can explain almost half of the distribution pattern in domestic extraction, which is one of the consumption components.

Weinzettel and Kovanda (2011) applied structural decomposition analysis (SDA) to the change in raw material consumption (RMC) of the Czech Republic between 2000 and 2007. They quantified the drivers of the changes in RMC, which is domestic material consumption (DMC) expressed in the form of all materials extracted and used in the production phase. The changes in individual material categories decomposed into effects of three factors, i.e. technology, the product structure of final demand, which refer to the concept of sustainable production and consumption respectively, and the final demand volume, which is related to economic growth. They showed that final demand structure has a very limited effect on the change in material flows. They found out by means of the SDA that technology tends to reduce most of the material flows, except for non-iron metal ores. However, it has not yet been able to fully compensate for the increase in consumption, stimulated by economic growth, for crude oil, metal ores, construction materials, food crops, and timber. They also claim that the role of technological development is ambiguous in minimizing the negative effects of growing consumption, because it also enables this growing consumption. Therefore, the focus of technological development on minimizing resource usage over the whole product life cycle can be encouraged by imposing additional costs on the natural resources use.

1.2. Decoupling Definition and Indicators

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 and many others. 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 (OECD, 2002). 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 (cited from Drastichová, 2014).

2. Data and Methodology

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

2.1. Foundation of Used Data

The SDIs for monitoring of the EU SDS are presented in ten themes. They include more than 130 indicators, whereas ten of them were identified as headline indicators (Eurostat, 2015b). In Sustainable Consumption and Production theme, the Resource Productivity (RP) indicator represents the headline indicator. It is defined as the ratio between GDP and DMC. The DMC indicator is based on the Economy-wide Material Flow Accounts. It measures the total amount of materials directly used in an economy, i.e. the annual quantity of raw materials extracted from the domestic territory of the focal economy (domestic extraction used), plus all physical imports minus all physical exports. The term „consumption" as used in DMC denotes apparent consumption, not final consumption. It is obvious from the previous description that the RP serves as a decoupling indicator and thus for monitoring if de/coupling of the DMC from GDP is taking place. Accordingly, the RP provides some insights into the SDS objective to decouple economic growth from natural resource use (Eurostat, 2015c).

International distribution of material consumption is mainly a result of economic drivers (Teixidó-Figueras et al., 2016). Thus the suitable DA helps to detect the factors behind the development of DMC and GDP and thus also those of the RP.

To carry out this analysis it is important to choose the appropriate GDP indicator. As the subject of the analysis is EU-28, the data of Eurostat (2015a) are used. When examining RP trends over time in a particular geographic area, the GDP in units of Euros in Chain-Linked Volumes (CLV) to the reference year at this year’s exchange rates should be used. If the RPs between countries in one particular time are being compared, the GDP in Purchasing Power Standards (PPS) should be applied because expressing GDP in PPS eliminates differences in price levels between countries. In summary, PPS series should be used for cross-country comparisons in a specific year but they do not constitute time series. Chain linking involves the loss of additivity for all years except for the reference year and the directly following year, because these are the only periods expressed in prices of the reference year. However, no GDP figures which allow for comparisons in two dimensions, both time and geographic area exist. To compare countries over time it would be necessary to use GDP in CLV PPS to a reference year, which does not exist (Eurostat, 2014a; b). Thus, both above-mentioned GDP indicators are applied in the DA to better estimate the effect of the factors. Particularly, data of Eurostat (2015a; c) for GDP at market prices, firstly in CLV (2010), in euro and secondly in current prices, PPS, were used to set up the model.

As it was explained, chain linking involves the loss of additivity and the sum of EU countries GDPs in chain linked volumes does not exactly equal to the aggregate level of the EU-28. Moreover, the differences can also be seen in the case of GDP in PPS and the DMC indicators. In case of the DMC these differences reach up to 1.5179% of the aggregate (in 2011). For GDP in CLV the highest deviation is 0.1554% (2003) and GDP in PPS the deviations are only marginal while the highest one reached only 0.0104% (2014). All deviations are expressed in the absolute values. As the EU economy is the subject of the analysis and the structure is composed of countries, it would be difficult to redistribute the deviations among the countries. However, in percentage terms, these deviations are low and thus the results of the analysis can still be reliable.

2.2. Decomposition Analysis

The DA is aimed at explaining the channels through which certain factors affect a variable (Ščasný and Tsuchimoto, 2011). Thus, the different factors need to be identified whereas this is fully a case-specific issue (Vehmas, Luukkanen and Pihlajamäki, 2008). There are two basic streams of DA, i.e. 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 analysed in the DA. The selected factors are often the ratios where the denominator of one factor is equal to the numerator of the next one:

$$X = \frac{X}{Y} \times Y \tag{1}$$

This is an example of a two-factor DA where *X* and *Y* are the relevant factors. In the following detailed description of the methodology the abbreviation E_{xk} is used for the factors/effects used in the DA. The factors choice should be determined by the conceptual model. 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 the overall production assuming the constant scale of the 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 of the environmental intensities in the sub-categories (Ščasný and Tsuchimoto, 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. For both categories, the decomposition 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). Only the LMDI method and refined Laspeyres index method satisfy all three desirable properties of Index Decomposition methods (Ang and Zhang, 2000). The LMDI I is recommended for general application. Its appropriateness is related to its desired properties, i.e. the compliance with basic tests for a good index number, such as the factor-reversal test and 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. 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. The logarithmic mean (L) of two positive numbers x and y is defined as:

$$L(x,y) = \frac{y-x}{ln\left(\frac{y}{x}\right)};\ If\ x \neq y,\ otherwise\ L(x,y) = x \tag{2}$$

Based on Ščasný and Tsuchimoto (2011) and Ang and Zhang (2000), the quantitative foundation of the applied DA using the LMDI is presented by Equations (3) – (10). As it was explained, 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 for the multiplicative and the additive LMDI decomposition are expressed by Eq. (3) and (4) respectively:

$$E_{total} = \frac{E_T}{E_0} = E_{x1} \times E_{x2} \times E_{x3} x \ldots \times E_{xn} \tag{3}$$

$$\Delta E_{total} = E_T - E_0 = \Delta E_{x1} + \Delta E_{x2} + \Delta E_{x3} + \ldots + \Delta E_{xn} \tag{4}$$

In Eq. (3) and (4) 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 that is the subject of interest (generally explained in Eq. (1)). E_T is the value of variable in time T and E_O is the value in time 0. 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}) which is indicated by Eq. (5). The following methodology description is focused only on the additive LMDI decomposition because this is applied in the analysis due to its features and simple application and interpretation.

For three-factor DA, the following formula is applied:

$$\Delta E_{total} = E_T - E_0 = \Delta E_{act} + \Delta E_{str} + \Delta E_{int} \tag{5}$$

Applying the additive LMDI decomposition, the three effects are generally calculated according to Eq. 6, where i denotes countries:

$$E_{xk} = \sum_i L\left(E_i^T, E_i^0\right) \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right) \quad (6)$$

The symbol L is used for the logarithmic mean of two positive numbers (see Eq. (2)). The symbol x_t represents the k^{th} effect of the i-th country and symbols 0 and T indicate the points in time. Resulting from Eq. (6) and applying the three factor DA, the above explained three effects are calculated as follows:

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

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

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

where symbols Y, S, I indicate the scale, structure 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. (7) – (9), is explained in Table 1. The first part of these equations expresses the logarithmic mean according to the Eq. 2 and the following is applied:

$$L(E_i^0; E_i^T) = \frac{E_i^T - E_i^0}{\ln E_i^T - \ln E_i^0} \quad (10)$$

To obtain the overall three effects in the EU, the particular effects are added up for all the EU countries in the monitored periods. Applying the IDA to the relations of DMC and GDP the variables and formulas are described in Table 1.

T a b l e 1

Description of Variables and Formulas Used in the Decomposition Analysis

Formula	**Indication**	**Description**
$\Delta_t DMC = \sum_i DMC_i$	Domestic Material Consumption	The total effect: total change of DMC in EU-28; DMC = sum of DMC_i – domestic material consumption in the i-th EU country (in tonnes, in period t)
$\Delta_t GDP = \sum_i GDP)$	Scale effect (Y)	The scale (activity) effect: the effect of change in performance of whole economy on the DMC change, i.e. the effect of the economic growth; GDP_i: GDP in i-th EU country; GDP: overall GDP of the whole EU-28 economy.
$\Delta_t \frac{GDP_i}{GDP} (S_i)$	Composition effect (S)	The composition (structural) effect: the effect of changes of the GDP structure in the EU, i.e. $GDPi/GDP$ ratios on the DMC.
$\Delta_t \frac{DMC_i}{GDP_i} (I_i)$	Intensity effect (I)	The intensity effect: the effect of changes in DMC intensities across the EU countries on the DMC.

Source: Ščasný and Tsuchimoto (2011); Ang and Zhang (2000); own elaboration.

To sum up the previous findings, the additive DA using the LMDI applied in this Paper has the form indicated by Eq. (11). The total DMC in the EU in time period *t* is split into three components:

$$\Delta_t DMC = \sum_{i=1}^{n} Y + S_i + I_i = \sum_i \Delta_t GDP + \Delta_t \frac{GDP_i}{GDP} + \Delta_t \frac{DMC_i}{GDP_i} \qquad (11)$$

whereas all the components of Eq. (11) are described in Table 1 (*i* – the country, *t* – the period). Generally, the formula is explained in Eq. (6) – (10) using the LMDI. The analysis is aimed at the EU and its countries and thus the structural effect is based on the „structure of the EU", i.e. the domestic products of its countries. This analysis should not only be regarded as the additional part of the SD analysis in the EU, but something like „connecting" and „trans" analysis because this methodology is applied to the issue of decoupling, i.e. the process operationalizing the SD, putting the SD concept into practice. Moreover, this analysis is applied to the EU SDIs which are the indicators for monitoring the EU SDS. However, as these indicators are organized in the theme-oriented framework, the concrete interlinks are less visible and thus they can be clearly detected using the DA.

3. Results

Firstly, the results the resource productivity analysis and subsequently the results of LMDI decomposition of DMC in the EU are presented.

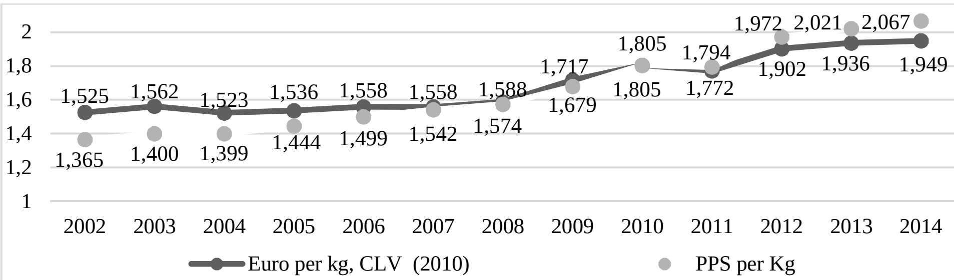
3.1. Resource Productivity in the EU

The first part of the analysis is focused on the assessment of the development of the RP indicators in the EU. The Figure 1 displays the development of both RP indicators, i.e. in Euro per kg CLV (2010) and in PPS per kg and their annual changes. In the monitored period 2002 – 2014, for which the IDA is subsequently carried out, both RP indicators increased in the EU-28. In the EU-28 the both RP indicators dropped annually only in 2004 and 2011 and these drops were very slight. Thus, in all the other years, the development showed the signs of decoupling, but not in all the years the desired type of decoupling occurred (see Sect. 1.2). The effects of economic shocks must be taken into consideration.

The absolute decoupling occurred in 2003, 2008, 2010, and 2013 when the DMC annually dropped and at the same time both GDP indicators increased. It is difficult to draw conclusions about this development, i.e. with a view to evaluating if the desired decoupling resulting from the appropriate structural reforms took place. It is also necessary to analyse the other years which are close to those showing the signs of absolute decoupling. In 2004, no decoupling occurs, but subsequently in 2005 and 2006, the relative decoupling took place. In 2007, according to the GDP in CLV no decoupling occurred, however, GDP in PPS increased more than DMC. In 2008, the positive changes of both GDP indicators were very slight, the DMC already dropped and in 2009, all the indicators dropped. Due to the fact that in 2009 the DMC dropped more than GDP, the RP indicator increased. The development continued with the slight growth of GDP in CLV in 2010 and 2011, whereas the positive changes of GDP in PPS were higher. The DMC continued declining in 2010 but increased more than both GDP indicators in 2011. In 2012 and 2013, DMC dropped, and GDP indicators increased very slightly and, moreover, GDP in CLV even slightly dropped in 2012. Thus in 2013, the sings of the absolute decoupling were detected. In the most recent year 2014, the relative decoupling was achieved because DMC increased by less than 1%, GDP in CLV by more than 1% and GDP in PPS was by almost 3% higher than in 2013.

F i g u r e 1

Resource Productivity in the EU-28, 2002 – 2014



Note: Until 2010, the RP in CLV is above the RP in PPS. From 2011, the opposite development took place.

Source: Eurostat (2015c); own elaboration.

According to the outlined development, it can be concluded that the absolute decoupling is more likely to be achieved in time of slow economic growth and, moreover, when the downturn of economy is expected which is the case of 2008, but also of 2010. In time of rapid economic growth, no decoupling (2004) or at most relative decoupling (2006) can be expected. In time of economic recession, the DMC usually drops more than GDP. This was especially the case of 2009. As it was shown, in the most recent year 2014 the EU economy achieved the relative decoupling of DMC from GDP again. Thus, it is a challenge to implement suitable strategies and reforms aimed at all the SD pillars, i.e. the economic, social and environmental ones. Such strategies have also been prepared in the context of the economic crisis in order to change the character of the economic growth that should be sustainable, i.e. environmentally and socially sustainable at the same time.

3.2. Results of Decomposition Analysis

To detect the factors of the DMC changes in the EU, the DA of DMC was carried out. The results of the DA and applying the additive form of LMDI to data of Eurostat (2015a; c) are presented in this subsection. It needs to be noted again that for comparisons over time the GDP in CLV should be used. However, because chain-linking involves the loss of additivity the GDP in PPS is also used in the DA. Thus, there are slight differences between the percentage changes of DMC and GDP in the EU-28 available on Eurostat (2015a; c), which used aggregates for the EU-28, and those calculated in the DA (Tables 2 and 3) where the sums for the 28 EU countries are used. These differences are not allowed for, i.e. the variables of the countries are not recalculated to include the deviations because it would be a difficult task, probably leading to even greater incorrectness in the shares of the partial effects.

The total effect reflects the percentage change of the DMC indicator and thus it showed the same magnitude for both GDP variables used. The applied GDP indicator, however, affects the division into three partial effects. Firstly, the results of the year-by-year DA are presented in Tables 2 and 3 applying GDP in CLV and GDP in PPS as the indicators of economic activity respectively. The total effect is positive in six years, i.e. 2004 – 2007, 2011 and 2014 and negative in the remaining six ones which is consistent with the DMC changes. In 2004, the highest positive DMC increase occurred. The largest annual drop, which was even higher than that in overall period 2002 – 2014, occurred in 2009 (see also Figure 2). Concerning the partial effects, Tab. 2 contains the results of DA where GDP in CLV (2010) is used as the variable reflecting the economic activity. The scale effect was negative only in 2009 and 2012 and the highest positive increases occurred in 2006 and 2007 which complies with the GDP in CLV growth rates (see Sect. 3.1). The composition effect was negative only in 2010 and the highest positive effect was reached in 2007 as compared to other years. In comparison with other two effects, it shows relatively lower magnitude. The intensity effect was predominantly negative, except for 2004 and 2011, which are the years with the relatively higher annual DMC growth exceeding the growth rate of GDP in CLV. It resulted in no decoupling development in these years. As compared between the years, the highest negative intensity effect occurred in 2009, which was followed by 2012 and 2010. The first two are the years showing the highest DMC drops respectively. In both years GDP in CLV dropped as well. In 2010 the absolute decoupling occurred when GDP increased by more than 2% by the simultaneous DMC drop.

T a b l e 2

The Scale (*Y*), Composition (*S*), Intensity (*I*) and Total Effect (*T*) of the Year-by-year DA of DMC, EU-28, 2002 – 2014, %; *Y* = GDP in CLV (2010)

E/P	03/02	04/03	05/04	06/05	07/06	08/07	09/08	10/09	11/10	12/11	13/12	14/13
Y	1.295	2.582	2.086	3.359	3.118	0.482	–4.208	2.031	1.778	–0.444	0.193	1.335
S	0.519	0.525	0.507	0.574	0.654	0.608	0.107	–0.175	0.123	0.242	0.216	0.267
I	–2.658	2.192	–1.355	–1.435	–0.649	–2.221	–7.475	–4.549	1.775	–7.169	–2.297	–0.632
T	**–0.844**	**5.299**	**1.238**	**2.497**	**3.123**	**–1.132**	**–11.576**	**–2.693**	**3.676**	**–7.370**	**–1.888**	**0.970**

Note: E – effect, *P* – period.

Source: Eurostat (2015a; c); own calculation.

Table 3 presents the results of DA using GDP in PPS as the indicator of the economic activity. In the year-by-year comparison of the extent of the scale effect, it was detected that it is negative only in 2009. In comparison with the previous GDP indicator, this effect shows the slight positive value also in 2012 (see Sect. 3.1). This effect reached the highest magnitude in 2007 and 2006. Comparing the magnitudes of the composition effect between the years, it showed the highest extent in 2007 similarly to the previous findings (Table 2), but using this GDP indicator it was still positive. The intensity effect was positive only in 2011 and in 2004 it showed the lowest negative extent as compared to other years. The highest negative magnitude of the intensity effect was shown in 2012. This was followed by the values of 2010 and 2009. It complies with the annual GDP and DMC changes as well at the character of the decoupling resulting from the development.

T a b l e 3

The Scale (*Y*), Composition (*S*), Intensity (*I*) and Total Effect (*T*) of the Year-by-year DA of DMC, EU-28, 2002 – 2014, %; *Y* = GDP in Current Prices, PPS

E/P	03/02	04/03	05/04	06/05	07/06	08/07	09/08	10/09	11/10	12/11	13/12	14/13
Y	1.599	5.049	4.403	5.682	5.928	0.616	–5.516	4.246	3.026	1.825	0.861	2.990
S	0.501	0.504	0.245	0.617	0.844	0.740	0.289	0.355	0.290	0.427	0.005	0.149
I	–2.943	–0.254	–3.410	–3.802	–3.649	–2.488	–6.349	–7.294	0.360	–9.622	–2.754	–2.169
T	**–0.844**	**5.299**	**1.238**	**2.497**	**3.123**	**–1.132**	**–11.576**	**–2.693**	**3.676**	**–7.370**	**–1.888**	**0.970**

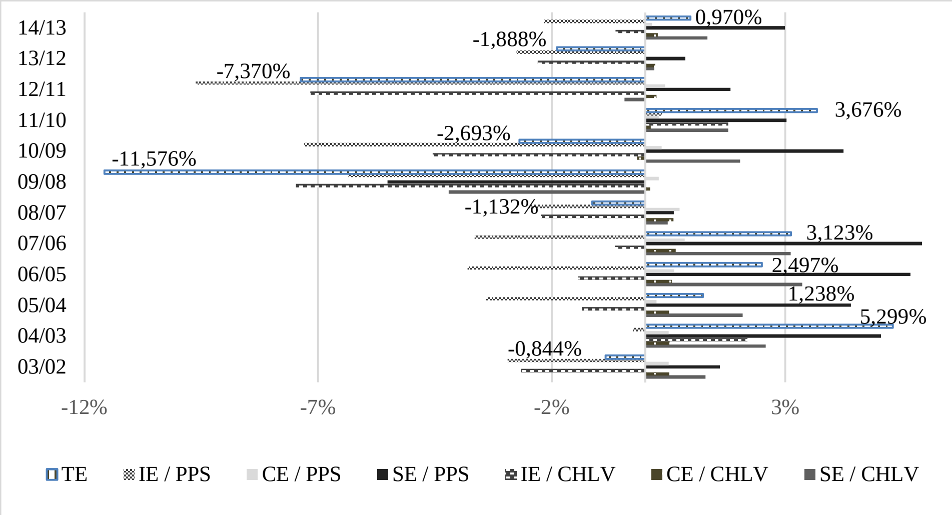
Note: E – effect, *P* – period.

Source: Eurostat (2015a; c); own calculation.

In 2004 and 2011 no decoupling occurred which was, among others, stimulated by the positive intensity effect in these years. Although in 2004 the very slight negative intensity effect was detected when GDP in PPS is used as the indicator of the economic activity, the scale and composition effects were positive.

Figure 2

The Scale, Composition, Intensity and Total Effect of the Year-by-year DA of DMC, EU-28, %; Summary



Note: Data description is related to the total effect.

Source: Eurostat (2015a; c), own calculation.

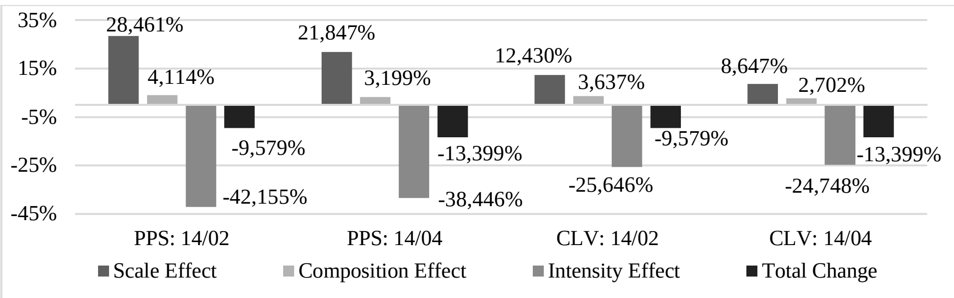
Figure 2 clearly indicates that, on average, the intensity effect in absolute values shows the highest magnitude (see also Fig. 3) and the relatively higher ratios in the majority of years when GDP in PPS is used. All this is determined by the annual percentage changes of the GDP indicators as far as they are compared with the changes of the same DMC indicator. In the half of the number of monitored years, the extent of the scale effect, often slightly, exceeded that of intensity effect, i.e. in 2004 – 2007, in 2011 and 2014 for both GDP indicators. All this affects the character of decoupling in these years. The magnitude of scale effect is relatively lower in each year when GDP in CLV is used in comparison to the results when GDP in PPS is used. This is caused by its lower annual changes of GDP in CLV and these results are more conclusive. On average and in the majority of the years, the composition effect is only marginal in comparison to other two effects. For both GDP indicators, the composition effect exceeded the scale effect in 2008 (and also in 2013 when GDP in CLV is used), when the annual GDP increases were very low, the intensity effect was below –2%, the overall DMC decreased by more than 1%. The positive composition effect, i.e. the change in the structure of the EU's GDP, mitigated this DMC drop in 2008 (see Tables 1 and 2). It is an interesting finding that this marginal effect played the more important role in the year before the year of most significant impacts of the economic crisis.

To sum up, the scale effect is the important factor encouraging consumption of materials, i.e. the DMC increase. On the other hand, the intensity effect is predominantly negative that leads to the mitigation of material consumption, i.e. the DMC decrease, which stimulates decoupling. The composition effect is marginal in size and has played the more important role only in extraordinary economic situations. The resulting total DMC change depends on the magnitudes of particular effects whereas the actual economic development significantly affects the form of de/coupling as well. In the years of rapid GDP growth, no decoupling or perhaps relative decoupling is more likely to occur. In the years of GDP decline, the DMC usually drops at a higher rate. Then the resulting situation shows the signs of decoupling leading to the increase of the resource productivity.

Next, the changes in the longer periods 2002 – 2014 and 2004 – 2014 are accessed. The period 2004 – 2014 was examined as well in order to detect the changes in the development since the new Member States, particularly the transitive economies, have joined the EU. Although these countries are also included in the analysis of the previous years, the entry into the EU can stimulate significant changes. The results are shown in Figure. 3. The total effect in both periods using both GDP indicators is negative and higher in magnitude in the period 2004 – 2014. However, the positive scale and composition effects, similarly the absolute value of the intensity effect, were slighter in magnitude in the period 2004 – 2014 in comparison to the period 2002 – 2014. To sum up, the overall result is better in the period 2004 – 2014, i.e. higher DMC decrease occurred. However, this development was determined by the slower economic growth and the change of the structure in the EU economy leading to the lower DMC increase, together with the lower decrease of DMC per unit of GDP reflected in the lesser extent of the intensity effect.

F i g u r e 3

The Activity, Structural and Intensity Effect of DMC Development in the EU-28, %; 2002 – 2014; 2004– 2014, GDP in Chain Linked Volumes (2010) and PPS



Note: CLV – Chain Linked Volumes.

Source: Eurostat (2015a; c); own calculation.

To sum up, in both longer-term periods, i.e. 2002 – 2014 and 2004 – 2014, the negative intensity effect exceeded the sum of the positive scale and composition effects. It led to decrease of DMC in and the absolute decoupling took place in these periods. According to the results of the DA, some recommendations can be made. Particularly, the relevant EU authorities should pay attention to developing policies to strengthen the negative intensity effect. This means that the DMC intensities of GDP in the EU countries should be further reduced which requires introduction of new technologies enabling the use of less resources included in the DMC indicator to produce the same amount of GDP. In such a way the decoupling of the DMC from GDP should be encouraged. Because the DMC is composed of particular resources, the possibilities of decoupling should be further investigated in detail in the individual sectors of the particular countries. The role of the EU is to continue preparing strategies to promote SD and its three pillars as well as decoupling in as many sectors as possible. The EU SDS has provided the groundwork for achieving SD since 2001 and this strategy has focused, among others, on the decoupling of particular environmental pressures from the economic growth. The last economic crisis significantly affected the development of the economic as well as environmental variables, including GDP and DMC. Following that, the particular strategies, such as the Europe 2020 Strategy, started being adopted in this context to change the character of the economic growth. This growth should be simultaneously sustainable from the economic, environmental and social point of view.

The scale effect is important factor stimulating the resource consumption. However, the technological advance associated with the high level of decoupling should lead to the more „dematerialized" economic growth and thus to the SD path. This is also the crucial focus of the EU strategies endeavoring to achieve the SD. Composition effect has not played the significant role in the EU and it especially showed the relatively higher level in 2008 that was followed by forthcoming economic problems. This effect results from the changes of the GDP composition in the EU, i.e. the shares of the EU countries' GDPs on the overall EU's GDP. Thus, it can also be affected by the GDP structure in each country and the productivity with which their GDP is produced. Probably, the results would be different if the variables in per capita terms were used. However, this Paper was aimed at detecting the factors of the total DMC development in the EU-28. Therefore, the changes in smaller economies does not have to affect the overall development in the EU significantly. Moreover, the convergence process in the EU has taken place in many areas, including the RP. Only Malta (both RP indicators) together with Estonia, Sweden and Romania (RP based on GDP in CLV) showed the drop in the RP in 2002 – 2014. Thus, the RP growth should be further stimulated by appropriate and more targeted measures at the EU level as well as in the Member States.

Conclusions

The aim of the Paper was to detect if decoupling of the DMC from the GDP in the EU took place and to detect the factors of that development. The IDA and the LMDI method was applied to examine the factors of the DMC development in the EU-28.

In the longer periods 2002 – 2014 and 2004 – 2014 the DMC declined in the EU-28 by 9,579% and 13,399% respectively which by the simultaneous positive change of GDP leads to the absolute decoupling. In these periods, the negative intensity effect exceeded the sum of both positive effects, i.e. the scale and composition effect, whereas all the partial effects showed the higher absolute values in period 2002 – 2014. However, the positive scale and composition effects, similarly the absolute value of the intensity effect, were slighter in magnitude in the period 2004 – 2014 as compared to the period 2002 – 2014. Thus, in the period 2004 – 2014 the slower growth of the economic activity more significantly encouraged the absolute decoupling comparing to the period 2002 – 2014. Overall, although the period affected by the economic crisis is included in the monitored periods, the general trend of development is positive, i.e. the GDP growth and the DMC decrease occurred simultaneously.

In the year-by-year DA the total effect is positive in six years, i.e. in 2004 – 2007, 2011 and 2014 and negative in the remaining ones which is consistent with the DMC changes. This means that annually the absolute decoupling occurred in 2003, 2008, 2010 and 2013 when DMC annually dropped and both GDP indicators increased. This indicates that the absolute decoupling is more likely to be achieved in time of slower economic growth (2003) and also when the significant downturn of economy is expected, which is especially the case of 2008 but also of 2010. In time of more rapid economic growth, no decoupling (2004) or at most relative decoupling (2006) is more likely to occur. In time of economic recession, the DMC usually drops more than GDP which was especially the case of 2009. In 2014, the most recent year for which data are available, the EU economy achieved the relative decoupling of DMC from GDP and this development should be further encouraged by the appropriate structural reforms towards the absolute decoupling. This should include periods of faster economic growth. In more years the development of DMC was determined by the economic situation although the intensity effect stimulated the development towards decoupling. All this is in compliance with the results of the analysis in the longer-term periods where exclusion of the year 2003 significantly affected the results.

Resulting from the year-by-year DA, the intensity effect was predominantly negative which stimulated decoupling of DMC from GDP. This effect was positive only in 2011, and, moreover, in 2004 when GDP in CLV is used. Consequently, in both years no decoupling occurred. Composition effect was often marginal in magnitude, whereas it was detected that it played the more significant role only in the case of important change in economic conditions. The relatively large negative scale effect in 2009 significantly encouraged the DMC drop leading to the increase of the EU's resource productivity. The negative scale effect was rare, occurring only in the years of economic downturn. Except for 2009, this took place only in 2012 when GDP in CLV declined.

All the partial effects showed the higher absolute values in the longer periods when GDP in PPS is used as the indicator of the economic activity because this GDP indicator showed the higher overall percentage increase. The same applies to the annual percentage changes. However, as regards the development over time, the results for the GDP in CLV should be more reliable. On the other hand, the problems with the additivity loss related to this indicator can affect the DA results.

Increasing resource productivity as a result of structural changes leads to decoupling which can subsequently encourage the SD path. The possibilities to achieve decoupling in the particular sectors and for the different sources and pollutant categories can significantly vary. These possibilities should be examined in detail for as much environmental pressures as possible in the sectors responsible for environmental degradation. The intensity effect of the DMC development, which was predominantly negative in the EU, is significantly related to the structural changes in the EU countries. On the other hand, the more efficient resource use was also partly affected by the adverse economic development due to the economic crisis and recession. The appropriate technological improvements to reduce material intensity in the EU countries and the suitable strategies at the EU level spurring dematerialization, resource productivity growth and decoupling are required. The effort to achieve the sustainable development path must also come from the bottom to the top and due to the strong integration and the interdependence of the EU countries, the lacks in one country to achieve such a path can significantly affect the other countries' success as well as the overall EU performance. In such a way the composition effect can also be affected. The further challenge of the research is, among others, to extend the DA to include more factors affecting the environmental variable.

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