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Drivers of CO_2 Emissions in the Slovak Economy: The Logarithmic Mean Divisia Index Approach of Decomposition

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Abstract

The paper examines driving forces of CO_2 *emissions of four sectors of the Slovak economy. Our analysis was based on extended Kaya Identity framework using Logarithmic Mean Divisia Index (LMDI) decomposition technique. We applied chaining analysis for period 1997 – 2012 and examined contributions of six effects. We found the primary mover of* CO_2 *emissions to be energy intensity effect (52%) followed by activity effect 25%) and economy structure effect (16%). The combined contribution of energy mix effect, emission factors effect and population effect reached only approximately 7%, which implies that as much as 93 %* CO_2 *emissions were determined to large extent by exogenous impetuses. Our evidence therefore suggests that the policies aimed at structural changes of economies are the most effective tool to address issue of* CO_2 *emissions.*

Keywords: *energy policy,* CO_2 *emissions, LMDI, Slovak republic*

JEL Classification: P18, Q48

Introduction

The climate change policies aimed at greenhouse gases emissions abatement have been integral part of EU's foreign and security policies for over decade now. EU 2020 goal to reduce Greenhouse gases emissions by 20% till 2020 stipulated in its 2020 Energy strategy with detailed commitments of individual countries has been followed by more vaguely drafted 2030 Energy strategy to reduce greenhouse gases emissions by 40% till 2030 avoiding specifics for individual countries as a result of growing unwillingness to threaten prospects of economic

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** Matej KORČEK, Institute of Economic Research SAS, Šancová 56, 811 05 Bratislava 1, Slovak Republic; e-mail: matej.korcek@savba.sk growth by Central and Eastern European members as well as several others hit by economic crisis such as Finland or Italy. As of now, the most far reaching plan to reduce greenhouse gases emissions by 80 – 95% by 2050 compared to 1990 levels is expressed in The Energy Roadmap. All those goals are based on IPCC reports, although they do not reflect the changes in fifth report which basically excluded some of EU members from the group of developed countries (they belong to the group as Economies in transitions), which only helps to understand growing resentment to these long-term reduction targets.

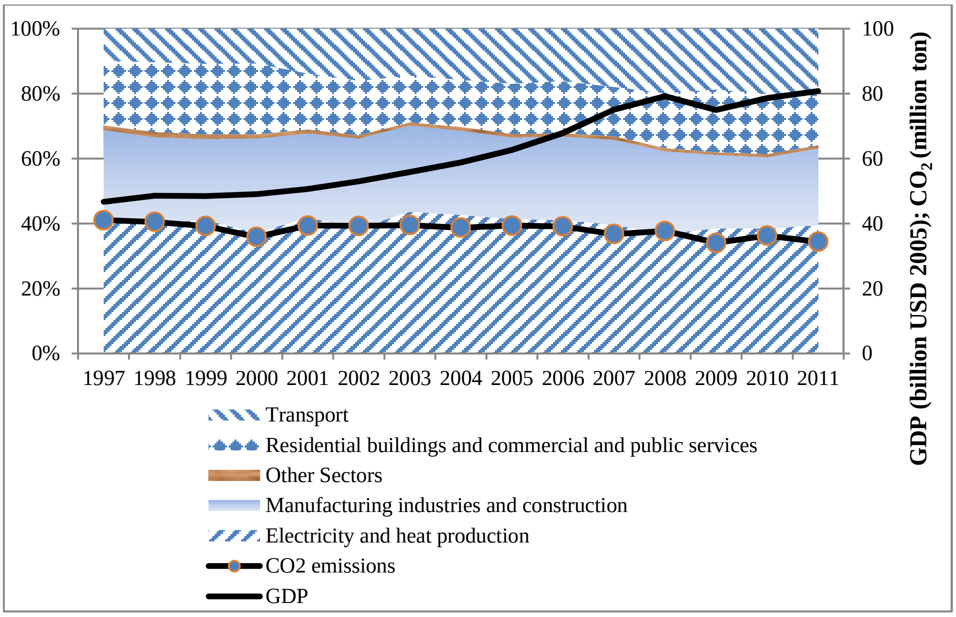
To be clear, multiple of those countries fighting EU goals in emissions area and Slovakia definitely being one of them have not been much affected by EU demands in this area due to changes in their industrial base as well as the whole economy and in many cases enterprises have benefitted from improper setup of policy tools such as EU Emissions Trading System (EU ETS). National Energy Policy of Slovak republic makes clear that the attitude of Slovak republic towards greening initiatives is quite pragmatic (Slovakia should try to angle its industry in such way it could be beneficiary from these actions) and primarily shaped by its international commitments. The Slovak Republic has been a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) since 1994 and a party to the Kyoto Protocol since 2002 (IEA, 2012). Under the Kyoto Protocol, it has bound to reduce its greenhouse gas emissions by 8% in the period from 2008 to 2012 relative to their 1990 level. According to European Environment Agency (EEA, 2014) report, Slovakia has significantly over achieved this target, when greenhouse gas emissions (GHG) were 40.7% below 1990 level in 2012. Apart from that Slovakia has to comply with EU commitments under the framework of EU climate and energy package which has aimed to lower EU emissions by 20% compare to 1990 for the whole EU. Emissions trading system covers 45% of European emissions and it aims to decrease these emissions by 21% till 2020 against 2005 level. Since the beginning of emission trading scheme Slovakia verified emissions were below the freely allocated allowances by as much as 36% on average. This has however changed upon the introduction of third phase of EU ETS scheme and freely allocated allowances did not cover all the verified emissions. The emissions from most sectors (transport (except aviation and international maritime shipping), buildings, agriculture and waste) not covered by EU ETS are subject to constraints imposed by mechanism of Effort Sharing Decision which establishes binding annual greenhouse gas emission targets for Member States for the period 2013 – 2020. The overall EU target is to limit emissions by 10% by 2020 compared to 2005 level, with individual member countries goals being set based on their relative wealth. Slovakian target within this scheme is to limit GHG emissions in sectors not covered by the EU

ETS to 13% above the 2005 level. Already in 2013 Slovakia's emissions were 10% below the target and according to its own projections, till 2020 emissions belonging into this scheme should 37% below the original target.

In 2012 GHG emissions excluding LULUCF (land use, land use change and forestry) in the Slovak Republic were around 43.12 million tones of CO_2 equivalent, or 19.4% lower than in 1995. Energy related emissions in 2012, respectively 1995 were 29.53 million CO_2Eq and 38.84 million CO_2Eq which represented 24% decline. According to IEA (2012) report the main driver to this decline was the steep, although temporary, slowing in economic activity, accompanied by the restructuring of the economy. An expansion in the use of more efficient technologies, the switch away from coal in industry and for electricity generation, a reduction in the share of energy-intensive industry and a larger share of services in GDP also played a role in the decline in emissions over the period, however this report does not suggest the importance of individual factors. Over the same period Slovakian GDP grew by 99% which documented decoupling between GDP and GHG emissions, while in 1997 each $1USD_{2005}$ of GDP led to production of 0.88 kg of CO_2 emissions, in 2011[1] it was approximately only 0.43 kg of CO_2 emissions/$1USD_{2005}$ of GDP.

Figure 1

Sources of CO_2 Emissions of Slovak Economy in the Period 1995 – 2011



Source: WB, World Development Indicators.

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[1] Data for 2012 were not available in IMF WDI database at time of writing this article (July 2015).

In terms of emissions by sector, according to World development indicators electricity and heat production 39.5% in 2011 which meant decline by one percentage point since 1997. It was followed by sector of manufacturing industries and construction accounting for 23.7% compared to 28.4% in 1997. Emissions originating from Residential buildings and commercial and public services declined by 5 percentage point (p.p.) to some 15% in observed period. The only sector where emissions increased was sector of transportation (mostly due to road transportation) which share increased from 9.8% in 1997 to 20.8% in 2011. According to OECD evaluation report of Slovakia, transportation alongside with industry might represent one of the risks threatening the accomplishment of mid-term and long-term goals of emission reduction and this area will require further environmental policies.

As of emissions sources, in 2011 the largest amount of CO_2 emissions came from coal combustion, representing 42% of total emissions, followed by gas (31%) and oil (23%), the percentage shares in 1997 in respective order were 47.3%, 31.3% and 17.7%. This shift has also been reflected in CO_2 intensity (expressed as CO_2 kg per kg of oil equivalent energy use) which declined from 2.27 to 1.98 illustrating so the influence of energy mix on emissions reduction in Slovakia.

The main objective of this paper is to analyze and quantify factors that influenced energy related CO_2 emissions in Slovakia´s economy. Due to data availability and used methodology we did apply this study on four sectors of economy – industry, construction, services and agriculture which account for approximately 40% of CO_2 emissions and we aim to quantify the contributions of main driving factors responsible for decreasing of CO_2 emissions in Slovakia´s economy during the period of high economic growth and shifts in structure of economy. We are aware that there are some limitations in our analysis (due to the lack of data the household sector has not been involved) to completely analyze all sectors of the Slovak economy that influenced energy related CO_2 emissions in the country.

1. Literature review

Decomposition analysis is one of the most effective tools for investigating the mechanisms influencing energy consumption and its environmental side effects. Two popular decomposition techniques are the index decomposition analysis (IDA) and the structural decomposition analysis (SDA). The original purpose of IDA in the late 1970s was to study changes in industrial energy consumption, or more specifically electricity consumption in industry. In contrast, SDA has been used to study other aspects of economic issues before it was used to study energy consumption and emissions in the 1970s and early 1980s. While SDA is based on the input-output modeling framework, IDA uses index number concept in decomposition. In recent decades, index decomposition analysis (IDA) has been widely accepted as a decomposition methodologies based on the Laspeyres and the Divisia indices. One basic drawback of the conventional Laspeyres and Divisia index methods was the large residual term found in most applications, leaving a significant part of the examined changes unexplained (Steenhof, Woudsma and Sparling, 2006). However, this problem has been effectively solved through the improved variants (Ang, 2004).

The advantage of the IDA is that it can readily be applied to any available data at any level of aggregation (Ma and Stern, 2008). Multiple techniques have been established under the scope of IDA framework but according to Ang (2004) the (LMDI) has increasingly become the preferred method as it has several advantages: it gives perfect decomposition, i.e. the results do not contain an unexplained residual term; it can be applied to more than two factors; there is a simple relationship between multiplicative and additive decomposition; it is consistent in the aggregation and the estimates of an effect at the subgroup level can be aggregated to give the corresponding effect at the group level. Another useful feature of this methodology is that it is capable to handle zero values by replacing all the zeros in the data set may by small positive constant, e.g. between 10^{-10} and 10^{-20}, while the computation proceeds as usual. LMDI was first used in 1998 to study the factor decomposition for the CO_2 emissions of energy consumption from China’s industrial sectors (Ang, Zhang and Choi, 1998). Since then its scope of analysis has been broadened to include analysis of energy supply and demand, energy-related emissions, material flow and dematerialization, monitoring of national energy efficiency trends and making cross-country comparisons of energy performance (Chen, Yang and Cheng, 2013).

Kaya identity (Kaya, 1990) is often being used to assess the driving factors of carbon intensity. An extended Kaya identity has been applied using LMDI I in a number of studies, e.g. Zhang and Ang (2001), Wang, Chen and Zou (2005), Ma and Stern (2008). This form of decomposition traditionally recognize several influencing factors, namely overall economic activity effect, economy mix effect, energy intensity effect and effects resulting from energy mix, emission factors and population.

Recently, energy-related carbon emissions have been studied by adopting LMDI approach in different scale levels. Pani and Mukhopadhyay (2010) studied the CO_2 emissions of 114 countries during 1992 – 2004 using LMDI framework and identified the effect of GDP on emission is substantially larger than that of population, however with former being of more fluctuating nature than the latter and with various differences across regions. As for other factors, they concluded that majority of the countries have been successful in increasing emission efficiency and that both energy and emission intensity have crucial roles in determining the level of emissions and should be primary object of environmental policies. In a more sector focused study covering the 10 OECD countries Greening, Ting and Davis (1999) found out that freight sector has historically shown different patterns of aggregate carbon intensity compared to other sectors. While aggregate carbon intensity declined for all other sectors, aggregate carbon intensity for freight increased. They found out that increases in aggregate carbon intensity have been driven primarily by an increase in activity. As changes in fuel price and taxes appeared not to be effective instruments for reducing energy consumption for this end use they suggested to focus on alternative policy options such as less-carbon intensive fuels and technologies, and reducing congestions. Greening, Ting and Krackler (2001) also examined the patterns of the evolution of aggregate carbon intensity from residential end uses in 10 OECD countries which show greater variability than other sectors. They found decrease in aggregate carbon intensity for six of the countries; however, for all of the countries, decreases were offset by shifts in end-use structure toward more carbon-intensive activities.

In the case of the European Union (EU), several studies have used IDA techniques in economic sectors. For instance, Diakoulaki and Mandaraka (2007) used refined Laspeyres model to determine the impact of output, energy intensity, structure, fuel mix and utility mix effect on CO_2 emissions in the manufacturing sector of EU-14 countries during the period 1990 – 2003. They found that most EU countries made a considerable but not always sufficient decoupling effort, while no significant acceleration is observed in the post-Kyoto agreement period. The decrease of GHG emissions in more recent period 1990 – 2012 was subject of EEA (2014) study. EEA reported 19.2% decrease of emissions during this period, 50.2% of which was accounted for by Germany and UK. As of sector wise analysis, Manufacturing and construction were identified to be the largest sources of emissions reductions, followed by power and heat generation and residential and commercial sectors. GHG originating in transportation sector has on the other hand risen. Generally, the effects that were identified by EEA as main emission decreasing drivers were lower energy and carbon intensity, improved transformation efficiency and energy mix effect. Switching to lower carbon intensive fuel supposedly accounted for 16% of improvement in carbon-intensity of EU. On the other hand, negative impact on emissions resulted primarily from increasing population and GDP per capita. Further this study concluded that at least since 2005, decoupling between economy performance and GHG emissions existed with lower carbon intensity of energy being a key factor, while decrease in primary energy intensity was largest contributing factor to lower CO_2 emissions from fossil fuel combustion. Despite decoupling between GHG emissions and GDP, EEA claims that third of the change in total GHG emissions in the EU between 1990 and 2012, on average, can be explained by changes in GDP (the relationship naturally varies across the countries, being stronger during the periods of economic recession). This however also means that various factors and policies other than strictly energy and environment have had significant development on GHG emissions.

Case studies at the national level researched the main factors driving changes in CO_2 emissions in different countries during different time periods, such as Thailand (Bhattacharyya and Ussanarassame, 2004), China (Chen, Yang and Chen, 2013), South Korea (Choi and Ang, 2001), India (Paul & Bhattacharya, 2004), Brazil (Luciano and Shinji, 2011), Turkey (Tunc et al., 2009). As of European Union countries, several studies analyzed development of CO_2 emission of specific countries using this technique. Hatzigeorgiou et al. (2011) decomposed CO_2 emissions of Greece into four factors: income effect, energy intensity effect, fuel share effect and population effect for period 1990 to 2002 and found 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. O`Mahony, Zhou and Sweeney (2012) analyzed the driving forces of CO_2 emissions in eleven final energy consuming sectors between 1990 – 2007 for Ireland. They found substantial heterogeneity in sectorial performance. Growth in economic and transport activity played major role and while some improvements in energy intensity were recorded in the economic sectors, and declining emission’s coefficient of electricity and decreasing energy intensity of households have mitigating effect, energy related carbon emissions grew considerably. Alves and Moutinho (2013) examined CO_2 emissions intensity and its components for 16 industrial sectors over 1996 – 2009 in Portugal. They have shown that CO_2 emissions intensity diminished significantly in the considered period mainly as the effect of lowered energy intensity of economic sectors, but substitution between fossil fuels also played salient role.

Among others, Obadi and Korček (2016) devoted a similar issue, one of a few authors which examined the issue of CO_2 emissions in Eastern Europe is by Moutinho et al. (2015). In their paper in which identified the driving forces of change in energy-related CO_2 emissions in regions of Europe including the region of Eastern Europe Moutinho et al. Have used the LMDI approach to decomposition analysis, and they concluded that their results showed that CO_2

emissions are correlated with the energy consumption of the economy for the group of countries under analysis, which is determined by the change of population among the various countries. Similarly, they found that renewable energy consumption is also determined by the size and structure of the countries, as reflected by the value added to the economy. Zachariadis and Kouvaritakis (2003) also examined the CO_2 emissions in Central and Eastern Europe but only from the sector of transport. As a long-term outlook they found that the transportation energy demand going to double and CO_2 emissions to be 70% higher in 2030 compared to 2000. Al-mulali and Ting (2014), using econometric model, they tried in their paper to explore the bi-directional long run relationship *inert alia* between trade, export and import and CO_2 emissions in six regions including Eastern Europe. They did not find, during the examined period 1990 – 2011, in the region of Eastern Europe, a positive feedback long run relationship between the trade variables, energy consumption and CO_2 emission.

Since the different methods used in the above mentioned papers (except the methods used in Moutinho et al., 2015) it is difficult to compare their results with ours in this paper. Regardless of the above carried out papers, it is necessary to carrying out many others paper in this issue; because the estimation of importance of individual factors that led to decrease in CO_2 emissions might be of interest for policymakers in order to recognize what policies might be effective in further process of decarbonisation of the economy.

2. Data and Methodology

2.1. Data

This study covers the period from 1997 to 2012 for which all the needed data are available. The primary source of data was statistical database of EU – EUROSTAT. In this paper we consider four energy sources (electrical energy, oil, natural gas and solid fuels) and four sectors of economy (agriculture and fishing, construction, industry and services). In order to apply LMDI methodology we needed to get information on energy consumption, CO_2 emissions, gross valued added of individual economic sectors and population figures. Data on energy consumption were retrieved from EUROSTAT table *[nrg_100a]* and these four types cover 88 – 96% of energetic needs within of selected sectors during the observed period.

As statistical data on sector emissions according individual energy types are not available, we estimated CO_2 emissions based on average conversion factors used by BP Statistical review, where conversion factors are as follows: oil, 3.07

tons CO_2 per ton; gas, 2.35 tons CO_2 per ton of oil equivalent; coal, 3.96 tons per ton of oil equivalent. In case of electricity, we used power generation mix as a base for our calculation and calculated the emission intensity of power generation as a simple weighted average. According this computations emission intensity of power generation reached just 0.83 tons CO_2/Toe in 2012 after falling there from initial 1.36 tons CO_2/Toe. Such result is perfectly plausible since power generation in Slovakia is in great extent emission free due to significant contribution of nuclear energy and hydro-energy which jointly accounted almost for 70% of power generation mix in Slovakia in 2012 with other RES adding another 4.7%. Even though this process of estimation is obviously not absolutely accurate, comparison of such calculated emissions against official CO_2 emissions figures published by World Bank confirmed adequacy of this approach.

The variable indicating level of economic activity in economic sectors (agriculture, industry, construction and services) – gross value added (GVA) in 2005 constant prices was retrieved from Eurostat table [*nama_nace10_k]*. It originally provided data for 10 branches, namely Agriculture and fishing, Construction, Industry and seven other economic activities[2] which we aggregated under Service sector. Those four sectors where selected despite the fact they cover only slightly over 40% of final energy consumption and CO_2. The reason for that was limitation of this procedure and selected variable – GVA, since as Marrero and Ramos-Real (2013) stated GVA is the best way to measure the level of activity in productive sectors, but it is not a good proxy to measure activity in other sectors such as the transport or the residential. Therefore it is also worth noted that energy consumption in service sector does not consider energy consumed in transportation as this is not sector specific (i.e. the energy reported to be consumed in transportation is linked to activities in all sectors) and neither energy consumption of households as those could lead to significant distortions of results. It also needs to be noted that with over 40% share on CO_2 emissions these sectors of economy represent single most important source of CO_2 emissions outrunning both transportation and power generation and heating.

The data on population development was retrieved from EUROSTAT table *[demo_pjan]*.

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[2] Namely: Wholesale and retail trade, transport, accommodation and food service activities, Information and communication, Financial and insurance activities, Real estate activities, Professional, scientific and technical activities; administrative and support service activities, Public administration, defense, education, human health and social work activities, Arts, entertainment and recreation; other service activities; activities of household and extra-territorial organizations and bodies.

2.2. Methodology

In conducting an IDA, the analysis begins by defining a governing function relating the aggregate to be decomposed to a number of predefined factors (O'Mahony, 2013). For decomposition of carbon emissions, Y. Kaya suggested the Kaya identity (Kaya, 1990), which can be expressed as follows:

$$C = \frac{C}{E} \times \frac{E}{GDP} \times P$$

where

C – carbon emissions,
E – energy consumption,
GDP – gross domestic product,
P – population.

As this formula does not allow for sector specific analysis, extended Kaya Identity using logarithmic mean divisia index (LMDI) has been proposed by Zhang and Ang (2001). This methodology has particularly plausible properties: completeness, time reversal and zero value robustness (Hoekstra and van den Bergh, 2003). Moreover it offers two ways of decomposition – additive and multiplicative which ease the interpretation of results while these forms are linked through a simple mathematical relationship (Ang, 2005). In our study the Divisia index is employed in both forms, chain-linked year-by-year. As claim Baležentis, Baležentis and Streimikiene (2011) chaining analysis should be preferred to period-wise comparison analysis as the corresponding results provide a more realistic measure of the real changes over the time and is not dependent on selection of specific years. This allows for annual analysis that can also be aggregated by sub-period and over the entire period. Our LMDI framework recognizes six possible factors determining energy emissions, namely overall industrial activity (activity effect – C_{act}), economy mix (structure effect – C_{str}), sector energy intensity (intensity effect – C_{int}), energy mix effect (C_{Mix}), emissions factors (C_{emf}) and population effect (C_P). Such idea can be expressed by following formulae:

$$C = \sum_{ij} C_{ij} \sum_i \sum_j \frac{Q_i}{Q} \times \frac{E_i}{Q_i} \times \frac{E_{ij}}{E_i} \times \frac{C_{ij}}{E_{ij}} \times \frac{Q}{P} \times P$$

where

C – the energy emissions in the economy,
C_{ij} – carbon emissions from energy j by economic sector i ,
$Q = \Sigma Q_i$ – total economic activity of all of i sectors of economy, while relation Q_i/Q describes the economic mix,
E_i/Q_i – the energy intensity of sector i,
Q/P – economic activity per capita,
P – population.

Carbon emissions further depend on energy mix consumed in individual sectors which can be expressed by equation E_{ij}/E_i (share of consumption of energy j in sector i on overall energy consumption by sector i); carbon emission coefficient (C_{ij}/E_{ij} – carbon emissions from energy j by sector in from consumption of energy j by sector i) – due to nature of our data this factor will have only marginal effect on overall emissions when electricity is the only energy source that has changing emissions coefficient. It needs to be added that using constant carbon emissions coefficients is standard procedure in practical applications of this methodology (Xu, He and Long, 2014).

In case of additive decomposition the change of energy consumption between periods T and 0 gains following form:

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{Act} + \Delta C_{Int} + \Delta C_{Str} + \Delta C_{Mix} + \Delta C_{Emf} + \Delta C_P$$

And formulas of individual parts of total energy consumption are computed as follows:

$$\Delta C_{Act} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} ln\left(\frac{\frac{Q^T}{P}}{\frac{Q^0}{P}}\right)$$

$$\Delta C_{Str} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} ln\left(\frac{S_i^T}{S_i^0}\right)$$

$$\Delta C_{Int} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} ln\left(\frac{I_i^T}{I_i^0}\right)$$

$$\Delta C_{Mix} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} ln\left(\frac{M_{ij}^T}{M_{ij}^0}\right)$$

$$\Delta C_{Emf} = \sum_i \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} ln\left(\frac{U_{ij}^T}{U_{ij}^0}\right)$$

$$\Delta C_P = \sum_i \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} ln\left(\frac{P^T}{P^0}\right)$$

M_{ij} represents fuel mix variable calculated as E_{ij}/E_i and U_{ij} is CO_2 emission factor which we obtained using equation C_{ij}/E_{ij}.

In similar manner the multiplicative decomposition of the change of energy consumption can be obtained according following rule:

$$D_{tot} = C^T / C^0 = D_{Act}\, D_{Int}\, D_{Str}\, D_{Mix}\, D_{Emf}\, D_P$$

while individual components are computed using formulas below:

$$D_{Act} = exp\left(\sum_{ij} \frac{\left(C^T_{ji} - C^0_{ij}\right) / \left(lnC^T_{ij} - lnC^0_{ij}\right)}{\left(C^T - C^0\right) / \left(lnC^T - lnC^0\right)} ln\left(\frac{\frac{Q^T}{P}}{\frac{Q^0}{P}}\right)\right)$$

$$D_{Str} = exp\left(\sum_{ij} \frac{\left(C^T_{ji} - C^0_{ij}\right) / \left(lnC^T_{ij} - lnC^0_{ij}\right)}{\left(C^T - C^0\right) / \left(lnC^T - lnC^0\right)} ln\left(\frac{S^T_i}{S^0_i}\right)\right)$$

$$D_{Int} = exp\left(\sum_{ij} \frac{\left(C^T_{ji} - C^0_{ij}\right) / \left(lnC^T_{ij} - lnC^0_{ij}\right)}{\left(C^T - C^0\right) / \left(lnC^T - lnC^0\right)} ln\left(\frac{I^T_i}{I^0_i}\right)\right)$$

$$D_{Mix} = exp\left(\sum_{ij} \frac{\left(C^T_{ji} - C^0_{ij}\right) / \left(lnC^T_{ij} - lnC^0_{ij}\right)}{\left(C^T - C^0\right) / \left(lnC^T - lnC^0\right)} ln\left(\frac{M^T_{ij}}{M^0_{ij}}\right)\right)$$

$$D_{Emf} = exp\left(\sum_{ij} \frac{\left(C^T_{ji} - C^0_{ij}\right) / \left(lnC^T_{ij} - lnC^0_{ij}\right)}{\left(C^T - C^0\right) / \left(lnC^T - lnC^0\right)} ln\left(\frac{U^T_{ij}}{U^0_{ij}}\right)\right)$$

$$D_P = exp\left(\sum_{ij} \frac{\left(C^T_{ji} - C^0_{ij}\right) / \left(lnC^T_{ij} - lnC^0_{ij}\right)}{\left(C^T - C^0\right) / \left(lnC^T - lnC^0\right)} ln\left(\frac{P^T}{P^0}\right)\right)$$

Results of our calculation enable us to quantify impacts of individual effects on the overall year-over-changes by simply calculating individual effect’s shares based on calculated values in their absolute forms. In order to provide more comprehensible conclusion we also apply the above logic on sums the individual results of our chain linked calculations for the whole observed period which enables us to express the importance of the individual effects in their period wise form.

3. Results

The estimated annual CO_2 emissions of the four examined productive sectors of Slovak economy recorded significant 33% decline in observed period which represents some 7 004 kt/year of CO_2. This decrease was unevenly split among the selected sectors. Sectors of agriculture, construction and services lowered their emissions by 56%, 59% and 54% respectively, while emissions in sector of industry decreased by more moderate 23%. Such uneven development led to increase of share of emissions originated from industry sector on total to 81.6% in 2012 from 72% in 1997, on the other hand share of service sector decreased to 15.9% from 24% and these figures for agriculture are 2% against original 3.2% and from 0.8% to 0.5% for construction sector. However, in absolute terms emissions decrease of 3 724 kt/year in industry sector was only followed by emission savings of service sector of 2 782 kt/year and emissions cut sectors of agriculture and construction reached only negligible 390 kt/year, and 108 kt/year respectively.

This development resulted from interaction of multiple influencing factors as we indicated in previous parts of the article. Firstly it must be noted that economic output of these economic sectors measured as GVA in constant prices 2005 increased by EUR 19.3 bil. or 71%. The steepest growth recorded industry sector which output measured by GVA grew by 171% (EUR 9.2 bil.), this indicator in case of agriculture grew by 48%, and 46% both for sectors of construction and services. Differing speed of growth of individual sectors obviously led to changes in economy mix and Slovakia unlike most of other developed economies has increased the importance of industry sector in economy mix (as defined in this article) increasing from 20% in 1997 to 32% in 2012 at the expense of service sector which share during the same time period decreased by 10 percentage points (p.p.) vto 58%. The weights of agriculture and construction sectors changed only slightly – from 4% to 3%, and from 8% to 7% respectively.

The development of above mentioned indicators show that decoupling between CO_2 emissions and economic activity is only partial, as economic activity still continue to determine development of emissions since higher economic activity implied lower decline of CO_2 emissions. The reason for that was lowering energy intensity, which showed similar patterns of improvement across all four observed sectors declining by 70% in agriculture and construction, 68% in industry and 58% in case of service sector. The most energy intensive sector stayed industry with 324 TOE/mil. EUR, significantly above intensity of service sector with 48 TOE/million EUR, agriculture with 83 TOE/million EUR and construction with 10 TOE/ million EUR.

The last set of data which enters our equation is population effect, which influence on CO_2 emissions was minimal in Slovakia, as number of inhabitants increased only by 0.47% (25 390 people). Further we proceed to interpretation of our results which enabled us to exactly quantify individual effects of above mentioned changes in economy.

As we already stated, CO_2 emissions in observed period in examined sectors decreased by 7 004 kt/year as a result of contradictory forces affecting the CO_2 emission trajectory. The most salient factor was energy intensity effect which would have caused emissions to decrease cumulatively by 20 249 kt/year itself during observed period under ceteris paribus condition. Under the same assumption the other factors that pulled the CO_2 emissions down were energy mix effect with overall cumulative estimated effect of –1 960 kt/year and emission factor effect with –820 kt/year resulting from changes in power generation mix. Contrary, factors that were pushing CO_2 emissions into higher levels were activity effect with supposed effect of 9 589 kt/year and structural effect with 6 356 kt/year resulting from economic growth accompanied by industrialization of economy due to wave of industry reallocation activities targeted to newer EU member states in first decade of 21st century. Population effect would have been only of minor importance with increase 80 kt/year.

Table 1

Results: CO_2 Emission Development (upper figure represents year-over-year /y-o-y/ change in kt, lower figure represents y-o-y percentage change)

Year	Activity effect	Structural effect	Intensity effect	Energy mix effect	EMF effect	Population effect	Total effect
1998	395 (1.87%)	854 (4.09%)	–2 363 (–10.49%)	–56 (–0.26%)	–44 (–0.21%)	34 (0.16%)	–1 179 (–5.38%)
1999	64 (0.32%)	–372 (–1.83%)	–218 (–1.08%)	–559 (–2.73%)	–88 (–0.44%)	21 (0.11%)	–1 152 (–5.56%)
2000	–157 (–0.78%)	1 101 (5.68%)	–84 (–0.42%)	141 (0.71%)	–318 (–1.58%)	19 (0.1%)	703 (3.59%)
2001	898 (4.78%)	345 (1.81%)	–2 528 (–12.32%)	–711 (–3.63%)	–25 (–0.13%)	–70 (–0.37%)	–2 092 (–10.31%)
2002	762 (4.26%)	67 (0.37%)	–544 (–2.93%)	44 (0.24%)	–156 (–0.85%)	1 (0.%)	173 (0.95%)
2003	551 (3.09%)	2055 (12.01%)	–3 076 (–15.61%)	–204 (–1.12%)	194 (1.08%)	–14 (–0.08%)	–493 (–2.68%)
2004	709 (4.09%)	1 601 (9.48%)	–2 679 (–14.06%)	1 (0.01%)	–22 (–0.12%)	–10 (–0.06%)	–399 (–2.24%)
2005	1 008 (5.81%)	–107 (–0.6%)	–48 (–0.27%)	24 (0.13%)	–100 (–0.56%)	3 (0.01%)	779 (4.46%)
2006	1757 (9.94%)	902 (4.98%)	–2 071 (–10.57%)	73 (0.4%)	–79 (–0.43%)	1 (0.%)	582 (3.19%)
2007	1 857 (10.65%)	163 (0.89%)	–2 606 (–13.23%)	–400 (–2.16%)	25 (0.14%)	1 (0.%)	–959 (–5.09%)
2008	1 081 (6.23%)	–259 (–1.44%)	–926 (–5.04%)	187 (1.05%)	–73 (–0.4%)	10 (0.05%)	19 (0.1%)
2009	–920 (–5.2%)	–1 358 (–7.58%)	404 (2.37%)	539 (3.18%)	–11 (–0.07%)	20 (0.12%)	–1 327 (–7.41%)
2010	796 (4.89%)	1 316 (8.2%)	–1 374 (–7.91%)	–434 (–2.57%)	–100 (–0.6%)	25 (0.15%)	228 (1.38%)
2011	409 (2.55%)	270 (1.67%)	–1 359 (–8.01%)	–444 (–2.69%)	79 (0.48%)	6 (0.04%)	–1 039 (–6.19%)
2012	377 (2.49%)	–221 (–1.43%)	–776 (–4.94%)	–162 (–1.05%)	–101 (–0.65%)	33 (0.22%)	–849 (–5.39%)

Source: Author's calculations.

3.1. Activity Effect

Activity effect resulting from growing output of examined sectors was the most significant factor pulling the emissions up, with total cumulative aggregate of 9 589 kt/year which overall represented contribution factor to overall CO_2 emission of 25%. As can be seen on graph 2, apart from 2000 and 2009 (years when Slovakia was affected by banking and credit crisis and 2009 – Great recession), effect would always have lead to emissions growth. However, even apart these two years activity effect shows great extent of variability when its impact ranged from 64 kt in 1999 representing only 5% of overall year over year change to 1 857 kt in 2007 which explained as much as 37% of CO_2 emissions change. Although, the largest importance of activity effect within the presented matrix of CO_2 took place in 2005 when activity effect could explain as much as 78% of yearly change in emissions. More detail analysis of activity effect reveals that primary driver were, unsurprisingly, changes in output of industry sector that have been accompanied by decreasing usage of coal and slight growth of natural gas consumption within this sector. Fact that the output growth did not translate into more significant activity effect can be explained by modernization of used technology and replacement of capital assets in industry due to transformation from heavy industries towards automotive, electronics etc. that use more energy efficient technologies and delivering higher added value products.

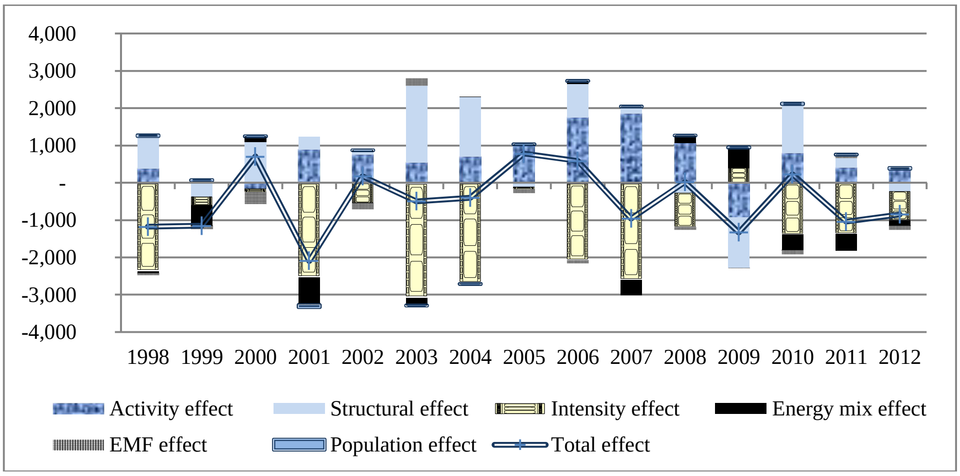
3.2. Structural Effect

Unlike in case of other developed countries that usually (in terms of CO_2 emissions) benefit from changes in economy mix, Slovakia has undergone the process of industrialization which has been reflected in contribution of structural effect to CO_2 emissions development. The overall effect of structural effect in given period represents increase of 6 356 kt of CO_2 emissions or 16% of total change. On average, yearly increments of CO_2 emissions resulting from structural effect reached 2 p.p. however this is to great extent influenced by year 2009 and slump in industrial activity that was deeper compared to other observed sectors. As Figure 2 illustrates, structural effect has used to be relatively influential factor that pushed CO_2 emissions into higher levels in 9 out of 15 years. The largest impact of structural effect came to existence in 2003 with 2 055 kt increase of CO_2 emissions representing 12% growth and having 34% share on overall emission change in that year, which can be explained by massive influx of industrial from the beginning of the century and commencement of industry's importance growth. The opposite extreme represented year 2009 when structural effect resulted into emission decline of 1 358 kt or 8% compared to previous year, and its total impact on overall CO_2 emissions development reached 42% as industry as the main exporting sector was obviously the one most hit by global bust in demand resulting from economic crisis. Throughout the observed period, structural effect was the most important factor influencing CO_2 emission in year 2000 with 60% share on total change (+1 101 kt) as the economic activity in given year basically stalled, output of service sector partially decreased as a result of slump in financial and insurance activities and industry output grew only negligibly which however increased its share in energy mix to this extent.

To conclude, the analysis of development trend of structural effect suggests that its impact is getting lower over time, which seemed to be plausible with respect to recent development of Slovakia's economy, however further influx of industry related foreign direct investment can abruptly reverse this trend once again.

Figure 2

Development of Slovakia CO_2 Emissions: Additive LMDI Decomposition



Source: Authors calculations.

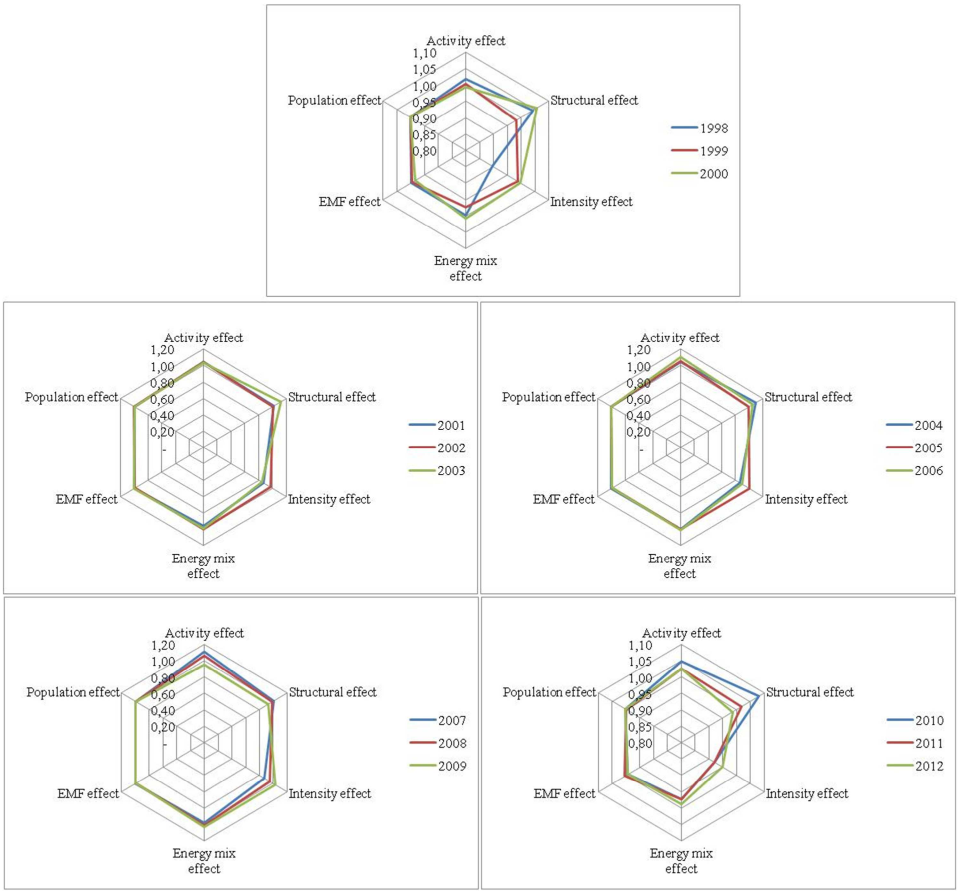
3.3. Intensity Effect

Intensity effect was single most important driver of CO_2 emissions. As we already described, energy efficiency of all four sectors increased considerably which overall led to decrease in emissions despite structural shifts in economy mix as well as its growing size. During the course of observed period intensity effect saved 20 249 kt of CO_2 emissions meaning that it can be accounted for as much as 52% of development trajectory of CO_2 emissions. Figure 2 also reveals that apart from 2009, intensity effect has always favorable environmental effect. The greatest savings of CO_2 emissions occurred between 2001 – 2007, when except for two years energy efficiency gains (2002 and 2005) were in range from 11% to 16%.

For instance, in 2003 alone, energy intensity secured that as much as 3 076 kt of CO_2 did not get release into atmosphere which represented 16% improvement on y-o-y basis and explained 50% of emission development trajectory of that year. The value of latter indicator was not any special since energy intensity component played the most salient part throughout ten years in the observed period and its importance among the other factors seemed to be intact by the aftermath of economic crisis and austerity measures adopted by both government and businesses. Despite that however, it needs to be noted that both Figures 2 and 3 suggest, when taking into accounts the real physical volume of CO_2 emissions or even y-o-y changes intensity effect was slightly diminishing since 2008. In total effect this was hidden by lower CO_2 increments that would have been accredited to activity effect, but our analysis suggests its decreasing trend.

Figure 3

Development of Slovakia CO_2 Emissions: Multiplicative LMDI Decomposition



Source: Authors calculations.

These development trends require deeper analysis which is not in scope of our paper but we suppose they were caused by influx of FDI which brought more advanced and more energy efficient technologies which enabled the jump shifts in all three analyzed components (energy efficiency, activity and structural effect) during the 2000's and as this impetus started disappearing in the wake of economic crisis of 2008 as all these effects have been flattening out since the influx of FDI to Slovakia significantly slowed down in recent years. In case Slovakia would become target of another wave of industrial production offshoring, the development trends we could expect, might be quite similar, though gains resulting from improved energy intensity will likely be lower as a consequence of historical gains. Therefore, further advancement in CO_2 savings could have more likely result from economic strategy that would aim on attracting service oriented companies rather than those of industry. On the other hand, Slovakian dependence on automotive sector creates assumptions for further industrial specialization in this segment and sudden reorientation of economy can hardly be expected. We also need to accept the fact that CO_2 emissions of Slovakia in global context, are basically negligible and no matter what happens to its economy they are going to stay on this level.

3.4. Energy Mix Effect, Emission Factors Effect and Population Effect

Contribution of these factors was significantly smaller than that of previous three. When summarizing the aggregate effect for the whole period, it can be said that energy mix was responsible for 5%, emission factors for 2% and population effect for approximately 0.2% of total CO_2 emissions development. To be specific both energy mix and emission factors led to decrease of emissions while population effect has the opposite impact. As this part of our analysis would have require more detail data which unfortunately were not available to us we stress these result are only approximate and need to be read with cautious. We estimated that energy mix saved approximately 1 960 kt of CO_2 emissions during the observed period, 820 kt could be attributed to emission factors (resulting from the changes in power generation mix) and increase of 80 kt of CO_2 emissions was the consequence of population growth. Overall it can be said that changes caused by these factors were more gradual as they were not subject of external shocks (in form of FDIs) as in case of activity effect, economic structure effect and intensity effect, and y-o-y changes varied between –4% to +3% for energy mix effect –2% to +1% for emissions factors and less than 0.4% changes as a result of population effect. These results also illustrates the fact, that gradually changing energy mix have had only limited influence on emissions, despite

18% drop of energy usage and significant shift towards less polluting energy sources (i.e. replacement of coal and oil by gas and electricity).

Even though this pathway can certainly bring further progress, it can hardly be expected do deliver anything more than gradual slow improvement of emissions. With projected demographic development of Slovakia we can only suppose that its contribution to CO_2 emissions will be only minor influencer of CO_2 emissions increments and expected negative population growth will most likely become another factor driving CO_2 emissions down.

Conclusion

Slovakia was able to significantly decrease its CO_2 emissions during the recent period which by large margin outperformed the commitments which Slovakia bound to in multiple international agreements. CO_2 emissions in four sectors of Slovak economy which we examined in this paper decreased by impressive 32% despite the record economic growth that Slovakia has been registered, clearly so suggesting possibilities of decoupling between greenhouse gases emissions and economic development. However, closer examination revealed continuing relation between those variables. Even more interestingly, our decomposition analysis using LMDI technique helped us to clarify the contribution of CO_2 emissions drivers of selected sectors, which is the main contribution of our paper in comparison with others conducted with similar issue, since other studies (IEA, 2012; OECD, 2011) lacked such quantification crucial for policymaking. We found the primary mover of CO_2 emissions responsible for 52% development was energy intensity effect pushing emissions down, while the following two effects – activity effect and economy structure effect can be attributed 25% and 16% respectively of overall change in CO_2 emissions in observed sectors during the period 1997 – 2012. In our opinion these three effects were to large extent driven by exogenous factors in form of FDIs and therefore with certain caution it can be stated that as much as 93% of determinants of CO_2 emissions development happened to large extent regardless of national energy policy, which was basically confirmed by incoherence and step changes in contributions of individual effects. Although it needs to be added that regulatory environment determining the environment impact of investment influenced by Slovakia membership in EU undoubtedly played an important role. The combined contribution of other three effects to Slovakian CO_2 emissions that we examined – energy mix effect, emission factors effect and population effect which can be characterizes as effects depending on indigenous policies – reached only approximately 7% (–5% energy mix effect, –2.1% emission factor effect, +0.2% population effect).

Observations of our study are in line with those covering other EU members for instance Portugal, Greece (or Ireland (see part 1 of this paper) that identified similar patterns of development. However, since other papers, which examined the similar issue in Eastern Europe, have used different methods (except of one of them – see part 1 of this paper) or aimed to identifying other factors, we cannot compare their results with ours.

Based on our observations we conclude that development of CO_2 emissions, despite its undisputable and desired significant decrease, were mainly result of exogenous actions not deliberate results of national energy policies. Furthermore, we assume that economy policy focused on attracting investors from service sector could enable further cuts in emissions. Although we need to accept the reality of industrial specialization that Slovakia is subject to and which place constraints on expectations of development of economy mix in near to medium term time frames.

The other factor that needs to be taken in to account is relative negligibility of Slovakian CO_2 emissions in global context. Therefore, with respect to climate change as a consequence of GHG emissions the most sensible standpoint Slovakia can adapt, is to direct available funds into sensible adaptation and mitigation measures.

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