Proceeding Paper

Factors Affecting Transport Sector CO_2 Emissions in Eastern European Countries: An LMDI Decomposition Analysis [†]

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Abstract: In this paper, we use the Logarithmic Mean Divisia Index (LMDI) to apply decomposition analysis on Carbon Dioxide (CO_2) emissions from transport systems in seven Eastern European countries over the period between 2005 and 2015. The results show that "economic activity" is the main factor responsible for CO_2 emissions in all the countries in our sample. The second factor causing increase in CO_2 emissions is the "fuel mix" by type and mode of transport. Modal share and energy intensity affect the growth of CO_2 emissions but in a less significant way. Finally, only the "population" and "emission coefficient" variables slowed the growth of these emissions in all the countries, except for Slovenia, where the population variable was found to be responsible for the increase in CO_2 emissions. These results not only contribute to advancing the existing literature but also provide important policy recommendations.

Keywords: CO_2 emissions; transport sector; LMDI; economic activity; modal share; energy intensity; Eastern Europe

1. Introduction and Theoretical Background

Recent studies by the European Environment Agency suggest that transport activities contribute 28.5% of total CO_2 emissions, and around 33.1% of final energy consumption in the European Union. Emissions from this sector have increased from 945.1 million tons in 1990 to 1169.6 million tons in 2015. On the other hand, the share of renewable energy used for transport in the EU rose from 7.4% in 2017 to 8.1% in 2018, which is well below the EU target of 10% set for 2020. Overall, some EU countries have succeeded in reducing their own emissions, while others are still struggling to achieve such objectives, notably Eastern European countries.

Many tools have been developed by economists and mathematicians to study the relationship between transport activities and their environmental effects, and to examine key factors that are thought to contribute to CO_2 emissions in particular.

The first theory in this regard is based on the Granger causality and Co-integration approach. This method examines the effects of a wide range of variables (urbanization, energy consumption energy efficiency, car ownership, economic activity, etc.) on CO_2 emissions from the transport sector. Studies include Gonzales and Marrero [1], Lu et al. [2] and Abbes and Bulteau [3].

Another theory focuses on optimization, either to forecast energy demand and CO_2 emissions, or to analyze energy planning for sustainable development [4–6].

Finally, the most widely used technique is the decomposition methods based on the redefined Laspeyres index method developed by Sun [7] and the Logarithmic Mean Divisia index method (LMDI; Ang and Choi [8]). At the beginning, the decomposition technique has been used to assess the total energy consumption caused by the energy crisis. Later, this technique was generalized for uses and applications in other sectors, particularly the transport sector, in the 1990s and 2000s. This method allows us to quantify the contributions

of various factors to CO_2 emissions from the transport sector. The basic idea is that transport CO_2 emissions is the sum of CO_2 emissions from each transportation mode. To extend the analysis, other sub-category levels can be added, such as the decomposition of emissions from the ith transportation mode to emissions coming from fuel type j in year t. Other variables such as population, energy consumption, motorization and economic growth can be introduced into these sub-categories to denote the various "effects" that contribute to transport CO_2 emissions.

One of the first works to use the decomposition method is that of Scholl et al. [9] who studied CO_2 emissions from passenger transport resulting from changes in transport activity, modal structure, CO_2 intensity, energy intensity and fuel mix in nine OECD countries between 1973 and 1992. One year later, Schipper et al. [10] used decomposition analysis to explain the change in energy consumption and carbon emissions from freight transport in 10 industrialized countries from 1973 to 1992, by introducing the following factors: transport activity, modal share and energy intensity. The two studies by Timilsina and Shrestha [11,12] were conducted in 12 countries in Asia, and 20 countries in Latin America and the Caribbean during 1980–2005.

Similarly, Papagiannaki and Diakoulaki [13] studied the variation in CO_2 emissions from passenger cars using decomposition analysis in Greece and Denmark over the period between 1990 and 2005. The variables used are car ownership, type of fuel mixture, annual mileage travelled, engine size or capacity, car engine technology, economic growth and population. The LMDI-I method was applied by Wang et al. [14] in China between 1985 and 2009, in order to obtain a decomposition of CO_2 emissions from transport. For the same country but with a different period from 1995 to 2006, Wang et al. [15] used the full decomposition approach to construct a decomposition model that summarises the impact of road freight transport-related factors on carbon emissions, and to predict its trend. In addition, Andreoni and Galmarini [16] used the decomposition analysis to investigate the main factors influencing CO_2 emissions from transport activities in the maritime and aviation sectors in 14 EU Member States, and in Norway. Similarly, a decomposition model was applied in Sweden by Eng-Larsson et al. [17]. They analysed the relationship between economic growth, freight transport, energy consumption, transport intensity and fuel carbon intensity. Guo et al. [18] presented the characteristics of CO_2 emissions from the transport sector in 30 Chinese provinces and analyzed the driving factors behind these emissions using the LMDI method. More recently, Fan and Lei [19] constructed a generalized multivariate Fisher's index decomposition model to identify potential drivers of carbon emissions in Beijing's transport sector from 1995 to 2012. Given the results, economic growth, energy intensity, and population size are considered to be the main drivers of CO_2 emission increases in the transport sector. Finally, to assess the Moroccan road transport sector from an environmental perspective, Kharbach and Chfadi [20] quantified the contributions of some key factors to CO_2 emissions from the sector using decomposition analysis for the period 2000–2011.

2. Specification of the Model and Results

Understanding the impact of transport activities on the environmental quality is becoming increasingly important as general environmental concerns are making their way into the main public policy agenda in the EU. To this end, time series variables from 2005 to 2015 were used in seven Western European countries (Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania and Slovenia) to investigate the factors affecting CO_2 emissions from the transport sector. The annual data have been extracted from the Eurostat database and European Commission Reports.

We use then the Logarithmic Mean Divisia Index, both in its additive and multiplicative form, to investigate the effect of several factors thought to be responsible for CO_2 emissions in the transport sector.

2.1. The Model and the Variable

The decomposition methods allow us to quantify the contributions of various factors to CO_2 emissions from the transport sector. The basic idea is that transport CO_2 emissions are the sum of CO_2 emissions from each transportation mode. To extend the analysis, other sub-categories levels can be added, such as decomposing emissions from the *i*th transportation mode, to emissions coming from fuel type *j* in year *t*. Other variables such as population, energy consumption, motorization and economic growth can be introduced into these sub-categories to denote the various "effects" that contribute to transport CO_2 emissions.

Mathematically, the application of a Divisia decomposition analysis in transport involves the use of the following equation:

$$CO2_t = \sum_{i,j} CO2_{ijt} \tag{1}$$

where $CO2_t$ are transport sector emissions in a given country in year *t*. *i*, which denotes the mode of transport (road, air, rail, sea and, finally, pipeline transport), and *j*, the type of fuel (i.e., diesel, motor gasoline, biofuels and kerosene).

Equation (1) can further be decomposed to include other sub-categories of variables:

$$CO2_t = \sum_{i,j} \frac{CO2_{ijt}}{CE_{ijt}} \times \frac{CE_{ijt}}{CE_{it}} \times \frac{CE_{it}}{CE_t} \times \frac{CE_t}{GDP_t} \times \frac{GDP_t}{POP_t} \times POP_t \tag{2}$$

CE refers to energy consumption, *GDP* is the gross domestic product and *POP* the population. Finally, Equation (2) is written:

$$CO2_t = \sum_{i,j} EC_{ijt} \times RC_{ijt} \times RM_{it} \times IE_t \times GDP_t \times POP_t \tag{3}$$

where EC_{ijt} is the emission coefficient or CO_2 intensity of a fuel *j* from the *i*th transport mode in year *t*;

RC_{ijt} refers to the fuel mix (i.e., share of consumption of a fuel *j* in the *i*th transportation mode);

RM_{it} is the modal mix given by the energy consumption of the *i*th transport mode to the total energy consumption of the transport sector;

IE_t refers to Energy intensity of transport for year *t* (total energy consumption from transport to GDP);

GDP_t measure the GDP per capita; and finally,

POP_t is the population of the country under study in year *t*.

According to the additive form of the LMDI (Ang, [21,22]), the change in CO_2 emissions can then be calculated using the formula:

$$\Delta CO2 = CO2_t - CO2_{t-1} = \Delta EC + \Delta RC + \Delta RM + \Delta IE + \Delta GDP + \Delta POP \tag{4}$$

The decomposition of each effect between the year *t* and *t-1* is given by the following formulas:

$$\Delta EC = \sum_{i,j} \Delta EC_{ij} = \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{EC_{ijt}}{EC_{ijt-1}}\right) \tag{5}$$

$$\Delta RC = \sum_{i,j} \Delta RC_{ij} = \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{RC_{ijt}}{RC_{ijt-1}}\right) \tag{6}$$

$$\Delta RM = \sum_{i,j} \Delta RM_{ij} = \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{RM_{it}}{RM_{it-1}}\right) \tag{7}$$

$$\Delta IE = \sum_{i,j} \Delta IE_{ij} = \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{IE_t}{IE_{t-1}}\right) \tag{8}$$

$$\Delta GDP = \sum_{i,j} \Delta GDP_{ij} = \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{GDP_t}{GDP_{t-1}}\right) \tag{9}$$

$$\Delta POP = \sum_{i,j} \Delta POP_{ij} = \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{POP_t}{POP_{t-1}}\right) \tag{10}$$

Equation (4) can finally be extended:

$$
\begin{aligned}
CO2_t - CO2_{t-1} = &\sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{EC_{ijt}}{EC_{ijt-1}}\right) + \\
&\sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{RC_{ijt}}{RC_{ijt-1}}\right) + \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{RM_{it}}{RM_{it-1}}\right) + \\
&\sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{IE_t}{IE_{t-1}}\right) + \sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{GDP_t}{GDP_{t-1}}\right) + \\
&\sum_{i,j} L(CO2_{ijt}, CO2_{ijt-1}) \ln\left(\frac{POP_t}{POP_{t-1}}\right)
\end{aligned}
\tag{11}
$$

Given that:

$$
\begin{aligned}
L(a,b) &= \frac{(a-b)}{(\ln a - \ln b)} && if \quad a \neq b \\
&= a && if \quad a = b
\end{aligned}
\tag{12}
$$

We have the next condition:

$$
\begin{aligned}
L(CO2_{ijt}, CO2_{ijt-1}) &= \frac{(CO2_{ijt} - CO2_{ijt-1})}{(\ln CO2_{ijt} - \ln CO2_{ijt-1})} && if \quad CO2_{ijt} \neq CO2_{ijt-1} \\
&= CO2_{ijt} && if \quad CO2_{ijt} = CO2_{ijt-1}
\end{aligned}
\tag{13}
$$

2.2. Empirical Results

In the following, we explain the results obtained by applying the additive form of LMDI (Equation (4)) after the calculation of the net effect of each variable in our model.

The average annual change (Table 1) is based on the calculation of the annual change in CO_2 emissions for the study period. The results show that all the countries in our sample have experienced strong growth in CO_2 emissions from the transport sector. Economic activity (i.e., GDP per capita) is the major factor causing the increase in these emissions, while the population variable was found to be an important factor explaining the decrease in CO_2 emissions, except for Slovenia.

Table 1. Average annual change in CO_2 emissions and underling factors.

Country	Variation of CO$_2$ Emissions	EC	RC	RM	IE	GDP	POP	Main Factors
Bulgaria	261	−24	−18	82	33	241	−53	RM, IE, GDP
Estonia	39	−8	12	−6	6	41	−6	RC, IE, GDP
Latvia	14	−40	12	−15	7	86	−36	RC, IE, GDP
Lithuania	97	−57	21	−2	39	158	−62	RC, IE, GDP
Poland	1054	−211	−6	0	−345	1637	−21	GDP
Romania	363	−51	12	−53	107	448	−100	RC, IE, GDP
Slovenia	86	−9	16	−15	47	31	16	RC, IE, GDP, POP

Source: Calculation of the author.

As shown in this table, energy intensity (IE) increases the CO_2 emissions in all the countries except Poland. In the latter, the consumed energy per unit of GDP was reduced during the study period. The results show that Poland is also an exception when it comes to the emissions of CO_2 per unit of consumed fuel (variable *EC*).

It is also important to note that the modal mix *RM* contributed directly to the decline of CO_2 emissions in most countries in our sample. However, the impact of this factor is

relatively small: 13% (45 mt instead of 39 mt) for Estonia, 2% (99 mt instead of 97 mt) for Lithuania, 12.7% (416 mt instead of 363 mt) for Romania and 15% (101 mt instead of 86 mt) for Slovenia. For Latvia, the impact of this factor is important as it contributes to the deterioration of emissions by a significant value. Similarly, this factor is an important contributor to the increase in CO_2 emissions in Bulgaria due to the national policy of this country consisting of the absence of a rigorous control of vehicle age and emissions. This factor (*RM*) has no impact on the growth of CO_2 emissions from transport in Poland. As mentioned above, the annual improvement of the energy intensity of transport also had a considerable impact on the increase in emissions in our sample; the adjustment of this factor comes from the adjustment of diesel consumption (Table 2).

Table 2. Fuel indicators in the transport sector.

| | **2005** | | | | | **2015** | | | | |
Country	Total	Diesel	Motors Gazoline	Bio-Fuels	Kerosene	Total	Diesel	Motors Gazoline	Bio-Fuels	Kerosene
				Fuel Share						
	Mtoe [1]			%		Mtoe			%	
Bulgaria	2.6	65.4	26.9	0	7.7	3.426	64.2	25.7	4.3	5.8
Estonia	0.7	50	42.9	0	7.1	0.854	65.6	28.2	0.4	5.8
Latvia	1.055	58.3	36	0	5.7	1.314	69.2	18.3	1.9	10.6
Lithuania	1.445	68.8	27.7	0	3.5	1.97	76.1	15.2	3.6	5.1
Poland	12.47	55.3	42.3	0	2.4	17.3	59.5	31.9	4.5	4.1
Romania	4.1	58.6	39	0	2.4	5.74	68.1	23.2	3.5	5.2
Slovenia	1.5	52	46	0	2	1.822	72.3	23.9	1.6	2.2
				Emission Coefficient						
	Mt [2]		%			Mt			%	
Bulgaria	7.5	72	26.6	0	1.4	9.41	78.6	18.1	2.2	1.1
Estonia	2.025	56.8	42	0	1.2	2.3745	71.2	27.3	0.2	1.3
Latvia	2.93	64.9	37.4	0	1	3.185	78.5	18.8	1.1	1.6
Lithuania	4.225	74.6	24.8	0	0.6	5.15	83.5	13.6	1.9	1
Poland	35.4	58.5	41.2	0	0.3	46	64.9	32.2	2.7	0.2
Romania	11.75	62.6	37	0	0.4	15.45	72.8	24.7	1.9	0.6
Slovenia	4.377	57.1	42.5	0	0.4	5.41	77.3	21.4	0.9	0.4

Source: Calculation of the author. [1] Mtoe: Million Tons of Oil Equivalent; [2] Mt: Millions of tons.

The emission coefficient has a negative influence on the growth of CO_2 emissions in all the countries in our sample, so this influence is very important. This factor can vary the average increase in emissions, which would have been 8% higher in Bulgaria (285 mt instead of 261 mt), 17% higher in Estonia (47 mt instead of 39 mt), 286% in Latvia (54 mt instead of 14 mt), 37% in Lithuania (154 mt instead of 97 mt), 17% in Poland (1265 mt instead of 1054 mt), 12% in Romania (414 mt instead of 363 mt) and 9% in Slovenia (95 mt instead of 86 mt).

3. Conclusions

In this study, we have carried out a decomposition of transport CO_2 emission elements using the Divisia index in its additive and multiplicative forms and some EU countries as the sample.

According to the results found using the LMDI method, economic activity is the main factor responsible for CO_2 emissions in all countries in our sample. Fuel mix is the second most important CO_2 emitting factor. Modal share and energy intensity also affect CO_2 emissions, but to a lesser extent. On the contrary, the emission factor and population variables reduced the growth of these emissions. Note that all variables have met their respected signs, respectively, except for the population factor in the case of Slovenia.

Since the exchange of goods within and between EU countries is intense, this explains the important impact of the economic activity on CO_2 emissions. Decoupling the increase in CO_2 emissions from economic growth and transport energy demand remains an important issue within the EU economies. On the one hand, implementing intelligent transport systems and encouraging the use of environmentally friendly transport modes and energies are still valid strategies. On the other hand, many other measures (fuel taxation, subsidies

and other fiscal instruments, registration tax, etc.) are not yet in place in the majority of the countries in our sample (Bulgaria, Estonia, Lithuania and Poland, for example).

Cleaner fuels and CO_2 efficient cars are also needed in all countries. Unfortunately, according to OECD statistics (2017), the level of investment in transport infrastructure is less than 1% of GDP.

Data Availability Statement: Eurostat; European Union statistical Pocketbooks.

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