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# Investigation of Transport Carbon Emissions in Korea

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The Republic of Korea was ranked 11th globally, in 2018, in terms of greenhouse gas emissions, of which the transportation sector contribution was estimated to be 14 % in 2017. Many policies have been drawn to enhance transport sustainability and reduce its emissions. According to the Climate Action Tracker (CAT), the policies and actions of South Korea to achieve the goal set in the Paris Agreement, are highly insufficient. Also, the environmental community in Korea has claimed the weakness of the 2017 emissions strategy. To increase policies' efficiency an investigation of the drivers behind greenhouse gases needs to be considered. This paper is decomposing both overall greenhouse gases and transport sector greenhouse gases, to analyse the effect of economic growth, energy intensity, energy mix, technology, urbanization, R&D expenditure, and population. The LMDI results showed that GDP, R&D expenditure, and energy consumption have a strong effect on increasing carbon emissions. While population and urbanization factors have a weak effect for the analysis period 2003-2016, due to the stable urbanization and population rate within the period. The significant contribution of R&D expenditure in increasing GHG emissions showed an urgent need to revise the R&D investment to boost non-carbon transportation research. Additionally, the energy structure effect was not significant, as the reliance on fossil fuel is high despite the efforts to reduce it. This revealed that the adopted fuel policies need strengthening measures and continuous improvement. The study deduced the vital need to raise the use of renewable and non-carbon energy, to strengthen sustainable transportation policies and investments, with a focus on public transportation modes, and finally to establish a good environment for a vigorous system for the implementation and enhancement of active modes.

## 1. Introduction

Transportation and energy are some of the drivers of the economic growth of developed countries. Aside from moving people, transportation is a prime mover of goods as it connects the industries to the supply chain, such as suppliers and customers. The Republic of Korea is one country that benefits from transportation to advance its economy. According to World Bank, the GDP per capita in 2020 is 31,327 USD/y which makes it the tenth-largest economy in the world. While many factors were identified to have contributed to its rapid economic growth, systematic and efficient transportation has been considered a decisive factor, and the expansion of transport facilities has contributed to its more balanced regional development (Hwang et al., 2014). While transportation can contribute to faster economic growth, it is a major contributor to greenhouse gas emissions, which requires government actions to adopt low-carbon economy models that take into consideration the country's prevailing economic characteristics (Wang, et al., 2020). In China, for example, carbon emissions and added value of the transport sector showed an upward trend (Wang and Wang, 2019). Likewise, the transportation industry was found to be a large source of energy consumption and carbon emissions in the said country. Further, the added value of transportation, energy consumption, and per capita emissions in the transport industry was found to be the major factors in the increased carbon emissions in China (Wang et al., 2018). Korea's total national greenhouse gas emissions in 2018 were 727.6 Mt of $CO_2$eq, according to Korean Environment Corporation. It increased by 2.5 % compared to 2017 emissions and increased by 149 % compared to the total of 292.2 Mt in 1990.

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Internationally, Korea's total greenhouse gas emissions are estimated to be 11th in the world as of 2018, with a share of about 1.51 %. Considering that Korea's population is 0.7 % of the world's population, studies consider that the proportion of greenhouse gas emissions is more than twice as high as the proportion of the population. In terms of carbon dioxide emissions per capita, Korea ranked 11, in 2018, and 17, in 2022 among the 100 countries globally (Our World in Data, 2022). In Korea, according to the 2050 policy report of Korea, transportation recorded accumulated greenhouse gas emissions of 101.66 Mt between 1990 and 2018. According to data from carbon, in brief, the transportation sector comes third after power and heat and industry in terms of carbon emissions in Korea from 2000 to 2016 (Figure 1). The transportation sector is divided into roads, railways, shipping, and aviation, of which the road sector accounts for most of the total energy in the transport sector (94.8 % in 2018). The transportation means in the transportation sector mainly use fossil fuels, and except for railways, they are particularly dependent on oil. The transportation sector emits 98.1 Mt of greenhouse gases, accounting for 13.5 % of the total greenhouse gas emissions in Korea (13.7 % including indirect emissions as of 2018). Greenhouse gas emissions in the transportation sector steadily increased due to the spread of automobiles, expansion of road systems, and rise of cargo transportation, increasing by about 2.8 times in 2018 from 1990.

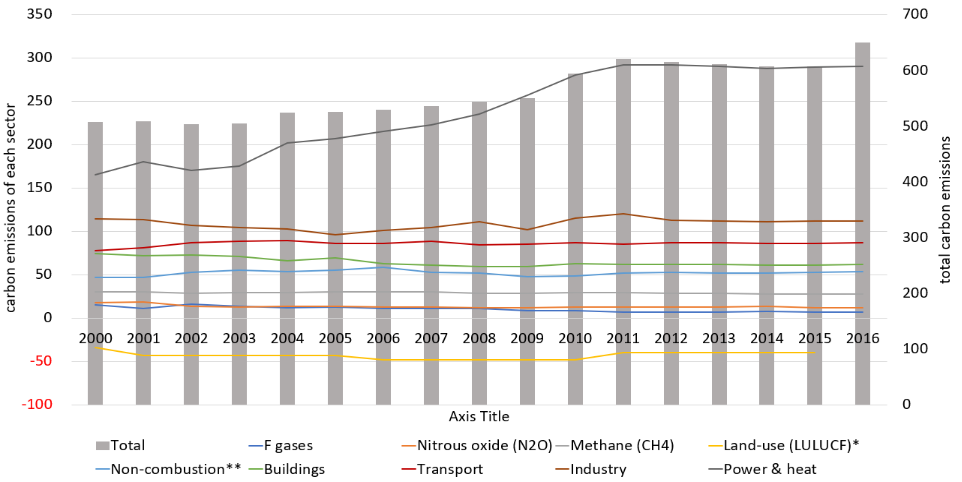


*Figure 1: Carbon emissions by sector in Korea from 2000 to 2016(Carbon Brief, 2020)*

Ever since The Republic of Korea has been putting a lot of effort into reducing transportation emissions. In 2010, Korea has adopted the “Green Transportation Movement” as one of its key policy actions reduce to reduce GHG emissions by one-third while maintaining its competitiveness (Soojeong, 2010). While much has changed in most recent years in the transport sector as Korea endeavors to make its transport sector cleaner and sustainable, carbon dioxide emissions are still mainly produced in the process of economic development, specifically in the road transportation sector in Korea. Hence, for stronger impact, the vision of the 2050 carbon neutrality promotion strategy has been implemented in late 2020. This strategy converted Korean efforts in reducing carbon emissions from “adaptive reduction” into “active response. The three major policy directions are (1) adaptation, (2) opportunity, and (3) fairness. The adaptation measure focuses mainly on adapting economic structure, accelerating energy conversion, and innovation within high-carbon industrial structures. The second measure consists of creating a new promising low-carbon industry ecosystem. The third measure focuses on permitting a fair transition to a carbon-neutral society to protect vulnerable industries and classes, realize regional-centered carbon neutrality, and raise public awareness of a carbon-neutral society. Through fiscal, green finance, R&D, and international cooperation, carbon price signals will be strengthened and the foundation for expanding investment in the carbon-neutral sector will be established. To ensure a high level of success and efficiency of the implemented policies and measures, it is very crucial to identify the drivers behind carbon emissions from the transportation sector and to compare them to the drivers behind the overall carbon emissions, which then would provide a strong theoretical basis for decision-makers. This study investigated the drivers behind carbon emissions, by investigating the following factors: population effect, economic effect using the GDP and the GDP growth rate, urbanization effect using the percentage of the urban population, energy intensity effect, the energy mix effect, and the technology effect through the R&D expenditure variable. The study adopted the decomposition analysis that is popular within similar topics related to energy and emissions, and more specifically this research adopted the Logarithmic Mean Divisia Index (LMDI) method. Many studies adopted the LMDI method in their carbon emission decomposition, Mousavi et al. (2017) exploited LMDI to derive the factors behind carbon emissions in the energy consumption sector. Tu et al. (2019) used the method to decompose urban passenger transport's carbon emissions in global cities, like London and, Paris. The study concluded lessons to be derived for developing cities, such as focusing on enhancing transit-oriented development and strengthening active modes. The rest of the research is as follows: (2) methodology, (3) Results and discussions, to show findings and provide interpretations, and finally (4) Conclusion.

## Methodology

Decomposition analysis is a very effective and widely used methodology to identify the factors impacting energy use and greenhouse gas emissions (Xu et al., 2016), by quantifying the influence of each of the studied factors on greenhouse gas emissions. Generally, decomposition analysis methods are divided into two groups: the Structural Decomposition Analysis method (SDA) and the Index Decomposition Analysis method (IDA) (Guan et al., 2008). The SDA method is defined as an "analysis of the economic change employing a set of comparative static changes in key parameters in an input-output table" (Rose and Casler, 1996), which allows the evaluation of the correlation between carbon emissions and the investigated macroeconomic factors (Liu et al., 2021). While the IDA method is often exploited to comprehend the drivers behind the emissions (Su and Ang, 2012). The IDA method requires less data, and it is more developed and often updated than the SDA method (Su and Ang, 2012), which makes it widely used to investigate many environmental topics, especially those that focus on a specific energy-consumption sector (Xu et al., 2016). There are two main types within the IDA methods: the Laspeyres index, which estimates the change percentage over time using weights, and the Divisia index, which is a "weighted sum of logarithmic growth rate" (Xu et al., 2016). The Divisia Index is the most popular, deals well with zero va led to an active improvement and framing of the methods by introducing new techniques and conceiving guidelines, etc. (Wang and Wang, 2019). This study adopted the IDA method and specifically exploited the Logarithmic Mean Divisia Index (LMDI) method, which is very popular in the research field due to its ability to deal with the zero values and also because of the absence of residual issue, which is present strongly in the SDA method (Wang and Wang, 2019). This paper will use the logarithmic mean Divisia index (LMDI) to identify the influencing factors on the $CO_2$ emissions from the road transport sector in Korea from 2003 to 2016, and it uses seven factors, namely: energy intensity, energy mix, population, urbanization, GDP, and R&D expenditure per GDP. The application of a Divisia decomposition analysis in transport $CO_2$ uses the Eq(1).

$$CO2 = \sum_{i,j} CO2_{ijt} \tag{1}$$

where CO2t are transported sector emissions in year t. i refers to the type of fuel source (oil, gas, other). This equation is extended to further decompose $CO_2$ while including the seven factors mentioned above, as shown in the Eq(2) and Eq(3):

$$CO2 = \sum_{i} \frac{CO2_{it}}{E_{it}}\, X \sum_{i} \frac{E_{it}}{E_t} X \sum_{i} \frac{E_t}{GDP_t}\, X \sum_{i} \frac{GDP_t}{\mathrm{RD}}\, X \sum_{i} \frac{\mathrm{RD}}{\mathrm{GDP}}\, X \sum_{i} \frac{\mathrm{GDP}}{\mathrm{Pop}} \sum_{i} \frac{\mathrm{Pop}}{uPop} X \quad uPop \tag{2}$$

$$CO2 = \sum_{i} CI_{it}\; X\; En_{it}\; X\; EI_t\; X\; RD_t X\; RD_c\; X\; GDP_c\; X\; Upop_r\; X\; uPop \tag{3}$$

$CI_{it}$refers to the $CO_2$ emission by energy $i$ in transportation sector $t$, $En_{it}$ energy $i$ consumption in transportation $t$, $EI_t$ energy intensity in transportation $t$, $RD_t$ R&D in transportation $t$, $RD_c$ R&D expenditure per overall GDP , $GDP_c$ is the GDP per capita, $Upop_r$ the urbanization rate, $uPop$ is the urban population.
The change in $CO_2$ emissions can be calculated using the additive form of LMDI (Ang, 2005) as shown by Eq(4):

$$\Delta CO2 = CO2_t - CO2_{t-1} = \Delta\mathrm{CI} + \Delta En + \Delta\mathrm{RD} + \Delta\mathrm{GDP} + \Delta\mathrm{POP} + \Delta\mathrm{Upop} \tag{4}$$

The decomposition of each effect between year t and t-1 is, where $X_{it}$ represents the factor X for the energy $i$ in the year $t$, is given by the Eq(5):

$$\Delta CO2 = \sum_{i} \Delta C_i = \sum_{i} L(CO2_{it}, CO2_{it-1}) \ln\left(\frac{X_{it}}{X_{it-1}}\right) \tag{5}$$

Given that:

$L\,(a,b) = \frac{(a-b)}{(ln\,a - lb\,b)}\quad if\ a \neq b$ or $L\,(a,b) = a\quad if\ a = b$

Then the next condition is:

$$L\,(CO2_t - CO2_{t-1}) = \left(\frac{(CO2_{ijt} - CO2_{ijt-1})}{(lnCO2_{ijt} - ln\,CO2_{ijt-1})}\right)\quad if\ CO2_{ijt} \neq CO2_{ijt-1}\ Or$$

$$L\,(CO2_t - CO2_{t-1}) = CO2_{ijt}\quad if\ CO2_{ijt} = CO2_{ijt-1}$$

## 2. Results and discussion

The data is so scarce, especially the specific ones like the emissions by a source within the transportation sector, and it is mainly collected from internet databases mainly: World Bank, Carbon Brief, Our World In Data, Korean Statistical Information Service, Knoema cooperation, Trading Economics, and International Energy Agency. The targeted period is between 2000 and 2022, but the full data suitable for LMDI analysis is only between 2003 and 2016. The energy intensity (IEA. 2020), $CO_2$ emissions by sector (Carbon Brief, 2020; WB, 2020), and transport emission were downloaded from Our World in Data database (OWID, 2020), the transport contribution in GDP from Trading Economics database (Trading Economics, 2022), the R&D expenditure and GDP from the World Bank database (WB, 2021), the population from Kosis institute (Kosis, 2021), urbanisation from Knoema cooperation (Knoema, 2021), and finally the energy consumption and share of renewable energy from IEA database (IEA, 2020). The statistics showed a steady increase in transport emissions along with the overall $CO_2$ emissions over the recent years, with an average growth rate of 1.14 % for transportation emissions per year. To conduct analysis, first, the study calculated the variation of the investigated factors for the study period (Table 1). Results showed that the changes in GDP of transportation $CO_2$, population, and urbanization follow the same pattern (Figure 2). Additionally, correlation analysis revealed that transport $CO_2$ variation has a strong positive correlation (0.99), followed by renewable energy, then the GDP. While it has a negative correlation with R&D spending, energy intensity, gas energy share, and other energy (Table 2).

*Table 1: Observed changes in transport $CO_2$ and the investigated factors (unit: %)*

| Year | Transport $CO_2$ | Population | Overall GDP | R&D expenditure | Renewable Energy | Urbanization | Energy Intensity |
|---|---|---|---|---|---|---|---|
| 2002 to 2003 | 2.20 | 0.52 | 11.36 | 3.12 | 35.74 | 0.43 | 0.96 |
| 2003 to 2004 | 0.73 | 0.40 | 12.11 | 6.78 | -11.54 | 0.43 | -1.78 |
| 2004 to 2005 | -3.29 | 0.21 | 16.44 | 3.23 | -16.47 | 0.43 | 0.15 |
| 2005 to 2006 | -0.13 | 0.53 | 11.92 | 7.64 | -0.47 | 0.22 | -2.75 |
| 2006 to 2007 | 3.07 | 0.51 | 10.74 | 5.37 | 11.26 | 0.12 | -1.64 |
| 2007 to 2008 | -5.17 | 0.76 | -11.30 | 4.10 | 4.49 | 0.12 | -0.43 |
| 2008 to 2009 | 1.06 | 0.51 | -10.42 | 5.21 | 8.05 | 0.12 | 0.59 |
| 2009 to 2010 | 1.79 | 0.50 | 19.25 | 5.26 | 44.34 | 0.13 | 2.48 |
| 2010 to 2011 | -1.72 | 0.77 | 9.12 | 7.82 | 28.77 | -0.02 | 1.70 |
| 2011 to 2012 | 2.84 | 0.53 | 2.00 | 6.99 | 2.11 | -0.09 | -1.29 |
| 2012 to 2013 | 3.70 | 0.46 | 6.98 | 2.56 | 16.67 | -0.09 | -2.57 |
| 2013 to 2014 | 1.72 | 0.63 | 7.96 | 3.24 | 12.75 | -0.09 | -2.42 |
| 2014 to 2015 | 6.23 | 0.53 | -1.26 | -2.48 | 7.54 | -0.10 | -1.21 |
| 2015 to 2016 | 2.91 | 0.40 | 2.27 | 0.25 | 7.34 | -0.09 | -0.39 |

*Table 2: Regression and Correlation Coefficients of Transport Emissions Variation on Factors' Variations*

| Factors | Population | GDP | R&D | Urbanisation | Energy Intensity | Fossil Energy | Gas Energy | Renewable energy | Other energy |
|---|---|---|---|---|---|---|---|---|---|
| Correlation | -0.208 | 0.063 | -0.450 | -0.428 | -0.260 | 0.999 | -0.322 | 0.251 | -0.113 |
| Regression | -0.677 | -0.007 | 0.031 | -0.464 | -0.017 | 0.977 | 0.005 | 0.006 | 0.003 |

The LMDI decomposition highlighted the big effect of GDP growth on increasing transportation emissions, which could be explained by the rise in car ownership and vehicle purchase in general. According to Statista, there are 0.5 passenger cars per inhabitant in the Republic of Korea in 2021. The energy intensity showed a strong effect in decreasing the transport carbon emissions, followed by the R&D expenditure which could not contribute to the decrease until recently, since 2014. Similarly, an OLS regression showed a weak effect (0.031) of R&D, while correlation has a significant negative coefficient (-0.450) (Table 2), which makes it a good factor, that was not correctly exploited yet, to mitigate transport GHG, by investing in research such as non-$CO_2$ energy, and a special focus should be allocated to active modes infrastructure and sustainable transportation policies (Table 3), as it would have the best long term effect on reducing GHG (Khamphilavanh and Masui, 2021).

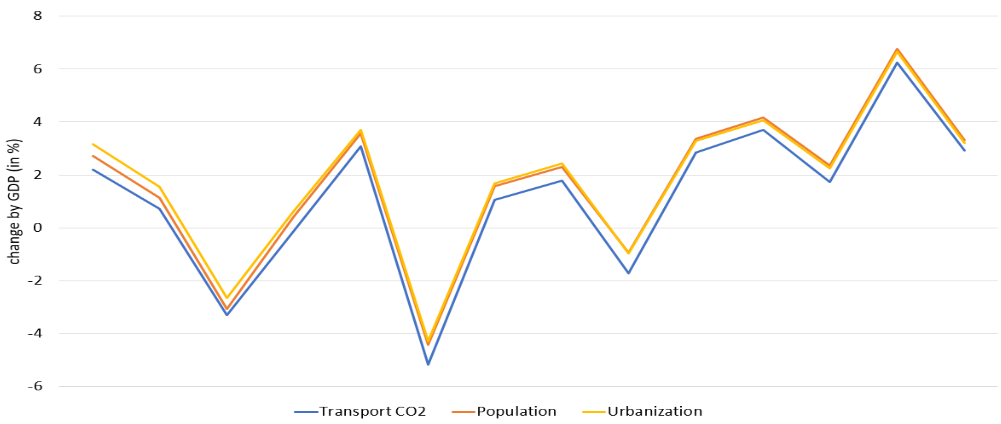


Figure 2: Transport $CO_2$*, population, urbanisation* changes by GDP variation

The population effect is low using the LMDI decomposition, as the population knows a very weak variation the recent years. The energy structure is a potential influencer that could be exploited to lower the $CO_2$ emissions from transportation. In this research, its effect was revealed to be so weak, and it is due to the high percentage of fuel consumption (about 95 % on average of the total transportation energy consumption), very low percentage of gas (2.5 % on average), and the modest percentage of other energies hydrogen or electric vehicles (1.3 % on average).

*Table 3: LMDI Decomposition of Transport carbon emission*

| Year | population | GDP | R&D Expenditure | Urbanisation | Energy intensity | Energy Structure |
|---|---|---|---|---|---|---|
| 2003 | 0.45 | 9.92 | 2.72 | 0.38 | 0.84 | 0.04 |
| 2004 | 0.35 | 10.73 | 6.01 | 0.38 | -1.57 | 0.06 |
| 2005 | 0.19 | 14.37 | 2.82 | 0.38 | 0.13 | 0.05 |
| 2006 | 0.45 | 10.25 | 6.57 | 0.19 | -2.36 | 0.01 |
| 2007 | 0.44 | 9.37 | 4.68 | 0.11 | -1.43 | -0.01 |
| 2008 | 0.66 | -9.76 | 3.54 | 0.11 | -0.37 | -0.03 |
| 2009 | 0.44 | -8.82 | 4.41 | 0.10 | 0.50 | 0.05 |
| 2010 | 0.43 | 16.51 | 4.51 | 0.12 | 2.12 | -0.05 |
| 2011 | 0.66 | 7.83 | 6.71 | -0.02 | 1.46 | 0.00 |
| 2012 | 0.45 | 1.72 | 6.04 | -0.07 | -1.11 | 0.02 |
| 2013 | 0.41 | 6.22 | 2.29 | -0.08 | -2.29 | 0.00 |
| 2014 | 0.58 | 7.29 | 2.97 | -0.08 | -2.22 | -0.00 |
| 2015 | 0.50 | -1.20 | -2.37 | -0.09 | -1.15 | 0.06 |
| 2016 | 0.40 | 2.26 | 0.25 | -0.09 | -0.39 | -0.08 |

## 3. Conclusion

LMDI results showed that the GDP growth contributes strongly to the increase of transport $CO_2$. Followed by the effect of the R&D expenditure that contributes to an increase the transport emissions, mainly because of not investing in research that support mitigating fossil energy use and sustainable policy investments, like strengthening active modes. Finally, energy intensity, energy structure, population, and urbanisation displayed a weak effect. The weak effect of energy structure and intensity revealed the need to more strong and more efficient policies in energy mitigation and diversification. For future direction, the impact of R&D expenditure could be explored deeply to identify the main issues and help enhance its contribution to the low carbon strategy. Further, research needs to identify issues behind the low impact of energy structure and energy intensity in the Korean context.

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