Policy Research Working Paper 9809

Understanding Drivers of Decoupling of Global Transport CO_2 Emissions from Economic Growth

Evidence from 145 Countries

Vivien Foster
Jennifer Uju Dim
Sebastian Vollmer
Fan Zhang

WORLD BANK GROUP
Infrastructure Chief Economist Office
October 2021

Policy Research Working Paper 9809

Abstract

This paper examines the extent to which countries have succeeded in decoupling transport emissions from economic growth, and how changes in emissions intensity, economic growth, and population growth have contributed to changes in transportation-related emissions. The paper employs a modified version of the Tapio decoupling model, and demonstrates that over the 1990–2018 study period only 12 of 145 countries achieved "absolute decoupling," defined as reducing emissions while growing gross domestic product. The majority of the top emitters remain in a "relative decoupling" state, with emissions growing more slowly than gross domestic product. Many of the middle- and low-income countries have not achieved decoupling; their emissions are growing as fast as or faster than gross domestic product. To understand the driving factors of transport-related carbon emissions, the paper conducts index-decomposition and an econometric analysis. The results reveal that while transportation emission intensity has declined in most countries, economic growth and population growth have offset these declines. If these patterns continue, achieving the goals of the Paris Agreement with improvements in efficiency alone seems unrealistic. The paper also shows evidence that higher energy prices are associated with strong emissions reduction.

This paper is a product of the Infrastructure Chief Economist Office. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://www.worldbank.org/prwp. The authors may be contacted at fzhang1@worldbank.org.

Understanding Drivers of Decoupling of Global Transport CO_2 Emissions from Economic Growth: Evidence from 145 Countries

Vivien Foster, Jennifer Uju Dim, Sebastian Vollmer, Fan Zhang

Keywords: Decoupling, Transport carbon emissions, Economic growth, Population

JEL Classification: O18, O44, Q54

1. Introduction

The transportation sector, which relies heavily on fossil fuels, is a major contributor to total global greenhouse gas emissions. In 2018, emissions from transport activities reached a level equivalent to 8.2 gigatons of CO_2, representing roughly 24 percent of all global CO_2 emissions. Carbon emissions from transport have more than doubled since 1970. This rapid increase in emissions from transportation is expected to continue, largely because the demand for transportation is likely to increase as global population grows and incomes rise. According to the International Energy Agency (IEA) Energy Technology Perspectives report, between 2019 and 2070, global transport demand is expected to double, and car ownership rates are projected to grow by 60 percent (IEA, 2020). According to the International Panel on Climate Change (IPCC), emissions linked to transportation will likely increase faster than those from any other sector unless the link between transportation and economic growth can be severed (IPCC et al., 2014).

Reducing transport-related carbon emissions without undermining economic growth is pivotal to combating climate change and maintaining living standards. An effective transport emissions-reduction strategy requires a deep understanding of the degree to which countries have broken or kept the connection between the growth of transportation emissions and the growth of their economies. Such strategy also demands a clear understanding of the drivers of transportation related emissions of CO_2. Thus, this paper aims to answer the following questions: To what extent have countries succeeded in decoupling economic growth from transport carbon emissions? What policies can facilitate decoupling?

To answer these questions, first, we explore the issue of decoupling of economic growth from transport-related carbon emissions at the country level. We use a modified version of the Tapio decoupling model (Tapio, 2005). We define three decoupling states: absolute decoupling, relative decoupling, and no decoupling. “Absolute decoupling” occurs when CO_2 emissions are decreasing or stabilized even though GDP is increasing. “Relative decoupling” occurs when both GDP and CO_2 emissions are increasing, but CO_2 emissions are increasing at a slower rate. “No decoupling” occurs when a country is in neither of these two states.

Only 12 countries achieved absolute decoupling over the study period. The remaining countries experienced either relative decoupling or no decoupling. This implies that transport emissions in most countries, including the top-emitting countries, are still increasing, and that the growth of their emissions remains strongly linked to their economic growth. Hence, to achieve decarbonization in the transport sector without prejudice to economic growth, there is a dire need to break this link.

The long-term decoupling results show considerable differences in the decoupling status among countries by income levels. While many advanced economies have managed to achieve absolute or relative decoupling, in many developing countries per capita transport emissions are increasing at a much faster rate than per capita GDP growth. Increases in transport CO2 emissions were particularly pronounced in the two largest middle-income countries: China and India. Both are still contributing less to global transport CO2 emissions than their population shares, unlike the United States or the EU countries, but they are rapidly catching up and are to a large extent driving current increases in global transport CO2 emissions.

Next, to explore the underlying drivers of CO2 emissions, we conduct both index decomposition and econometric analyses. For the decomposition analysis we specify two identities. The first decomposition breaks down emissions into three factors: emission intensity measured by transportation emissions per unit of GDP, economic growth (in terms of GDP per capita), and population growth. In many developed countries, declining emission intensity contributes to the decoupling of transportation emissions from economic growth. In most developing countries, although emission intensity also fell, population and GDP growth outstripped these efficiency-related transport emission savings.

In the second decomposition analysis, we further break down emission intensity (measured as CO2 emissions per unit of GDP) into carbon intensity of fuel consumption, energy intensity of transportation, and transport demand. We focus on the inland transportation sector, including rail and road sectors for which disaggregated data are available on travel volume measured by kilometers traveled by passengers and freight. Inland transportation is the largest source of global transport emissions, accounting for 84 percent of total emissions in 2018. The results again show that efficiency improvements have played an important role in flattening the emissions curve. Most countries have managed to reduce the energy intensity of inland transport. By contrast, there has so far been minimal progress in reducing the carbon intensity of energy consumption, and that concentrated in a handful of countries. Gasoline and diesel are still the dominant fuels for transportation; renewable fuels and electricity accounted for about 10 percent of the energy mix as of 2018.

To further explore the economic drivers of transport carbon emissions, we conduct country-level regression analysis to understand the associations between CO2 emissions and GDP, urbanization, structural changes, energy prices and public transit. Urbanization is first associated with an increase then a decrease in emissions – possibly because urbanization initially coincides with a rise in vehicle ownership and then later allows for economies of scale through improved public transit. The results also show that per capita CO2 emissions are negatively correlated with agriculture value-added share. Higher energy prices and the presence of transportation policies (such as fuel economy standards and tailpipe emissions control) are both significantly correlated with lower per capita CO2 emissions.

The remainder of the paper is structured as follows: Section 2 reviews the existing literature. Section 3 describes the methodology. Section 4 presents the data. Section 5 discusses results from index decomposition and the econometric analyses. Section 6 concludes with a summary of the main findings and a discussion of policy implications.

2. Related literature

This study contributes to two strands of the literature: the decoupling literature and the literature on the drivers of carbon emissions from the transportation sector. Decoupling analyses have been conducted in different contexts – at the global level (Shuai et al., 2019), national level (Chen et al., 2018; de Freitas & Kaneko, 2011; Jiang et al., 2016; Q. Wang et al., 2018; Zhang et al., 2020), provincial level (FY Fan, 2016; JJ Jiang, 2017; A. Li et al., 2017; Q. Lu et al., 2015; Wu et al., 2019), and sectoral levels, such as agriculture, construction, and transportation (Bai et al., 2019; Hang et al., 2019; Huo et al., 2021; M & C, 2019).

Decoupling analysis examines the relationship between environmental pressure and economic prosperity. The relationship between economic growth and carbon emissions has been widely studied using the decoupling indices created by the Organisation of Economic Development and Co-operation (OECD) and Tapio (OECD, 2002; Tapio, 2005). Although the OECD decoupling index is easier to calculate, it is sensitive to the choice of the base period, leading to poor stability in calculated results. In addition, the OECD decoupling index is associated with emission intensity reductions only. It does not specifically address the percentage change of emissions in relation to GDP growth (Grand 2016). The Tapio decoupling index addresses these shortcomings. In the Tapio model, decoupling states are divided into three categories and eight subcategories. We adopt the Tapio model but slightly modify and simplify the categorization of the decoupling states.

Many studies have explored the determinants and drivers of carbon emissions from the transportation sector. For instance, (Lakshmanan & Han, 1997) employ a decomposition analysis to identify the magnitude and the relative effects of the various factors in U.S. transportation energy use and carbon emissions between 1970 and 1991. They show that the growth in the propensity to travel, population, and GDP were the three most important factors driving U.S. transportation energy use and CO2 emissions. Timilsina & Shrestha (2009a, 2009b) analyze the factors influencing the growth of carbon dioxide (CO2) emissions from the transportation sector in selected Asian and Latin American and Caribbean countries. Using the Log Mean Divisia Index (LMDI) approach, they decomposed annual emissions growth into several factors; they find that changes in GDP per capita and transportation energy intensity are the main factors driving transport-sector CO2 emission growth.

Several decomposition methods can be used to understand the drivers of the changes in transport carbon emissions including index decomposition, variance decomposition and structural decomposition. However, the index decomposition method is the most commonly used approach in the literature, with the Laspeyres and Divisia being the most popular (Ang, 2004; F. Li et al., 2019; & Shrestha, 2009b; Yasmeen et al., 2020). The index decomposition approach allows the change in emissions to be decomposed into several factors, including GDP per capita, population, energy intensity, fuel mix, fuel carbon intensity, modal structure, and car ownership. The approach (W. W. Wang et al., 2011). We employ this approach to identify the driving forces of the past changes in transport CO2 emissions.

Some papers have explored the determinants of transport emissions using regression techniques including, dynamic panel quantile regressions, dynamic nonparametric additive regressions, and fully modified ordinary least squares regressions (Huang et al., 2020; Saboori et al., 2014; Xu & Lin, 2015). Typically, these papers have employed either an index decomposition analysis or a regression approach, but not both. We use both methods to obtain a robust understanding of the determinants of global transport emissions. The fixed effects and generalized method of moments regressions expand the results of the index decomposition by including additional economic and policy factors that influence the change in global transport emissions.

Furthermore, previous decomposition analyses were conducted at either the country level (Georgatzi et al., 2020; Kwon, 2005; Liang et al., 2017; I. J. Lu et al., 2007; Rasool et al., 2019; Q. Wang et al., 2018), regional level (Amin et al., 2020; Andreoni & Galmarini, 2012; Timilsina & Shrestha, 2009a, 2009b), or city level (Fan & Lei, 2016; Li et al., 2019; Wang et al., 2011). There have been mixed results in the literature. While some studies find that population growth decreases carbon emissions (I. J. Lu et al., 2007; Xie et al., 2017), others find a positive relationship between population growth and carbon emissions (Fan & Lei, 2016; Kim, 2019; Timilsina & Shrestha, 2009b). In addition, the majority of the studies focused on road transportation, specifically passenger cars (González et al., 2019; Papagiannaki & Diakoulaki, 2009; Shiraki et al., 2020). None of the existing papers has conducted a comprehensive study that looks at the main factors affecting the growth of all types of transport emissions on a global scale.

In sum, our paper contributes to the literature in three ways: First, we provide the literature's first comprehensive study of transport-related emissions globally; our data allow us to examine the situation in 145 countries over an extensive period, from 1990 to 2018. Such in-depth analysis of the trends, patterns, and drivers of transport emissions of countries in different development stages is important for the design of effective decarbonization policies for the transportation sector. Second, the study provides evidence of the degree of decoupling between economic growth and emissions in the transport sector that has taken place – or failed to occur – in a large number of countries with widely differing economic conditions and income levels. Third, we estimate associations of transport carbon emissions with various country level indicators. These analyses provide helpful insights for the design and implementation of effective emission-reduction policies in the transportation sector, which are urgently needed to address its role as a driver of climate change.

3. Methodology

In this section, we present the methodology used to conduct the decoupling analysis and to examine the sources and drivers of CO2 emissions in the transport sector. First, we employ the Tapio decoupling model to identify the decoupling status of countries. Second, we conduct an index decomposition analysis using two identities. The first identity investigates how changes in CO2 emissions are driven by changes in population, economic growth, and transportation carbon intensity (measured by transportation emissions per unit of GDP). The second identity further examines how changes in transport emission intensity are driven by changes in carbon intensity of transport energy consumption, transport energy intensity, and transport demand. Third, we explore the economic determinants of CO2 emissions and emission intensity based on a panel regression analysis.

3.1. Tapio decoupling model

The formula for the Tapio decoupling model is given by:

$$\beta = \frac{\%\,\Delta CO2}{\%\,\Delta GDP} = \frac{(CO2_t - CO2_0)/CO2_0}{(GDP_t - GDP_0)/GDP_0}$$

Where $\Delta CO2$ and ΔGDP denote the change of transport carbon emissions and economic growth between a base year 0 to a target year t respectively. Different from Tapio (2005) in which the decoupling status is divided into eight categories depending on the magnitude and sign of the elasticity (β), we define the decoupling status into three categories – absolute decoupling, relative decoupling, and no decoupling.

1. ***Absolute decoupling***: occurs when carbon emissions are decreasing, and GDP is increasing, i.e. $\Delta CO2 < 0$ and $\Delta GDP > 0$. This follows that $\beta < 0$.
2. ***Relative decoupling***: occurs when both carbon emissions and GDP are increasing, but GDP is increasing at a faster rate. Here $\Delta CO2 > 0$ and $\Delta GDP > 0$. This follows that $0 < \beta < 1$.
3. ***No decoupling***: is defined as residual category where no absolute or relative decoupling occurs.

3.2. Index decomposition analysis

To conduct the decomposition analysis of the driving forces of CO2 emissions, we specify two identities starting from an IPAT equation, one in which environmental impact (I) is a product of population (P), affluence (A), and technology (T) (Commoner et al., 1971; Ehrlich & Holdren, 1971). According to Kwon (2005), the IPAT formula is a valuable starting point to understand the determinants of past changes in an aggregate environmental indicator to inform future environmental policies. Our first IDA identity is given by:

$$CO2_t = \sum_j POP_t * \frac{GDP_t}{POP_t} * \frac{CO2_{jt}}{GDP_t} \qquad (1)$$

where *j* and *t* represent transportation modes (road, rail, domestic navigation, domestic aviation, and pipeline transport) and year, respectively. *CO2* are transport-related carbon emissions; *GDP* represents gross domestic output in million dollars based on 2015 PPP rates; and *POP* refers to the population size. Equation (1) can be rewritten as:

$$CO2_t = \sum_j POP_t * GDPPC_t * EI_{jt} \qquad (2)$$

where *CO2* represents the environmental-impact (I) variable in the IPAT identity. The first term on the right-hand side of equation (2) measures the population effect (P). The second term is GDP per capita, a measure of economic growth and a proxy for affluence (A). The third term is the emissions intensity per unit of GDP, which is a proxy for technology (T).

In addition to the first decomposition equation, we specify another identity to further examine the factors affecting the changes in carbon intensity measured by CO2 emissions per unit of GDP in inland transportation for which more disaggregated data on travel volumes are available. The identity is given by equations (3) below:

$$\frac{CO2_t}{GDP_t} = \sum_j \frac{CO2_{jt}}{ENECONS_t} * \frac{ENECONS_t}{Total\ KM_t} * \frac{Total\ KM_t}{GDP_t} \qquad (3)$$

where *ENECONS* represents transport energy consumption. *Total KM* represents total transport turnover, i.e., total kilometers traveled by both passenger and freight. The first and second terms on the right-hand side of equation (3) represent the carbon intensity of transport energy consumption and transport energy efficiency, respectively. The third term represents transportation demand normalized by GDP. By further breaking down carbon intensity (measured by emissions per unit of GDP) into carbon intensity of fuel and fuel efficiency, equation (3) complements equation (1) to help understand the importance of various factors in determining the trajectory of carbon emissions from transport.

Various index-decomposition approaches have been used in the literature to isolate the impact of one variable from the other in determining the changes in CO2 emissions. In this paper, we adopt the Logarithmic Mean Divisia Index (LMDI) approach because it provides a perfect decomposition, i.e., the changes in the aggregate indicator are fully explained by predefined factors, and the decomposition results do not leave an unexplained residual term. The LMDI is consistent in aggregation, meaning that the results obtained from subgroups can be aggregated to a higher aggregation level in a consistent manner (Ang & Liu, 2001).

Applying the multiplicative LMDI formula to equation (2), the change in the transport CO2 emissions from the base year zero to year *t* is given as:

$$\frac{CO2_t}{CO2_0} = exp\left[\sum_j v_j \ ln \ \frac{POP_t}{POP_0}\right] \times exp\left[\sum_j v_j \ ln \ \frac{GDPPC_t}{GDPPC_0}\right] \times \ exp\left[\sum_j v_j \ ln \ \frac{EI_{jt}}{EI_{j0}}\right] \qquad (4)$$

where $v_j = \frac{(CO2_{jt} - CO2_{j0})/(ln\ CO2_{jt} - ln\ CO2_{j0})}{(CO2_t - CO2_0)/(ln\ CO2_t - ln\ CO2_0)} \quad for\ CO2_{jt} \neq CO2_{jo}$

$$v_j = CO2_{jt} \quad for \ \ CO2_{jt} = CO2_{jo}$$

The terms on the right-hand side of equation (4) quantify the relative contribution of each term on the changes in transport emissions. The first term on the right-hand side of equation (4) represents the population effect. The second term represents the economic-growth effect. The third term represents the emissions-intensity effect. A similar formula is applied for equation (3).

3.3 Panel regression analysis

Lastly, we estimate a dynamic model to understand the effects of various economic factors on the level of transport-related CO2 emissions. We assume current level of per capita emissions depends on the level of per capita emissions in the previous year, that is, transport activities respond to changes in economic factors with some lags. The model is specified as follows:

$$CO2PC_{it} = \beta_0 + \beta_1 CO2PC_{i,t-1} + \beta_2 GDPPC_{it} + \beta_3 GDPPC2_{it} + \beta_4 Diesel_{it} + \beta_5 Gasoline_{it} + \beta_6 Urban_{it} + + \beta_7 BRT_{it} + \gamma X_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \quad (5)$$

Where $CO2PC_{it}$ is the natural logarithm of per capita CO2 emissions in country *i* in year ***t***. *GDPPCit* is per capita GDP. *GDPPC2* is the square term of *GDPPC*. *Diesel* and *Gasoline* are diesel and gasoline prices, respectively. *Urban* is the percentage of the total population living in urban areas. *BRT* represents the number of Bus Rapid Transit (BRT) systems a country has. X_{it} is a vector of variables, including the value-added share of agriculture, manufacturing, and service sectors. α_i is an unobserved country fixed effect, which includes country-specific characteristics that are fixed over time, such as culture, climate zone, and government regulation. We also include year fixed effects, λ_t, to control for common cyclical components such as a common technology shock. ε_{it} is an idiosyncratic error term. $\beta_0 - \beta_7 \; and \; \gamma$ are parameters to be estimated. We opted for a relatively modest set of explanatory variables because due to limited data availability the inclusion of some further explanatory variables would have substantially cut the sample size.

4. Data

Data used in this study come from several sources. The CO2 emissions and energy consumption data are from International Energy Agency (IEA) Fuel Combustion Statistics database and World Energy Statistics and Balances database, respectively. The databases report CO2 emissions and final energy consumption due to fuel combustion of transportation activities at the country level. The transportation sector is further divided into road, rail, domestic navigation, domestic aviation, and pipeline transport. The study period is from 1990 to 2018. The full sample contains 145 countries for which data are available. In 2018, the full sample of countries contributed to 84 percent of global transport carbon emissions. International aviation and marine bunkers account for the remaining 16 percent. The list of countries included in the study is presented in Table A1 in the appendix. We obtain PPP-based GDP (based on 2015 PPP rates) and population data from IEA.

For the decomposition analysis of emissions intensity, we obtain annual country-level total passenger and freight transport traveled by road and rail from the World Road Statistics and the International Transport Forum databases. Total passenger transport, measured in million passenger-kilometers, refers to the total movement of passengers using inland transportation. It represents the transport of one passenger for one kilometer. Total freight transport, measured in million tons-kilometer, refers to the total movement of goods using inland transport. It represents the transport of one ton over one kilometer. The total kilometer variable is available for 65 countries during the period from 2000 to 2018. These countries are listed in Table A2 in the appendix.

The level of urbanization, and the value added from agriculture, manufacturing, and service sectors are all obtained from the World Bank World Development Indicators database. Data on country-level BRT systems are obtained from global BRT database. Diesel and gasoline prices are compiled from fuel price documentation from the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ). The summary statistics of variables are presented in Table 3.

5. Results

In this section, we describe the results of the decoupling analyses, the general pattern of transport-related CO2 emissions, and the results of the regression analyses. The descriptive statistics reveal that CO2 emissions of the transport sector account for 24 percent of global CO2 emissions, making the transport sector the second-largest contributor to global CO2 emissions after the energy sector, which accounts for 42 percent of such emissions. Within the transport sector, road transportation is the predominant driver, accounting for 74 percent of all CO2 emissions; international sea transport accounts for 9 percent, and international aviation accounts for 7 percent (Figure 1). The composition of global transport CO2 emissions by mode has been fairly stable over time; the shares in 1990 were about the same as those in 2018 (Figure A1). There is interesting variation between income groups and regions; the CO2 emissions from road transportation are slightly below the global average in high-income countries, and above average in lower-middle and low-income countries (Figure A3).

Figures 2a and 2b present the distribution of global transport CO2 emissions in terms of GDP and population by income group and major emitting countries in 2018. The area of each rectangle represents the contributions of a country/income group to total global transport emissions. The rectangle's width represents the share of global GDP (population), and the height represents transport emissions per unit of GDP (population). Figure 2a suggests that the countries with the most carbon-intensive transport sectors are the Russian Federation, Brazil, Mexico, and India. Excluding China, the transport sectors in middle-income countries are more carbon intensive than those of high-income countries. In terms of the fuel mix, Russia has a high fraction of “other” fuels, composed of mainly natural gas, compared to other countries and aggregates. The high share of biofuels in Brazil’s transportation-sector fuels also stands out.

Figure 2b provides additional insights on the global carbon footprint of the transport sector. In 2018, the global average per capita emissions from the transport sector were 1.09 ton of CO2. Per capita emissions in the United States were five times the world average. Per capita emissions of other high-income countries were three times the world average, and those from the EU countries were double the world average. Although middle-income countries at that time had relatively carbon-intensive transport sectors, their per capita emissions were significantly lower than those of high-income countries.

In absolute levels, the findings show that high-income countries originated as many transport CO2 emissions as all low- and middle-income countries combined (Figure 3). However, this is rapidly changing due to high emissions growth in middle-income countries. Lower-middle-income countries have more than tripled their transport CO2 emissions, and upper-middle-income countries have more than doubled their transport CO2 emissions since 1990. In 1990, high-income countries still generated about twice the level of transport-related CO2 emissions as those created by low- and middle-income countries combined. By 2018, levels generated by high-income countries, and by the combination of low- and middle-income countries were about even. In per capita terms, the gap between high- and middle-income countries is still wide. A person in a high-income country is generating around three times as much in the way of transport CO2 emissions as a person in a middle-income country. But this gap is also rapidly decreasing. Per capita transport CO2 emissions in middle-income countries have doubled since 1990, while they remained relatively stable in high-income countries. Since 1990, transport-related CO2 emissions per unit of GDP have declined for all income groups, but obviously not enough to make up for the large increases in GDP that we have observed over the same period. We show these trends by world regions in the appendix (Figure A2).

The United States is by far the leading contributor to global transport CO2 emissions; it generates 21 percent of such emissions, while accounting for less than 5 percent of the world’s population. The United States is followed by China and the EU-28 countries (still including the United Kingdom), which both contribute around 11 percent to global transport CO2 emissions (Figure 4). The EU-28 countries contribute slightly more than their share of the world population and China contributes less than its world population share. However, transport CO2 emissions in China are rapidly increasing, experiencing a tenfold increase since 1990 (Figure 5). Transport CO_2 emissions have also increased by around 20 percent in the United States. Among the lower-middle-income countries, India is growing rapidly, and has increased its transport CO_2 emissions by a factor of five since 1990; it now contributes around 4 percent of global transport CO_2 emissions, still much less than its population share. There is not a single low-income country that accounts for more than 1 percent of the transport CO_2 emissions compared to the United States.

Looking at the fuel mix, we see that motor gasoline and gas/diesel oil account for the vast majority of the transport fuel mix, and today both account for around 35 percent of fuels used. Since 1990, the share of motor gasoline has steadily declined, and the share of gas/diesel oil has steadily increased. The share of the remaining fuel types has remained relatively stable (Figure 6). Consequently, motor gasoline and gas/diesel oil also account for the majority of transport CO_2 emissions.

Only a dozen countries achieved absolute decoupling over the study period. The remaining countries experienced either relative decoupling or no decoupling. This implies that transport emissions in most countries, including the top-emitting countries, are still increasing and strongly linked to economic growth. Hence, in order to achieve decarbonization in the transport sector, there is an urgent need to break this link. This is especially the case in middle- and low-income countries. While about 72 percent of high-income countries are in the absolute or relative decoupling states, only 29 percent of middle- and lower-income countries have achieved some level of decoupling.

Moving onto the decomposition analysis, the first decomposition results show that since 1990, transport related CO_2 emissions have increased by around 80 percent, despite sizeable improvements in efficiency. The results also reveal that these efficiency improvements did not fully compensate for the increase in emissions due to population growth. The net increase in transport CO_2 emissions is almost in sync with the increase that is due to GDP growth (Figure 7). If these patterns continue, achieving the goals of the Paris Agreement with improvements in efficiency alone seems unrealistic. According to the UN population projections, the world population will continue to grow rapidly and reach about 10 billion people by 2050. Then population growth will gradually slow down, and the world population is projected to peak at around 11 billion people in 2100. Notwithstanding the uncertainty surrounding these projections, the slowdown in population growth will likely come too late to allow further efficiency improvements to outweigh the increases in emissions due to economic growth.

If we look at the results of the index decomposition by income group, we see that in high-income countries the improvements in efficiency fully compensate for the effect of population growth, and even partially outweigh the effect of economic growth. The efficiency improvements in upper-middle income countries are almost as large as in high-income countries, but there they are only just enough to outweigh the effects of population growth such that total transport-generated CO2 emissions continue to rise with growth of GDP. Efficiency improvements are much less in lower-middle-income countries, such that in these countries increases in transport-related CO2 emissions are driven by both sizeable population growth and GDP growth (Figure 8).

The first decomposition results for top-emitting countries reveal several interesting points (Figure 9). All countries shown, except Japan and Russia, reveal increases in transport emissions since 1990. In line with the descriptive analysis, the decomposition results suggest that China experienced the most significant increase in transport-related CO2 emissions since 1990. This increase was largely driven by economic growth, which is not surprising, given that the Chinese economy is among the fastest-growing economies in the world, with an average annual GDP growth rate of 9.5 percent between 1990 and 2018. Transportation emissions intensity in China declined slightly, but population growth remained relatively stable. In contrast to China, in India, the country with the second-largest increases in transportation emissions, the increases have been driven by both population growth and economic growth.

Among the largest emitters, Japan is the only country that achieved absolute decoupling in the transportation sector over the last three decades (i.e., it experienced economic growth while transport CO2 emissions fell absolutely). Efficiency improvements and stable population growth in Japan were sufficient to decrease transport-related emissions. On the other hand, the United States and the EU countries achieved relative decoupling of transport emissions, meaning that GDP grew faster than emissions.

To better understand the drivers of the changes in transportation emissions intensity, we further decompose the emissions intensity of transportation (i.e., transport-generated CO2 emissions divided by GDP) by carbon intensity of fuel, energy consumption of kilometers traveled, and total kilometers traveled (Figure 10). Due to limited data and time coverage for total kilometers traveled, the base year for the second decomposition is 2000. Nevertheless, we observe a similar decreasing trend of transport emissions intensity as in the first decomposition. Transport emissions intensity in India and Mexico have remained at the same level where they were in 2000. In India this happened because kilometers traveled per unit of GDP increased, and energy consumption per kilometer decreased, balancing each other out. In Mexico all indicators are at levels from 2000, with some movements in between. China also increased kilometers traveled per unit of GDP, but its increase was more modest than that of India, and the reduction in energy consumption per kilometer was sufficient to outweigh this increase.

The significant decrease in transport carbon intensity that contributed to the absolute decoupling of CO2 emissions in Japan was driven by improvements in the energy efficiency of the transport sector and a decrease in transport demand. The carbon intensity of transport fuel consumption was relatively stable in both countries. Results for Ukraine and Kazakhstan are similar to those of Japan and Russia. The United States results reveal that the decrease in transport demand was the main contributing factor to the decline in transport carbon intensity. Conversely, the main contributing factor for the decline of transport carbon intensity in EU countries was the improvements in transport energy efficiency. This implies that energy consumption per kilometer traveled in EU countries has declined since 2000.

We now turn to a regression analysis of the determinants of per capita transport CO2 emissions measured by transport-generated CO2 emissions per unit of GDP. The first three columns of Table 2 report results from static panel regression via OLS, the random-effects and fixed-effects methods.. The last column report results identified in equation (5) using the generalized methods of moments (GMM) technique outlined in Arellano and Bond (1991). Because governments may respond to increasing pollutions and growing traffic congestion by raising energy prices, energy price could be endogenous to carbon emissions. To address the potential endogeneity concern, we use observations on energy price lagged two to four periods as instruments in the GMM model. The coefficient associated with the lagged CO2 emissions is statistically significant, suggesting that the current level of emissions is indeed strongly correlated with the level of emissions in the previous period. The dynamic panel regression reported in column (4) of Table 2 is therefore our preferred specification.

Controlling for country and year fixed effects, the parameter estimates suggest that per capita GDP, energy price, urbanization, and structural transformation are strongly correlated with transport related emissions. The squared term of GDP per capita is negative and statistically significant, but if we calculate the maximum of the inverted U, the point where the slope changes from positive to negative, we find that it is out of sample, and that all observations are on the increasing part of the parabola.

The estimates of economic structure measured by the relative share of the value added of agriculture, manufacturing, and services show that as countries move away from agriculture, transport-related emissions decreases. Another interesting finding that emerged from the results is that CO2 emissions first increase and then decrease with the increase of the percentage of people living in urban area. The turning point occurs at 58 percent of urbanization. Finally, higher diesel prices is associated with lower per capita carbon emissions. The coefficients associated with gasoline prices are of the expected sign but are not statistically significant. Because gasoline prices are highly correlated with diesel prices, including the diesel price in the regression could absorb most of the explanatory power.

In the above analysis, we do not control for the existence of transportation policies aimed at reducing transport-related emissions. As a robustness check, we collect data from IEA transportation policy database and control for the existence of various transportation policies in the estimation. We use the principal component analysis method to create one comprehensive transport decarbonization policy variable that summarizes several transportation policies: fuel efficiency standards, tailpipe emissions regulations, driving restrictions, promotion of electric vehicles, promotion of biofuels, R&D and vehicle emission standards. Including transportation policy variable in the regression reduces the sample size by half due to limited data availability for many developing countries. The results are reported in Table 3. The existence of transportation policies has a strong impact, sharply decreasing per capita emissions. The coefficients of the other variables have the expected sign, but the statistical significance reduces due to the smaller sample.

6. Conclusions

Emissions from the transportation sector – which includes travel of people and goods by road, rail, aircraft, and marine vessels; and the pipeline transportation of many fuels – represented more than 24 percent of global CO2 emissions in 2018. Worldwide, emissions from transportation are increasing faster than those from any other sector. Decarbonization of the transport sector therefore plays a crucial role in achieving the Paris Agreement target of limiting global temperature rise to 2 degrees Celsius – and preferably to below 1.5 degree Celsius – compared to pre-industrial levels.

This paper examines the status of the decoupling of transport-generated carbon emissions and economic growth of 145 countries. In addition, it studies the patterns and drivers of transport-related CO2 emissions of 145 countries during the period from 1990 to 2018. We observe considerable differences in the decoupling status of countries according to their income levels. Most high-income countries are in the relative decoupling states while most of the countries with low incomes are in no decoupling states. This implies that there is considerable room for breaking the linkage between economic growth and carbon emissions in low- and middle-income countries.

The empirical results in this paper point to several opportunities for developing countries to decouple CO_2 emissions from transportation. First, transport's reliance on fossil fuels needs to shift dramatically. Renewables and electricity still account for a negligible share of transportation fuel. Thus, there is large, unexploited potential to reduce CO_2 emissions from mobility by leveraging technological advances (in batteries, for example) that have made "green" vehicles possible and more practical transportation options than previously has been thought. Nevertheless, the impact of electrification on transport-related CO_2 emissions will be much higher once the power system itself has been decarbonized. Second, continued energy price reforms to phase out subsidies for fossil fuel could lead to a sizable reduction in emissions. Third, rapid urbanization in developing countries could provide both challenges and opportunities for the decarbonization of transportation. On the one hand, the high concentration of people and activities in cities could lead to a rise in vehicle ownership and traffic congestion. On the other hand, urbanization allows for the development of complex public transportation systems and other economies of scale to facilitate emissions reductions. It is important for policy makers to integrate land-use planning and transportation options to encourage low-emission mobility so as to avoid urbanization being associated with a phase of extremely high carbon intensity of transportation.

References

Amin, A., Altinoz, B., & Dogan, E. (2020). Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization. *Clean Technologies and Environmental Policy*, *22*(8), 1725–1734. https://doi.org/10.1007/s10098-020-01910-2

Andreoni, V., & Galmarini, S. (2012). European CO2 emission trends: A decomposition analysis for water and aviation transport sectors. *Energy*, *45*(1), 595–602. https://doi.org/10.1016/j.energy.2012.07.039

Ang, B. W. (2004). Decomposition analysis for policymaking in energy: Which is the preferred method? *Energy Policy*, *32*(9), 1131–1139. https://doi.org/10.1016/S0301-4215(03)00076-4

Ang, B. W., & Liu, F. L. (2001). A new energy decomposition method: Perfect in decomposition and consistent in aggregation. *Energy*, *26*(6), 537–548. https://doi.org/10.1016/S0360-5442(01)00022-6

Bai, C., Chen, Y., Yi, X., & Feng, C. (2019). Decoupling and decomposition analysis of transportation carbon emissions at the provincial level in China: perspective from the 11th and 12th Five-Year Plan periods. *Environmental Science and Pollution Research 2019 26:15*, *26*(15), 15039–15056. https://doi.org/10.1007/S11356-019-04774-2

Chen, J., Wang, P., Cui, L., Huang, S., & Song, M. (2018). Decomposition and decoupling analysis of CO2 emissions in OECD. *Applied Energy*, *231*, 937–950. https://doi.org/10.1016/J.APENERGY.2018.09.179

Commoner, B., Corr, M., & Stamler, P. J. (1971). The causes of pollution. *Environment*, *13*(3), 2–19. https://doi.org/10.1080/00139157.1971.9930577

de Freitas, L. C., & Kaneko, S. (2011). Decomposing the decoupling of CO2 emissions and economic growth in Brazil. *Ecological Economics*, *70*(8), 1459–1469. https://doi.org/10.1016/J.ECOLECON.2011.02.011

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth. *Science*, *171*(3977), 1212–1217. https://doi.org/10.1126/science.171.3977.1212

Fan, F., & Lei, Y. (2016). Decomposition analysis of energy-related carbon emissions from the transportation sector in Beijing. *Transportation Research Part D: Transport and Environment*, *42*, 135–145. https://doi.org/10.1016/j.trd.2015.11.001

FY Fan, Y. L. (2016). Decomposition analysis of energy-related carbon emissions from the transportation sector in Beijing. *Transp Res D*, *42*, 135–145. https://doi.org/10.1016/j.trd.2015.11.001

Georgatzi, V. v., Stamboulis, Y., & Vetsikas, A. (2020). Examining the determinants of CO2 emissions caused by the transport sector: Empirical evidence from 12 European countries. *Economic Analysis and Policy*, *65*, 11–20. https://doi.org/10.1016/j.eap.2019.11.003

González, R. M., Marrero, G. A., Rodríguez-López, J., & Marrero, Á. S. (2019). Analyzing CO2 emissions from passenger cars in Europe: A dynamic panel data approach. *Energy Policy*, *129*, 1271–1281. https://doi.org/10.1016/j.enpol.2019.03.031

Hang, Y., Wang, Q., Zhou, D., & Zhang, L. (2019). Factors influencing the progress in decoupling economic growth from carbon dioxide emissions in China's manufacturing industry. *Resources, Conservation and Recycling*, *146*, 77–88. https://doi.org/10.1016/J.RESCONREC.2019.03.034

Huang, Y., Zhu, H., & Zhang, Z. (2020). The heterogeneous effect of driving factors on carbon emission intensity in the Chinese transport sector: Evidence from dynamic panel quantile regression. *Science of The Total Environment*, *727*, 138578. https://doi.org/10.1016/J.SCITOTENV.2020.138578

Huo, T., Ma, Y., Yu, T., Cai, W., Liu, B., & Ren, H. (2021). Decoupling and decomposition analysis of residential building carbon emissions from residential income: Evidence from the provincial level in China. *Environmental Impact Assessment Review*, *86*, 106487. https://doi.org/10.1016/J.EIAR.2020.106487

IEA. (2020). *Energy Technology Perspectives 2020*. www.iea.org/t&c/

IPCC, Edenhofer, O., Sokona, Y., Minx, J. C., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Kriemann, B., Savolainen Web Manager Steffen Schlömer, J., von Stechow, C., & Zwickel Senior Scientist, T. (2014). *Climate Change 2014 Mitigation of Climate Change Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. www.cambridge.org

Jiang, X.-T., Dong, J.-F., Wang, X.-M., & Li, R.-R. (2016). The Multilevel Index Decomposition of Energy-Related Carbon Emission and Its Decoupling with Economic Growth in USA. *Sustainability 2016, Vol. 8, Page 857*, *8*(9), 857. https://doi.org/10.3390/SU8090857

JJ Jiang, B. Y. D. X. J. T. (2017). Provincial-level carbon emission drivers and emission reduction strategies in China: combining multi-layer LMDI decomposition with hierarchical clustering. *J Clean Prod*, *169*, 178–190. https://doi.org/10.1016/j.jclepro.2017.03.189

Kim, S. (2019). Decomposition Analysis of Greenhouse Gas Emissions in Korea's Transportation Sector. *Sustainability*, *11*(7), 1986. https://doi.org/10.3390/su11071986

Kwon, T. H. (2005). Decomposition of factors determining the trend of CO2 emissions from car travel in Great Britain (1970-2000). *Ecological Economics*, *53*(2), 261–275. https://doi.org/10.1016/j.ecolecon.2004.06.028

Lakshmanan, T. R., & Han, X. (1997). Factors underlying transportation CO2 emissions in the U.S.A.: A decomposition analysis. *Transportation Research Part D: Transport and Environment*, *2*(1), 1–15. https://doi.org/10.1016/S1361-9209(96)00011-9

Li, A., Zhang, A., Zhou, Y., & Yao, X. (2017). Decomposition analysis of factors affecting carbon dioxide emissions across provinces in China. *Journal of Cleaner Production*, *141*, 1428–1444. https://doi.org/10.1016/J.JCLEPRO.2016.09.206

Li, F., Cai, B., Ye, Z., Wang, Z., Zhang, W., Zhou, P., & Chen, J. (2019). Changing patterns and determinants of transportation carbon emissions in Chinese cities. *Energy*, *174*, 562–575. https://doi.org/10.1016/j.energy.2019.02.179

Liang, Y., Niu, D., Wang, H., & Li, Y. (2017). Factors Affecting Transportation Sector CO2 Emissions Growth in China: An LMDI Decomposition Analysis. *Sustainability*, *9*(10), 1730. https://doi.org/10.3390/su9101730

Lu, I. J., Lin, S. J., & Lewis, C. (2007). Decomposition and decoupling effects of carbon dioxide emission from highway transportation in Taiwan, Germany, Japan and South Korea. *Energy Policy*, *35*(6), 3226–3235. https://doi.org/10.1016/j.enpol.2006.11.003

Lu, Q., Yang, H., Huang, X., Chuai, X., & Wu, C. (2015). Multi-sectoral decomposition in decoupling industrial growth from carbon emissions in the developed Jiangsu Province, China. *Energy*, *82*, 414–425. https://doi.org/10.1016/J.ENERGY.2015.01.052

M, W., & C, F. (2019). Decoupling economic growth from carbon dioxide emissions in China's metal industrial sectors: A technological and efficiency perspective. *The Science of the Total Environment*, *691*, 1173–1181. https://doi.org/10.1016/J.SCITOTENV.2019.07.190

OECD. (2002). *Indicators to Measure Decoupling of Environmental Pressure from Economic Growth*.

Papagiannaki, K., & Diakoulaki, D. (2009). Decomposition analysis of CO2 emissions from passenger cars: The cases of Greece and Denmark. *Energy Policy*, *37*(8), 3259–3267. https://doi.org/10.1016/j.enpol.2009.04.026

Rasool, Y., Zaidi, S. A. H., & Zafar, M. W. (2019). Determinants of carbon emissions in Pakistan's transport sector. *Environmental Science and Pollution Research*, *26*(22), 22907–22921. https://doi.org/10.1007/s11356-019-05504-4

Saboori, B., Sapri, M., & bin Baba, M. (2014). Economic growth, energy consumption and CO2 emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: A fully modified bi-directional relationship approach. *Energy*, *66*, 150–161. https://doi.org/10.1016/J.ENERGY.2013.12.048

Shiraki, H., Matsumoto, K., Shigetomi, Y., Ehara, T., Ochi, Y., & Ogawa, Y. (2020). Factors affecting CO2 emissions from private automobiles in Japan: The impact of vehicle occupancy. *Applied Energy*, *259*, 114196. https://doi.org/10.1016/j.apenergy.2019.114196

Shuai, C., Chen, X., Wu, Y., Zhang, Y., & Tan, Y. (2019). A three-step strategy for decoupling economic growth from carbon emission: Empirical evidence from 133 countries. *Science of The Total Environment*, *646*, 524–543. https://doi.org/10.1016/J.SCITOTENV.2018.07.045

Tapio, P. (2005). Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transport Policy*, *12*(2), 137–151. https://doi.org/10.1016/J.TRANPOL.2005.01.001

Timilsina, G. R., & Shrestha, A. (2009a). Factors affecting transport sector CO_2 emissions growth in Latin American and Caribbean countries: An LMDI decomposition analysis. *International Journal of Energy Research*, *33*(4), 396–414. https://doi.org/10.1002/er.1486

Timilsina, G. R., & Shrestha, A. (2009b). Transport sector CO2 emissions growth in Asia: Underlying factors and policy options. *Energy Policy*, *37*(11), 4523–4539. https://doi.org/10.1016/j.enpol.2009.06.009

Wang, Q., Zhao, M., Li, R., & Su, M. (2018). Decomposition and decoupling analysis of carbon emissions from economic growth: A comparative study of China and the United States. *Journal of Cleaner Production*, *197*, 178–184. https://doi.org/10.1016/J.JCLEPRO.2018.05.285

Wang, W. W., Zhang, M., & Zhou, M. (2011). Using LMDI method to analyze transport sector CO2 emissions in China. *Energy*, *36*(10), 5909–5915. https://doi.org/10.1016/j.energy.2011.08.031

Wu, Y., Tam, V. W. Y., Shuai, C., Shen, L., Zhang, Y., & Liao, S. (2019). Decoupling China's economic growth from carbon emissions: Empirical studies from 30 Chinese provinces (2001–2015). *Science of The Total Environment*, *656*, 576–588. https://doi.org/10.1016/J.SCITOTENV.2018.11.384

Xie, R., Fang, J., & Liu, C. (2017). The effects of transportation infrastructure on urban carbon emissions. *Applied Energy*, *196*, 199–207. https://doi.org/10.1016/j.apenergy.2017.01.020

Xu, B., & Lin, B. (2015). Factors affecting carbon dioxide (CO2) emissions in China's transport sector: a dynamic nonparametric additive regression model. *Journal of Cleaner Production*, *101*, 311–322. https://doi.org/10.1016/J.JCLEPRO.2015.03.088

Yasmeen, H., Wang, Y., Zameer, H., & Solangi, Y. A. (2020). Decomposing factors affecting CO2 emissions in Pakistan: insights from LMDI decomposition approach. *Environmental Science and Pollution Research*, *27*(3), 3113–3123. https://doi.org/10.1007/s11356-019-07187-3

Zhang, J., Fan, Z., Chen, Y., Gao, J., & Liu, W. (2020). Decomposition and decoupling analysis of carbon dioxide emissions from economic growth in the context of China and the ASEAN countries. *Science of The Total Environment*, *714*, 136649. https://doi.org/10.1016/J.SCITOTENV.2020.136649

Figure 1: Sectoral CO2 emissions and global transport emissions by mode, 2018

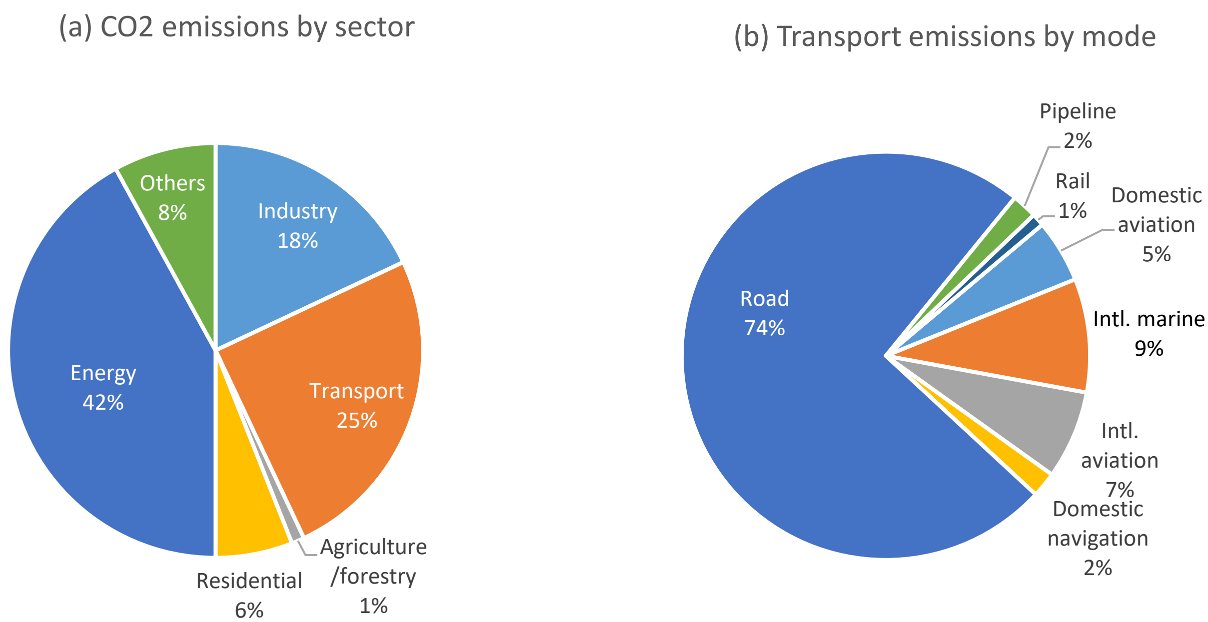


Figure 2: CO2 footprint of the transport sector, 2018

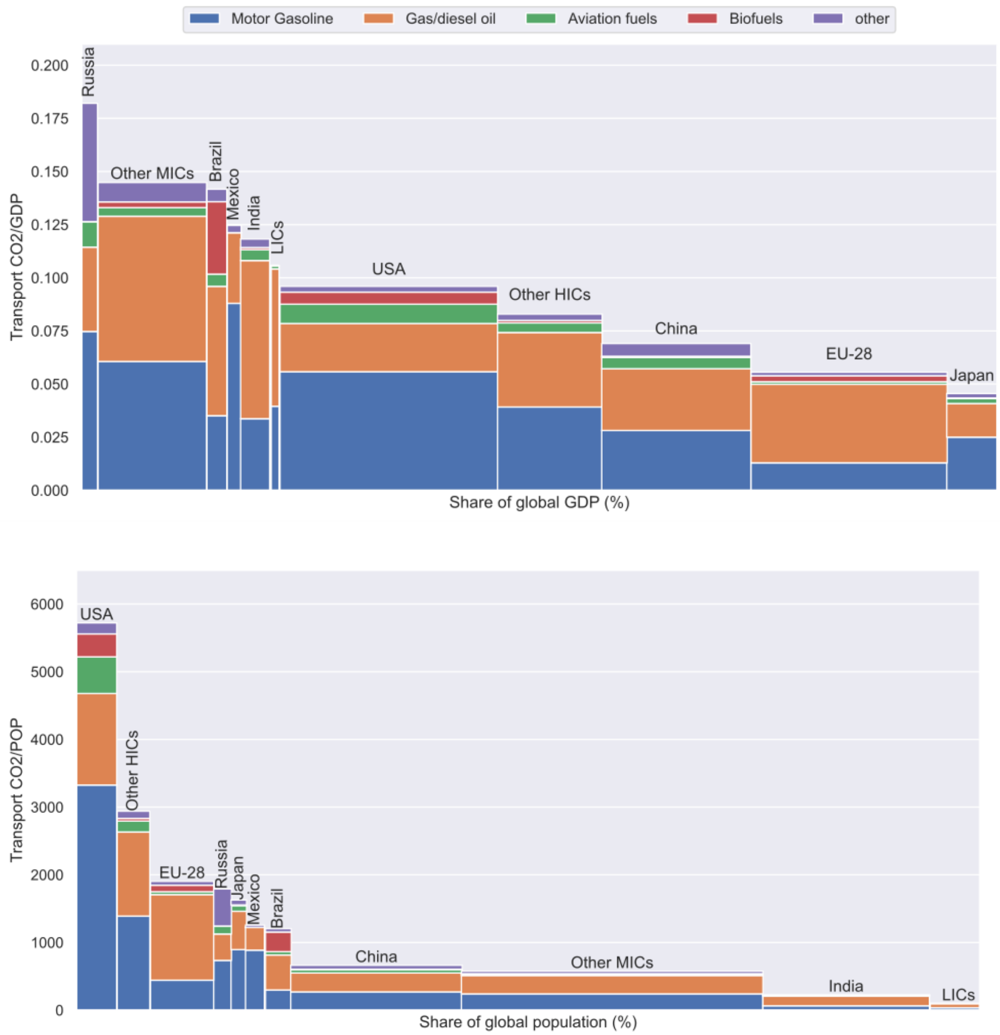


Figure 3: Trends in transport carbon emissions by income group (1990 – 2018)

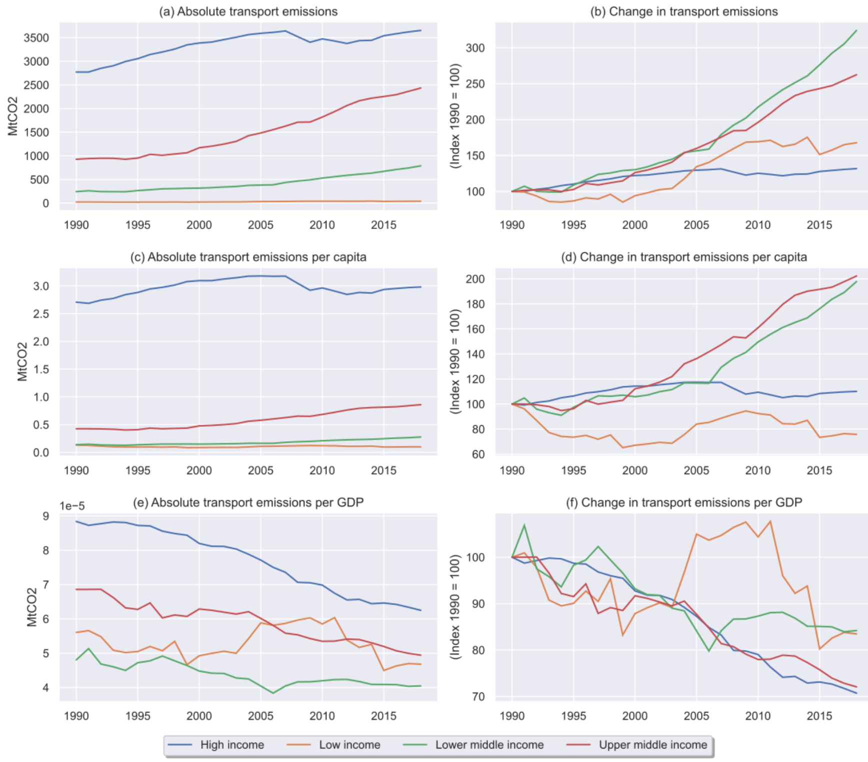


Figure 4: Transport CO2 emissions by country

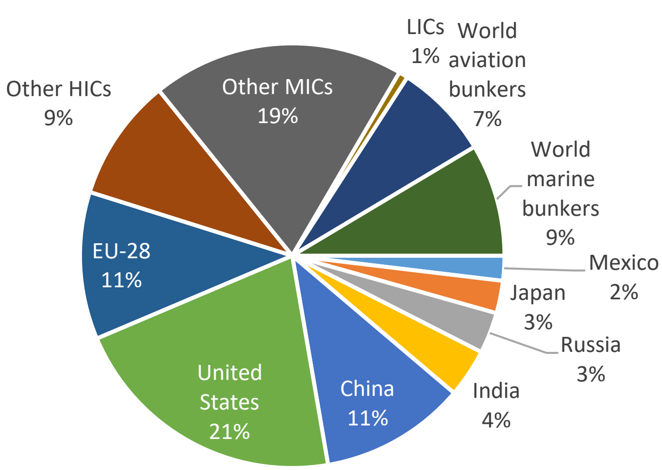


Figure 5: Top transport CO2 emitters by income group

Figure 6: Global transportation fuel mix (1990 – 2018)

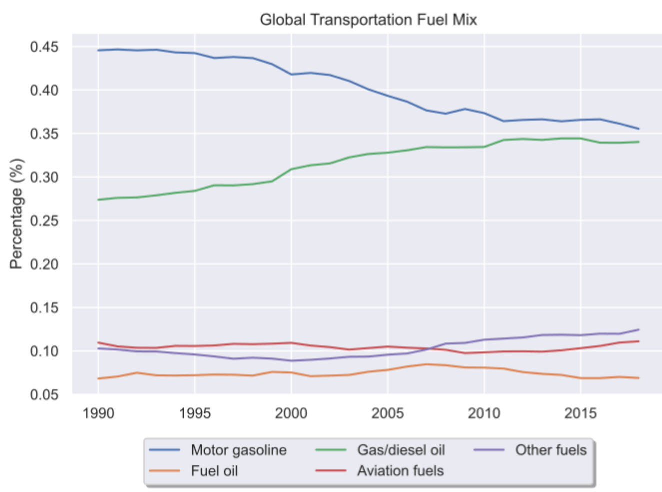


Figure 7: Trend in global transport emissions (1990 – 2018)

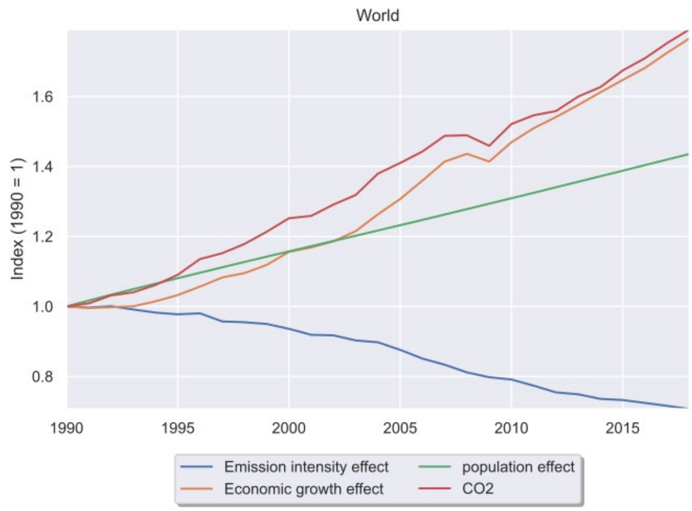


Figure 8: Trend in global transport emissions by income group (1990 – 2018)

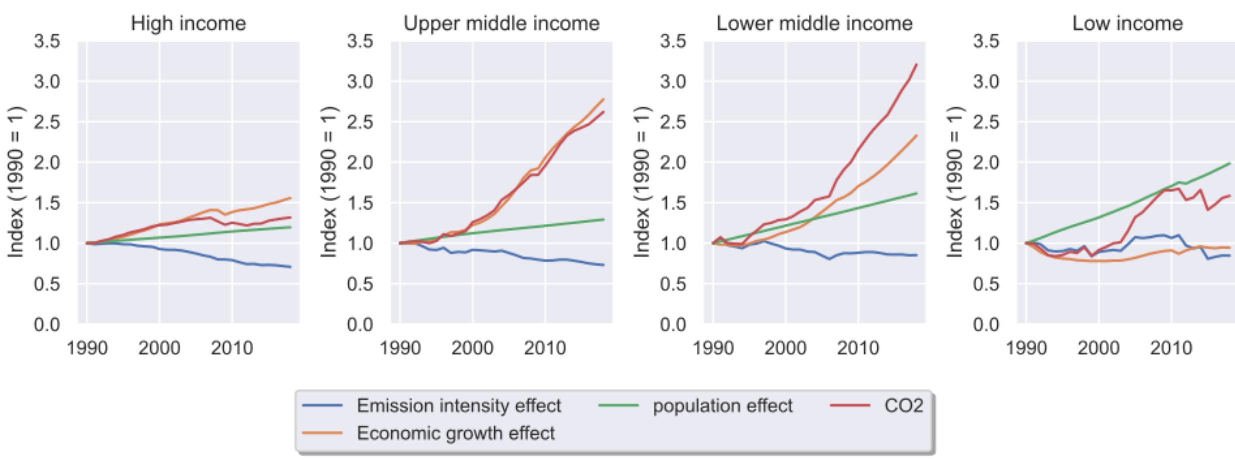


Figure 9: Trend in global transport emissions by country (1990 – 2018)

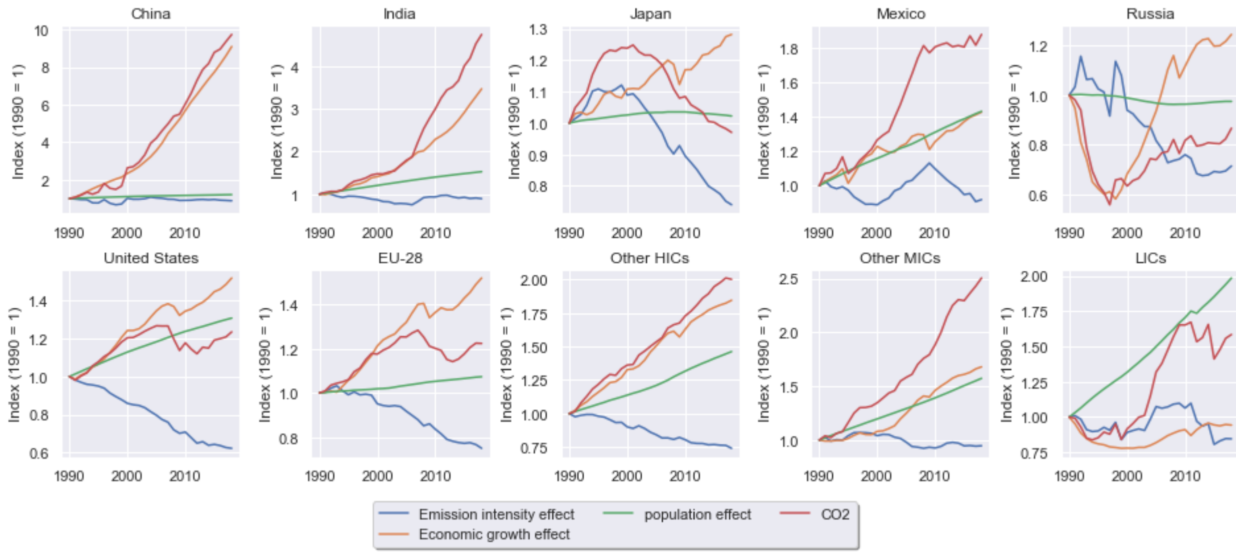


Figure 10: Decomposition of global transport emissions per unit of GDP (1990 – 2018)

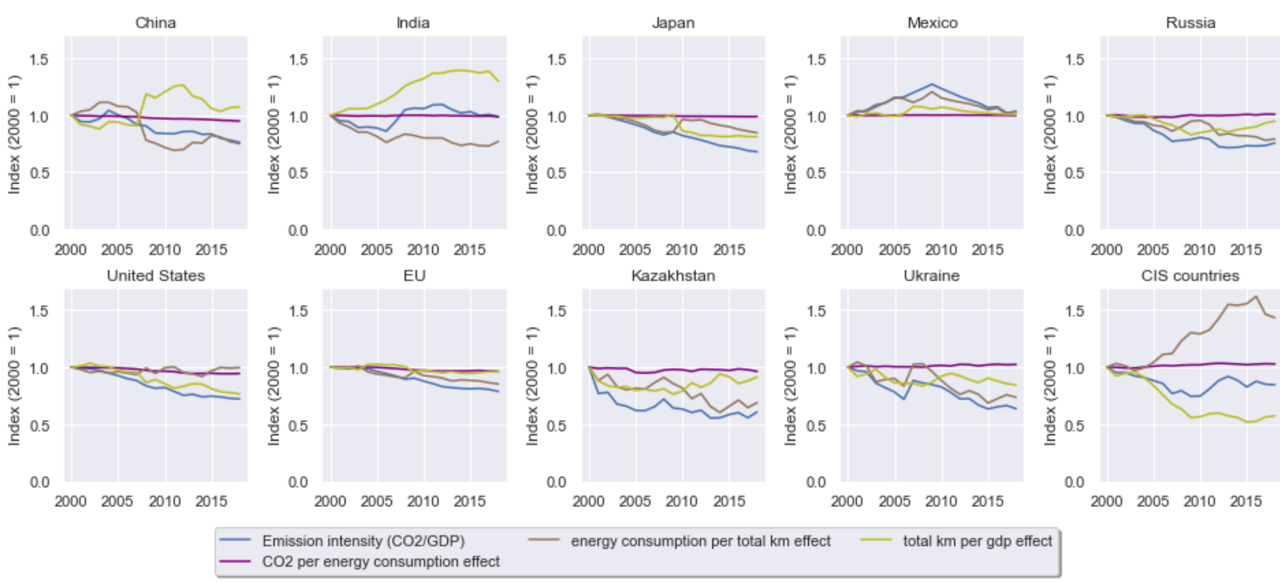


Table 1: Status of the level of decoupling of the link between transport emissions and GDP

country	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	1990-2018
High-income countries																													
Australia	AD	RD	RD	RD	ND	RD	RD	RD	RD	ND	AD	RD	RD	ND	RD	RD	RD	ND	AD	ND	RD	RD	RD	RD	RD	RD	RD	ND	RD
Austria	ND	RD	ND	RD	RD	ND	AD	ND	AD	ND	ND	ND	ND	RD	ND	AD	RD	AD	ND	ND	AD	AD	ND	AD	ND	ND	RD	RD	ND
Bahrain	RD	ND	RD	ND	ND	RD	ND	ND	RD	ND	ND	ND	ND	ND	ND	RD	ND	ND	AD	RD	AD	ND	RD	RD	ND	RD	RD	ND	ND
Belgium	RD	ND	ND	RD	RD	ND	RD	ND	RD	RD	ND	AD	ND	ND	AD	RD	RD	RD	ND	AD	AD	AD	AD	RD	ND	AD	AD	RD	RD
Brunei Darussalam	ND	ND	ND	ND	ND	ND	ND	ND	AD	AD	ND	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	ND	ND
Canada	ND	ND	RD	ND	ND	ND	RD	RD	RD	AD	AD	ND	RD	RD	RD	AD	ND	AD	ND	RD	RD	RD	ND	AD	AD	RD	RD	ND	RD
Chile	RD	RD	ND	ND	RD	ND	RD	ND	ND	RD	AD	ND	AD	RD	ND	AD	ND	ND	ND	RD	RD	RD	ND	AD	ND	ND	ND	RD	RD
Chinese Taipei	RD	ND	ND	RD	RD	RD	RD	ND	RD	RD	ND	RD	AD	RD	RD	AD	AD	AD	ND	RD	RD	AD	AD	RD	ND	ND	AD	AD	RD
Croatia	ND	ND	ND	ND	RD	ND	ND	ND	ND	RD	RD	ND	ND	RD	RD	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	ND
Curacao	ND	ND	ND	ND	ND	RD	RD	ND	RD	RD	ND	ND	RD	ND	ND	RD	RD	RD	ND	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND
Cyprus	AD	ND	ND	RD	RD	ND	ND	RD	RD	RD	RD	AD	ND	ND	RD	AD	ND	RD	ND	ND	AD	ND	ND	ND	ND	RD	RD	RD	RD
Czech Republic	ND	ND	ND	ND	AD	ND	ND	ND	ND	RD	ND	ND	ND	RD	ND	RD	RD	AD	ND	AD	AD	ND	ND	ND	RD	ND	RD	RD	ND
Denmark	ND	AD	ND	RD	RD	RD	RD	RD	RD	AD	RD	ND	ND	ND	RD	RD	ND	ND	ND	AD	AD	AD	AD	RD	ND	RD	RD	RD	RD
Estonia	ND	ND	ND	ND	RD	ND	RD	ND	ND	AD	ND	RD	AD	RD	RD	RD	RD	ND	ND	ND	AD	RD	AD	RD	ND	RD	RD	RD	RD
Finland	ND	ND	ND	ND	AD	AD	RD	RD	RD	AD	RD	RD	RD	RD	RD	RD	RD	AD	ND	ND	AD	ND	ND	ND	AD	ND	AD	ND	AD
France	ND	ND	ND	RD	RD	AD	RD	ND	RD	RD	RD	AD	AD	RD	AD	RD	AD	AD	ND	RD	ND	AD	AD	RD	RD	RD	RD	AD	RD
Germany	RD	RD	ND	AD	RD	RD	RD	RD	ND	AD	AD	ND	ND	AD	AD	AD	AD	RD	ND	RD	RD	AD	ND	RD	ND	RD	RD	AD	AD
Greece	ND	ND	ND	RD	RD	ND	RD	ND	RD	AD	RD	RD	RD	RD	ND	RD	RD	ND	ND	ND	ND	ND	ND	RD	ND	ND	AD	RD	RD
Hong Kong (China)	ND	ND	ND	ND	AD	AD	RD	ND	ND	AD	AD	AD	AD	AD	ND	AD	AD	AD	ND	AD	AD	AD	RD	RD	ND	ND	ND	AD	RD
Hungary	ND	ND	ND	AD	ND	AD	ND	ND	ND	AD	ND	ND	ND	RD	ND	ND	ND	AD	ND	AD	AD	ND	AD	ND	ND	RD	ND	ND	ND
Iceland	ND	ND	AD	ND	ND	ND	AD	RD	RD	RD	RD	ND	RD	RD	ND	ND	RD	AD	ND	ND	AD	AD	RD	RD	RD	ND	ND	RD	RD
Ireland	ND	ND	RD	RD	RD	ND	RD	ND	ND	RD	RD	RD	RD	RD	ND	ND	RD	ND	ND	AD	AD	AD	RD	RD	AD	ND	AD	RD	RD
Israel	RD	ND	ND	ND	ND	ND	ND	AD	ND	RD	AD	ND	ND	AD	AD	RD	RD	ND	AD	RD	AD	ND	AD	RD	ND	RD	RD	RD	RD
Italy	ND	ND	ND	AD	RD	ND	RD	ND	ND	RD	RD	ND	ND	ND	AD	RD	RD	ND	ND	AD	AD	ND	ND	ND	AD	AD	AD	ND	RD
Japan	ND	ND	ND	ND	ND	RD	RD	ND	ND	AD	ND	AD	AD	AD	AD	AD	AD	ND	ND	RD	ND	AD	AD	AD	AD	AD	AD	AD	AD

Note: AD: Absolute decoupling (color-coded: dark green); RD: Relative decoupling (color-coded: light green); ND: No decoupling (color-coded: red). The columns are one-year-interval time periods from 1990 to 2018.

country	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	1990-2018
High-income countries																													
Korea	ND	ND	ND	RD	ND	RD	RD	ND	RD	RD	RD	RD	RD	RD	AD	AD	RD	AD	ND	RD	AD	ND	ND	RD	ND	ND	RD	AD	RD
Kuwait	ND	ND	RD	RD	ND	ND	ND	RD	ND	RD	ND	ND	RD	RD	RD	ND	RD	ND	ND	ND	AD	RD	ND	ND	ND	RD	ND	ND	ND
Latvia	ND	ND	ND	AD	ND	AD	RD	AD	AD	ND	ND	RD	RD	RD	RD	RD	ND	ND	ND	ND	AD	AD	RD	ND	ND	RD	ND	RD	RD
Lithuania	ND	ND	ND	AD	ND	ND	ND	RD	ND	AD	ND	RD	RD	ND	RD	RD	ND	AD	ND	ND	AD	RD	AD	ND	ND	ND	ND	ND	RD
Luxembourg	ND	ND	RD	RD	AD	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND	AD	AD	ND	ND	ND	ND	ND	AD	AD	AD	AD	ND	ND	RD
Malta	ND	RD	ND	ND	ND	AD	ND	AD	AD	AD	AD	AD	ND	ND	ND	ND	RD	ND	ND	ND	AD	AD	RD	RD	RD	AD	RD	ND	RD
Mauritius	RD	ND	ND	RD	AD	AD	AD	RD	ND	RD	RD	ND	RD	RD	ND	RD	AD	RD	ND	ND	RD	RD	RD	RD	RD	ND	RD	RD	RD
Netherlands	RD	ND	ND	AD	RD	ND	RD	RD	RD	RD	RD	ND	ND	RD	RD	RD	AD	RD	ND	ND	RD	ND	ND	AD	RD	RD	RD	RD	RD
New Zealand	ND	ND	RD	ND	ND	RD	RD	ND	RD	ND	RD	RD	RD	RD	RD	RD	RD	ND	AD	AD	RD	AD	RD	RD	RD	RD	ND	RD	RD
Norway	RD	RD	ND	AD	ND	RD	RD	ND	RD	AD	RD	RD	ND	RD	RD	ND	ND	AD	ND	ND	AD	AD	ND	RD	RD	AD	AD	ND	RD
Oman	ND	RD	ND	RD	RD	ND	ND	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND	ND	RD	ND	ND	ND	ND	ND	ND	AD	AD	AD	ND
Panama	RD	RD	ND	ND	ND	ND	ND	ND	ND	RD	AD	ND	ND	RD	ND	RD	AD	ND	ND	RD	RD	RD	AD	ND	ND	ND	RD	AD	RD
Poland	ND	RD	AD	RD	RD	ND	RD	ND	ND	AD	AD	AD	ND	ND	ND	ND	ND	ND	RD	ND	RD	AD	AD	RD	ND	ND	ND	RD	ND
Portugal	ND	ND	ND	ND	RD	ND	RD	ND	ND	ND	RD	ND	ND	ND	AD	AD	RD	RD	ND	AD	ND	ND	ND	RD	RD	ND	RD	RD	ND
Qatar	ND	RD	ND	ND	ND	ND	RD	RD	AD	RD	ND	ND	ND	RD	ND	RD	RD	ND	RD	RD	RD	AD	ND	ND	ND	ND	ND	AD	RD
Romania	ND	ND	AD	ND	AD	ND	ND	ND	ND	RD	ND	RD	ND	RD	AD	RD	RD	ND	ND	ND	RD	ND	AD	RD	RD	ND	RD	RD	RD
Saudi Arabia	RD	ND	ND	ND	AD	ND	ND	RD	ND	RD	ND	ND	RD	RD	RD	ND	ND	ND	ND	RD	ND	ND	RD	ND	ND	AD	ND	AD	ND
Singapore	ND	AD	AD	RD	ND	AD	AD	ND	RD	RD	ND	AD	RD	RD	RD	RD	RD	ND	ND	RD	ND	AD	AD	RD	ND	AD	AD	AD	RD
Slovak Republic	ND	ND	AD	ND	ND	AD	ND	RD	ND	AD	ND	ND	AD	RD	ND	AD	RD	ND	ND	ND	AD	AD	RD	AD	AD	ND	ND	AD	RD
Slovenia	ND	ND	ND	ND	ND	ND	RD	AD	AD	AD	ND	RD	RD	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND	RD	AD	ND	RD	AD	ND
Spain	ND	ND	ND	ND	RD	ND	AD	ND	ND	RD	ND	RD	ND	ND	RD	RD	RD	AD	ND	AD	ND	ND	ND	RD	RD	ND	ND	RD	RD
Sweden	ND	ND	ND	RD	RD	AD	RD	RD	RD	RD	AD	RD	RD	RD	AD	RD	RD	ND	ND	RD	AD	ND	AD	AD	RD	AD	AD	AD	AD
Switzerland	ND	ND	ND	ND	AD	RD	ND	RD	AD	ND	AD	RD	ND	RD	RD	RD	RD	ND	ND	AD	AD	RD	AD	AD	AD	AD	AD	RD	RD
Trinidad and Tobago	ND	AD	ND	ND	ND	RD	ND	RD	RD	RD	RD	RD	AD	ND	RD	ND	ND	ND	ND	ND	ND	AD	AD	ND	RD	ND	ND	ND	RD
United Arab Emirates	ND	RD	ND	AD	RD	RD	AD	AD	ND	RD	ND	ND	ND	RD	ND	RD	RD	ND	ND	ND	RD	RD	ND	RD	AD	ND	ND	AD	ND
United Kingdom	ND	ND	RD	RD	AD	ND	RD	AD	RD	AD	AD	RD	RD	RD	RD	RD	RD	ND	ND	AD	AD	AD	AD	RD	ND	ND	RD	AD	RD
United States	ND	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	RD	AD	RD	ND	ND	ND	AD	AD	ND	AD	ND	RD	RD	RD	RD
Uruguay	ND	RD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	ND	RD	ND	ND	RD	ND	RD	RD	RD	ND	AD	ND	ND	ND	AD	ND

Country	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	1990-2018
Upper-middle-income countries																													
Albania	ND	ND	ND	ND	AD	AD	ND	ND	ND	RD	RD	ND	ND	ND	RD	AD	ND	ND	RD	AD	ND	AD	ND	RD	AD	AD	RD	AD	ND
Argentina	RD	RD	RD	AD	ND	ND	AD	ND	ND	ND	ND	ND	RD	RD	RD	RD	RD	ND	ND	RD	RD	ND	ND	ND	ND	ND	RD	ND	RD
Armenia	ND	ND	ND	AD	AD	AD	ND	RD	ND	ND	AD	AD	RD	RD	RD	AD	ND	ND	ND	ND	RD	RD	AD	ND	AD	AD	RD	ND	AD
Azerbaijan	ND	ND	ND	ND	ND	AD	ND	AD	AD	ND	ND	ND	RD	ND	RD	RD	AD	ND	AD	ND	ND	ND	ND	ND	AD	ND	ND	ND	RD
Belarus	ND	ND	ND	ND	ND	ND	RD	RD	AD	AD	AD	ND	RD	RD	ND	ND	RD	ND	AD	RD	ND	ND	ND	AD	ND	ND	ND	ND	RD
Bolivarian Republic of Venezuela	RD	AD	ND	ND	RD	ND	AD	ND	ND	RD	ND	ND	ND	RD	ND	RD	RD	RD	ND	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND
Bosnia and Herzegovina	ND	ND	ND	ND	RD	RD	RD	ND	AD	ND	RD	AD	RD	ND	AD	ND	RD	ND	ND	AD	RD	ND	AD	ND	ND	ND	ND	AD	RD
Botswana	ND	ND	AD	AD	ND	RD	RD	ND	RD	ND	ND	AD	ND	ND	RD	RD	RD	ND	ND	RD	RD	RD	RD	RD	ND	ND	RD	RD	ND
Brazil	ND	ND	RD	RD	ND	ND	ND	ND	AD	RD	ND	RD	AD	ND	RD	RD	RD	RD	ND	ND	ND	ND	ND	ND	ND	ND	RD	AD	ND
Bulgaria	ND	ND	ND	AD	ND	AD	ND	ND	ND	AD	RD	RD	ND	ND	ND	RD	AD	RD	ND	AD	ND	ND	AD	ND	ND	RD	RD	RD	RD
Colombia	ND	ND	RD	AD	ND	ND	ND	AD	ND	AD	ND	AD	RD	ND	AD	RD	RD	RD	AD	RD	ND	ND	AD	RD	ND	ND	AD	RD	RD
Costa Rica	ND	ND	RD	ND	AD	RD	RD	ND	RD	AD	ND	ND	RD	ND	AD	RD	RD	RD	ND	RD	RD	RD	RD	RD	ND	ND	RD	RD	ND
Cuba	ND	ND	ND	AD	ND	ND	ND	AD	AD	AD	RD	AD	AD	RD	AD	AD	RD	AD	AD	AD	AD	AD	ND	ND	ND	AD	ND	ND	AD
Dominican Republic	AD	RD	ND	ND	ND	ND	ND	ND	ND	RD	RD	ND	ND	ND	RD	RD	RD	AD	ND	RD	ND	ND	AD	AD	ND	ND	AD	ND	RD
Ecuador	RD	RD	RD	ND	AD	ND	ND	AD	ND	AD	ND	RD	ND	RD	RD	RD	AD	AD	ND	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND
Equatorial Guinea	ND	ND	AD	AD	ND	ND	RD	AD	ND	ND	AD	ND	ND	RD	RD	ND	RD	RD	RD	ND	RD	RD	ND	ND	ND	ND	ND	ND	RD
Gabon	ND	ND	ND	AD	ND	RD	ND	ND	ND	ND	ND	ND	AD	ND	AD	ND	ND	ND	ND	ND	ND	RD	ND	AD	AD	ND	AD	ND	AD
Georgia	ND	ND	ND	ND	AD	ND	AD	AD	AD	AD	ND	RD	RD	AD	ND	RD	ND	AD	ND	RD	RD	RD	ND	ND	ND	ND	AD	AD	ND
Guatemala	ND	RD	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND	AD	AD	ND	RD	RD	AD	ND	AD	AD	RD	ND	ND	ND	ND	ND	ND	ND
Indonesia	ND	RD	ND	ND	ND	ND	ND	ND	AD	ND	ND	RD	RD	RD	AD	AD	RD	ND	ND	ND	ND	ND	RD	RD	AD	ND	ND	ND	ND
Iraq	ND	RD	RD	RD	AD	AD	AD	RD	RD	ND	ND	ND	ND	RD	ND	AD	AD	AD	RD	ND	ND	RD	AD	AD	AD	RD	ND	ND	RD
Islamic Republic of Iran	RD	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	RD	ND	ND	ND	AD	ND	ND	AD	RD	ND	ND	ND	ND	AD	RD	ND	ND

country	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	1990-2018
Upper-middle-income countries																													
Jamaica	AD	ND	RD	RD	ND	ND	ND	ND	ND	RD	AD	ND	AD	ND	ND	AD	AD	ND	ND	ND	AD	ND	ND	ND	AD	ND	ND	ND	ND
Jordan	AD	RD	RD	RD	ND	RD	ND	RD	RD	ND	RD	RD	RD	ND	ND	AD	RD	AD	ND	RD	RD	ND	ND	AD	ND	ND	ND	AD	RD
Kazakhstan	ND	ND	ND	ND	ND	AD	AD	ND	AD	ND	AD	ND	AD	RD	RD	RD	ND	ND	AD	RD	RD	ND	AD	ND	ND	ND	AD	ND	RD
Kosovo										ND	RD	ND	RD	ND	RD	ND	RD	ND	ND	AD	RD	RD	AD	ND	ND	ND	ND	ND	ND
Lebanon	RD	ND	ND	AD	ND	RD	AD	ND	ND	AD	AD	RD	ND	RD	RD	AD	AD	ND	ND	AD	RD	ND	AD	ND	ND	ND	ND	AD	RD
Libya	RD	ND	ND	ND	ND	ND	ND	ND	ND	RD	ND	ND	RD	RD	RD	RD	AD	ND	ND	ND	ND	RD	ND	ND	ND	ND	AD	AD	ND
Malaysia	RD	RD	RD	ND	RD	ND	ND	ND	ND	RD	ND	RD	ND	ND	AD	AD	ND	ND	ND	RD	RD	AD	ND	ND	AD	RD	AD	RD	RD
Mexico	ND	RD	RD	ND	ND	RD	RD	RD	ND	RD	ND	ND	ND	ND	ND	ND	ND	ND	ND	RD	RD	RD	AD	RD	AD	ND	AD	ND	RD
Montenegro															ND	AD	ND	RD	ND	ND	AD	ND	AD	AD	ND	ND	ND	ND	ND
Namibia	ND	ND	ND	ND	ND	ND	RD	ND	RD	AD	ND	AD	ND	RD	ND	AD	RD	ND	ND	RD	RD	AD	ND	RD	ND	RD	ND	ND	ND
Paraguay	AD	ND	ND	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND	AD	AD	ND	ND	RD	ND	ND	ND	ND	RD	ND	ND	ND	ND	ND	ND
People's Republic of China	RD	RD	RD	AD	RD	ND	AD	AD	ND	ND	RD	RD	ND	ND	RD	RD	RD	RD	RD	RD	RD	ND	ND	RD	ND	RD	RD	RD	RD
Peru	AD	ND	RD	ND	ND	ND	RD	ND	ND	AD	AD	AD	ND	ND	AD	RD	RD	ND	ND	ND	RD	RD	ND	AD	ND	ND	RD	RD	RD
Republic of North Macedonia	ND	ND	ND	ND	ND	ND	AD	AD	ND	AD	ND	ND	RD	RD	RD	RD	ND	RD	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	ND
Russian Federation	ND	ND	ND	ND	ND	ND	AD	ND	RD	AD	RD	RD	RD	RD	AD	RD	RD	ND	ND	ND	RD	AD	RD	ND	ND	AD	ND	ND	AD
Serbia	ND	ND	ND	AD	RD	ND	ND	AD	ND	AD	ND	ND	ND	ND	RD	ND	AD	ND	ND	RD	AD	ND	ND	ND	AD	RD	ND	RD	RD
South Africa	ND	ND	RD	ND	ND	AD	ND	AD	RD	AD	RD	RD	ND	ND	RD	RD	ND	AD	ND	ND	ND	RD	ND	AD	ND	AD	ND	RD	RD
Suriname										ND	RD	ND	ND	RD	ND	ND	RD	ND	RD	ND	AD	ND	AD	ND	ND	ND	AD	RD	ND
Thailand	RD	RD	ND	ND	ND	ND	ND	ND	RD	AD	RD	RD	RD	ND	AD	AD	ND	AD	ND	RD	ND	RD	AD	AD	ND	ND	ND	RD	RD
Turkey	AD	RD	ND	ND	ND	RD	AD	AD	ND	RD	ND	RD	RD	RD	RD	ND	ND	AD	ND	AD	RD	ND	ND	ND	ND	ND	RD	RD	RD
Turkmenistan	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	RD	ND	ND	RD	RD	AD	RD	RD	AD	ND	ND	RD	RD	RD	ND	ND	ND	ND	RD

country	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	1990-2018
Lower-middle-income countries																													
Algeria	ND	AD	ND	ND	AD	AD	RD	RD	ND	RD	RD	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	AD	ND	ND
Angola	ND	ND	ND	ND	AD	AD	RD	AD	ND	AD	ND	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND	AD	ND	RD	RD	ND	ND	ND	ND
Bangladesh	ND	ND	RD	RD	ND	ND	ND	RD	AD	AD	ND	RD	RD	ND	ND	RD	RD	ND	ND	ND	ND	RD	AD	ND	RD	RD	ND	ND	ND
Benin	AD	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	RD	ND	ND	ND	RD	ND	ND	ND	RD	ND	RD	ND	ND	RD	ND	ND
Cambodia					ND	RD	RD	ND	AD	AD	ND	AD	RD	RD	RD	RD	ND	RD	ND	ND	RD	RD	RD	ND	ND	ND	RD	ND	ND
Cameroon	ND	ND	ND	ND	AD	RD	ND	RD	AD	ND	RD	ND	RD	RD	AD	AD	ND	RD	ND	ND	RD	RD	RD	ND	AD	RD	AD	AD	RD
Cote d'ivoire	AD	ND	ND	AD	ND	RD	ND	AD	ND	ND	AD	ND	ND	ND	ND	ND	RD	ND	RD	AD	ND	ND	RD	RD	ND	ND	AD	ND	ND
Egypt	ND	RD	ND	ND	ND	ND	ND	ND	ND	RD	AD	ND	ND	RD	AD	ND	ND	RD	ND	ND	ND	ND	RD	ND	RD	ND	AD	AD	ND
El Salvador	ND	ND	ND	ND	ND	AD	RD	ND	ND	AD	RD	AD	ND	ND	ND	AD	ND	AD	ND	AD	RD	AD	RD	RD	ND	ND	AD	ND	ND
Ghana	AD	ND	RD	ND	ND	ND	ND	ND	ND	AD	AD	ND	AD	ND	AD	RD	ND	RD	ND	RD	RD	ND	RD	RD	ND	AD	AD	ND	ND
Honduras	ND	ND	ND	ND	RD	AD	ND	ND	ND	AD	ND	RD	RD	RD	AD	AD	ND	AD	ND	RD	RD	RD	AD	ND	ND	RD	AD	ND	ND
India	ND	RD	RD	RD	ND	RD	RD	RD	RD	RD	AD	RD	RD	ND	RD	RD	ND	ND	ND	RD	ND	ND	RD	RD	ND	RD	ND	RD	RD
Kenya	ND	ND	AD	AD	ND	ND	AD	RD	AD	ND	AD	ND	AD	ND	RD	ND	RD	ND	ND	ND	AD	ND	ND	ND	ND	ND	AD	ND	ND
Kyrgyzstan	ND	ND	ND	ND	ND	RD	RD	AD	AD	AD	RD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	RD	AD	AD	ND	AD	AD	AD
Lao People's Democratic Republic										ND	ND	RD	RD	RD	RD	RD	ND	ND	ND	RD	AD	ND	ND	ND	RD	ND	RD	RD	ND
Mongolia	ND	ND	ND	AD	ND	ND	AD	AD	ND	ND	AD	ND	AD	ND	AD	ND	ND	RD	ND	AD	ND	ND	AD	RD	RD	AD	ND	RD	RD
Morocco	ND	ND	ND	RD	ND	RD	ND	RD	ND	ND	RD	ND	RD	RD	ND	RD	ND	ND	ND	ND	ND	RD	RD	RD	ND	ND	RD	ND	ND
Myanmar	ND	AD	ND	ND	ND	ND	AD	ND	RD	ND	AD	ND	RD	RD	RD	AD	RD	AD	RD	RD	RD	ND	ND	ND	ND	RD	ND	RD	RD
Nepal	ND	ND	ND	ND	ND	RD	ND	ND	RD	ND	AD	ND	AD	ND	AD	ND	RD	ND	ND	ND	RD	ND	ND	ND	AD	ND	ND	ND	ND
Nicaragua	ND	ND	ND	ND	ND	RD	ND	ND	RD	RD	RD	ND	AD	AD	AD	RD	RD	AD	ND	RD	RD	RD	AD	ND	ND	RD	ND	ND	ND
Nigeria	ND	ND	ND	ND	ND	ND	ND	AD	ND	ND	ND	RD	RD	RD	AD	AD	AD	ND	AD	ND	ND	ND	ND	ND	AD	ND	RD	ND	ND
Pakistan	RD	ND	ND	ND	RD	ND	ND	ND	ND	AD	AD	RD	ND	ND	AD	RD	ND	AD	RD	ND	ND	RD	RD	ND	ND	ND	ND	RD	ND
Philippines	ND	ND	ND	ND	ND	ND	ND	ND	AD	AD	ND	RD	AD	RD	AD	AD	AD	RD	ND	RD	AD	RD	RD	RD	ND	ND	RD	RD	RD
Plurinational State of Bolivia	RD	AD	ND	RD	ND	RD	AD	RD	RD	AD	AD	RD	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND	ND	ND	RD	RD	ND	ND	ND
Republic of Moldova	ND	ND	ND	ND	ND	ND	AD	ND	ND	AD	RD	ND	ND	ND	AD	RD	ND	ND	ND	ND	ND	ND	RD	RD	ND	ND	RD	RD	AD
Republic of the Congo	ND	AD	ND	ND	ND	AD	ND	ND	ND	ND	ND	AD	ND	ND	RD	ND	ND	ND	ND	ND	ND	AD	ND	RD	AD	ND	ND	ND	ND
Senegal	ND	ND	AD	ND	RD	ND	ND	ND	ND	ND	AD	ND	ND	ND	AD	ND	ND	ND	AD	ND	ND	AD	ND	RD	ND	ND	AD	RD	ND
Sri Lanka	RD	ND	ND	ND	ND	ND	AD	RD	ND	AD	ND	RD	ND	RD	ND	AD	ND	AD	AD	ND	RD	AD	ND	ND	ND	ND	ND	AD	RD

country	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	1990-2018
Lower-middle-income countries																													
Tunisia	RD	RD	ND	ND	ND	RD	ND	RD	ND	RD	RD	ND	RD	RD	ND	AD	RD	AD	ND	ND	ND	AD	AD	ND	ND	ND	ND	RD	ND
Ukraine	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	RD	RD	AD	RD	AD	AD	ND	AD	ND	RD	AD	AD	ND	ND	ND	ND	ND	AD	ND
United Republic of Tanzania	AD	ND	ND	ND	ND	ND	AD	ND	AD	ND	ND	ND	RD	RD	ND	RD	AD	ND	AD	ND	ND	ND	ND	AD	RD	AD	RD	RD	ND
Uzbekistan	ND	ND	ND	ND	ND	ND	RD	ND	RD	ND	RD	AD	AD	AD	RD	RD	AD	RD	AD	RD	AD	AD	AD	AD	AD	AD	ND	ND	RD
Viet Nam	AD	ND	ND	ND	AD	ND	ND	RD	ND	ND	ND	ND	ND	ND	RD	AD	ND	ND	ND	ND	AD	AD	AD	RD	ND	ND	RD	AD	ND
Zambia	ND	ND	AD	ND	AD	AD	ND	ND	AD	ND	RD	ND	RD	RD	RD	RD	AD	ND	ND	RD	ND	ND	RD	ND	ND	AD	AD	AD	RD
Zimbabwe	AD	ND	AD	AD	ND	AD	RD	AD	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	RD	ND	RD	ND	AD	AD	AD	RD	ND	ND
Low-income countries																													
Democratic People's Republic of Korea	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	ND	ND	ND	ND	ND	AD	ND	AD	ND	ND	AD	AD	ND
Democratic Republic of the Congo	ND	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	AD	ND	ND	AD	ND	ND	AD	AD	ND	AD	ND
Eritrea		ND	ND	ND	ND	ND	AD	AD	ND	ND	ND	ND	ND	AD	AD	ND	AD	ND	RD	ND	ND	ND	RD	RD	RD	ND	ND	ND	ND
Ethiopia	ND	ND	ND	ND	ND	RD	ND	ND	RD	ND	ND	ND	ND	RD	AD	RD	RD	RD	RD	RD	RD	ND	ND	ND	ND	ND	ND	ND	ND
Haiti	AD	ND	ND	ND	ND	ND	RD	ND	ND	ND	ND	ND	ND	ND	RD	RD	ND	AD	RD	ND	RD	AD	AD	ND	ND	RD	ND	RD	ND
Mozambique	AD	ND	ND	AD	ND	RD	RD	RD	RD	RD	AD	RD	ND	RD	AD	RD	ND	AD	ND	ND	ND	AD	ND	ND	ND	RD	ND	ND	RD
Niger										ND	RD	RD	ND	ND	RD	RD	ND	RD	ND	ND	AD	ND	ND	RD	RD	AD	RD	ND	ND
South Sudan																						ND	AD	ND	ND	ND	ND	ND	ND
Sudan	AD	AD	AD	ND	AD	AD	ND	AD	AD	ND	ND	ND	AD	ND	ND	ND	RD	ND	AD	ND	ND	AD	ND	ND	ND	ND	AD	ND	RD
Syrian Arab Republic	RD	AD	RD	RD	AD	ND	ND	RD	ND	ND	AD	ND	ND	ND	ND	ND	ND	RD	AD	AD	ND	AD	AD	ND	ND	ND	ND	ND	AD
Tajikistan	ND	ND	ND	ND	ND	ND	ND	AD	AD	AD	ND	ND	AD	ND	AD	ND	ND	AD	AD	ND	RD	ND	RD	ND	AD	AD	AD	RD	ND
Togo	ND	ND	ND	ND	ND	ND	AD	ND	ND	ND	ND	ND	ND	AD	AD	AD	ND	ND	ND	AD	AD	AD	AD	AD	ND	AD	ND	ND	RD
Yemen	ND	RD	AD	RD	AD	AD	RD	ND	ND	AD	ND	AD	ND	RD	ND	AD	AD	ND	ND	AD	ND	AD	ND	ND	ND	ND	ND	ND	AD

Note: AD: Absolute decoupling (color-coded: dark green); RD: Relative decoupling (color-coded: light green); ND: No decoupling (color-coded: red). The columns are one-year-interval time periods from 1990 to 2018.

Table 2 Correlates of transport-related carbon emissions per capita

	(1)	(2)	(3)	(4)
	OLS	Random Effects	Fixed Effects	GMM
GDP per capita	5.55e-08**	5.53e-08**	5.53e-08**	4.79e-08*
	(1.72e-08)	(1.94e-08)	(1.94e-08)	(1.99e-08)
GDP pc sq	-2.01e-15*	-1.38e-15	-1.38e-15	-1.38e-15*
	(1.00e-15)	(7.39e-16)	(7.39e-16)	(6.86e-16)
Agriculture	-0.0597***	-0.0238***	-0.0238***	-0.0143***
	(0.00228)	(0.00165)	(0.00165)	(0.00131)
Manufacturing	0.00338	0.00232	0.00232	-0.00321*
	(0.00212)	(0.00160)	(0.00160)	(0.00137)
Service	0.00942***	-0.00140	-0.00140	-0.00151
	(0.00157)	(0.00111)	(0.00111)	(0.000775)
Urbanization	0.0317***	0.0765***	0.0765***	0.0211***
	(0.00377)	(0.00457)	(0.00457)	(0.00385)
Urbanization sq	-0.0000710*	-0.000574***	-0.000574***	-0.000183***
	(0.0000290)	(0.0000373)	(0.0000373)	(0.0000324)
Diesel price	1.087***	-0.102*	-0.102*	-0.0632*
	(0.0856)	(0.0404)	(0.0404)	(0.0254)
Gasoline price	-1.218***	-0.0528	-0.0528	-0.00659
	(0.0843)	(0.0403)	(0.0403)	(0.0257)
BRT	0.0383	-0.0720***	-0.0720***	-0.00156
	(0.0384)	(0.0190)	(0.0190)	(0.0175)
L.co2pc				0.723***
				(0.0170)
Obs.	2816	2816	2816	2689
Year fixed effects	Yes	Yes	Yes	Yes

Standard errors in parentheses
="* p<0.05 ** p<0.01 *** p<0.001"

Table 3 Correlates of transport-related carbon emissions per capita (with transport policy)

	(1)	(2)	(3)	(4)
	OLS	Random Effects	Fixed Effects	GMM
Log GDP per capita	-8.51e-08***	9.31e-08***	13.0e-08***	2.89e-08***
	(1.55e-08)	(1.41e-08)	(1.50e-08)	(7.55e-09)
Log GDP pc sq	3.88e-15***	-2.39e-15***	-3.13e-15***	-8.21e-16***
	(8.10e-16)	(4.60e-16)	(4.68e-16)	(2.32e-16)
Agriculture	-0.103***	-0.0436***	-0.0351***	-0.0128***
	(0.00566)	(0.00467)	(0.00474)	(0.00234)
Manufacturing	-0.00213	-0.00262	-0.00240	-0.000847
	(0.00302)	(0.00152)	(0.00148)	(0.000719)
Service	0.0149***	-0.000240	-0.000670	-0.00358***
	(0.00281)	(0.00175)	(0.00170)	(0.000829)
Urbanization	0.0321***	0.0777***	0.0574***	0.00889
	(0.00739)	(0.00874)	(0.00951)	(0.00471)
Urbanization sq	-0.000151**	-0.000487***	-0.000403***	-0.0000593
	(0.0000525)	(0.0000601)	(0.0000637)	(0.0000316)
Log diesel price	0.290**	-0.00163	-0.0309	-0.0268
	(0.101)	(0.0465)	(0.0452)	(0.0220)
Log gasoline price	-0.677***	-0.167***	-0.141***	-0.0349
	(0.0955)	(0.0391)	(0.0378)	(0.0184)
Transportation policy	0.117***	-0.0812***	-0.0898***	-0.0105**
	(0.0214)	(0.00769)	(0.00746)	(0.00393)
BRT	-0.128***	0.00421	0.0126	-0.00119
	(0.0352)	(0.0148)	(0.0142)	(0.00692)
L.ln_co2pc				0.820***
				(0.0157)
Observations	1010	1010	1010	936
Year fixed effects	Yes	Yes	Yes	Yes

Note: Standard errors in parentheses

* p<0.05 ** p<0.01 *** p<0.001

Appendix

Table A1: List of countries included in the study

Albania	Cyprus	Ireland	Netherlands	Spain
Algeria	Czech Republic	Iran, Islamic Rep.	New Zealand	Sri Lanka
Angola	Korea, Dem. People’s Rep.	Israel	Nicaragua	Sudan
Argentina	Congo, Dem. Rep.	Italy	Niger	Suriname
Armenia	Denmark	Jamaica	Nigeria	Sweden
Australia	Dominican Republic	Japan	Norway	Switzerland
Austria	Ecuador	Jordan	Oman	Syrian Arab Republic
Azerbaijan	Egypt, Arab Rep.	Kazakhstan	Pakistan	Tajikistan
Bahrain	El Salvador	Kenya	Panama	Thailand
Bangladesh	Equatorial Guinea	Korea	Paraguay	Togo
Belarus	Eritrea	Kosovo	China	Trinidad and Tobago
Belgium	Estonia	Kuwait	Peru	Tunisia
Benin	Ethiopia	Kyrgyzstan	Philippines	Turkey
Venezuela, RB	Finland	Lao PDR	Bolivia	Turkmenistan
Bosnia and Herzegovina	France	Latvia	Poland	Ukraine
Botswana	Gabon	Lebanon	Portugal	United Arab Emirates
Brazil	Georgia	Libya	Qatar	United Kingdom
Brunei Darussalam	Germany	Lithuania	Moldova	Tanzania
Bulgaria	Ghana	Luxembourg	North Macedonia	United States
Cambodia	Gibraltar	Malaysia	Congo, Rep.	Uruguay
Cameroon	Greece	Malta	Romania	Uzbekistan
Canada	Guatemala	Mauritius	Russian Federation	Vietnam
Chile	Haiti	Mexico	Saudi Arabia	Yemen, Rep.
Chinese Taipei	Honduras	Mongolia	Senegal	Zambia
Colombia	Hong Kong SAR, China	Montenegro	Serbia	Zimbabwe
Costa Rica	Hungary	Morocco	Singapore	
Côte d'Ivoire	Iceland	Mozambique	Slovak Republic	
Croatia	India	Myanmar	Slovenia	
Cuba	Indonesia	Namibia	South Africa	
Curacao	Iraq	Nepal	South Sudan	

Table A2: List of subset of countries

Argentina	Denmark	Kazakhstan	North Macedonia	Turkey
Armenia	Ecuador	Kenya	Norway	Ukraine
Australia	Estonia	Korea, Rep.	Pakistan	United Kingdom
Austria	Finland	Kyrgyzstan	Peru	United States
Azerbaijan	France	Latvia	Poland	Vietnam
Belarus	Georgia	Lithuania	Portugal	
Belgium	Germany	Luxembourg	Romania	
Bosnia and Herzegovina	Greece	Mexico	Russian Federation	
Bulgaria	Hungary	Moldova	Serbia	
Canada	Iceland	Mongolia	Slovak Republic	
Chile	India	Montenegro	Slovenia	
China	Ireland	Morocco	Spain	
Croatia	Israel	Myanmar	Sweden	
Cuba	Italy	Netherlands	Switzerland	
Czech Republic	Japan	New Zealand	Tunisia	

Table A3: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Log CO2 per capita	3,915	-0.4257	1.311756	-4.96185	2.755506
Log GDP per capita	3,828	9.361465	1.136264	6.154889	11.81192
Squared log GDP pc	3,828	88.92779	20.96595	37.88266	139.5214
Agriculture va	3,554	10.68645	10.43098	0.028407	63.83134
Manufacturing va	3,394	14.53169	6.285805	0	50.03699
Service va	3,454	52.31527	11.73463	10.56928	91.92164
Urbanization	3,915	61.91061	20.78944	8.854	100
Log diesel price	3,120	-0.55517	0.869384	-4.60517	0.854415
Log gasoline price	3,125	-0.3038	0.714075	-3.91202	0.932164
Existence of BRT	3,886	0.147967	0.355113	0	1
Existence of Metro	3,886	0.348945	0.476698	0	1

Figure A1: Global transport emissions by mode (1990-2018)

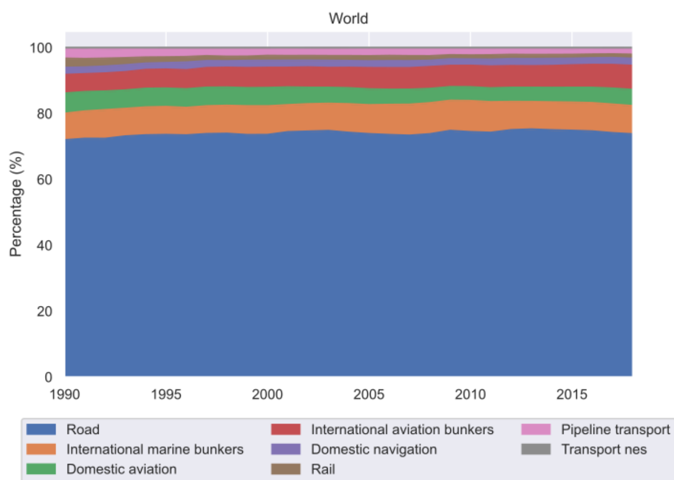


Figure A2: Trends in transport carbon emissions by regions (1990 – 2018)

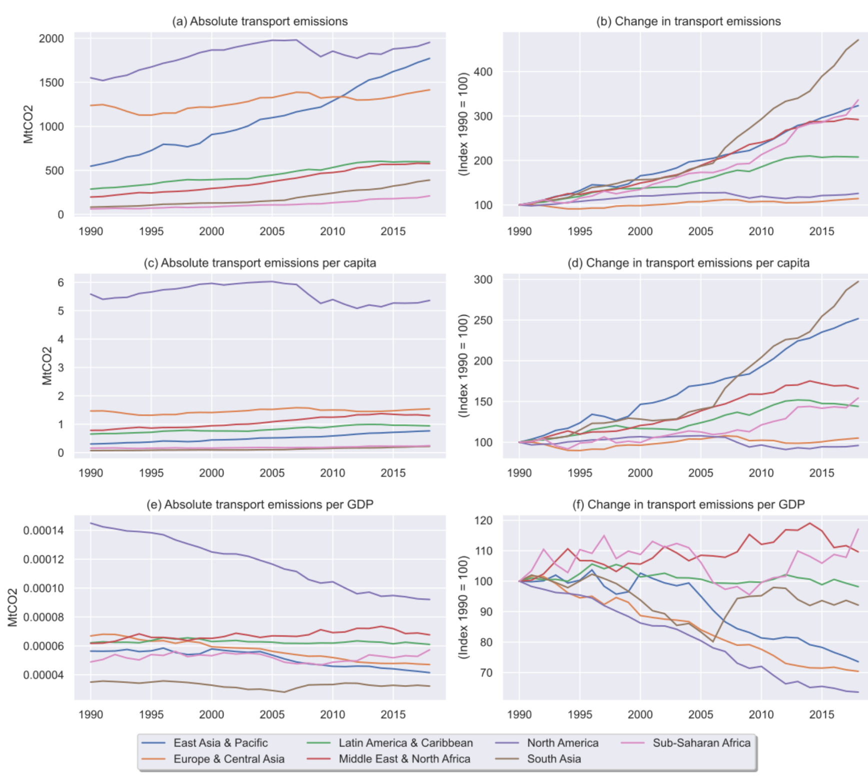
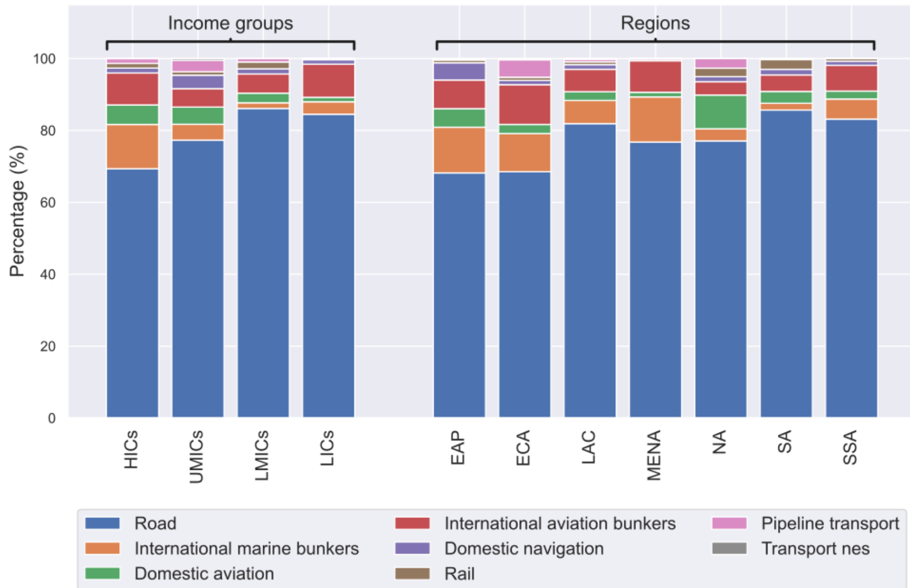


Figure A3: Transport emissions by mode by income groups and regions, 2018


Income groups
Regions
Percentage (%)
0
20
40
60
80
100
HICs
UMICs
LMICs
LICs
EAP
ECA
LAC
MENA
NA
SA
SSA
Road
International marine bunkers
Domestic aviation
International aviation bunkers
Domestic navigation
Rail
Pipeline transport
Transport nes