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Citation for published version:
Kiwan, B & Kalib, NS 2022, 'A review on the method for investigating carbon dioxide emissions in ASEAN', *IOP Conference Series: Earth and Environmental Science*, vol. 1074, 012012. https://doi.org/10.1088/1755-1315/1074/1/012012

Digital Object Identifier (DOI):
10.1088/1755-1315/1074/1/012012

Link:
Link to publication record in Heriot-Watt Research Portal

Document Version:
Publisher's PDF, also known as Version of record

Published In:
IOP Conference Series: Earth and Environmental Science

IOP Conference Series: Earth and Environmental Science

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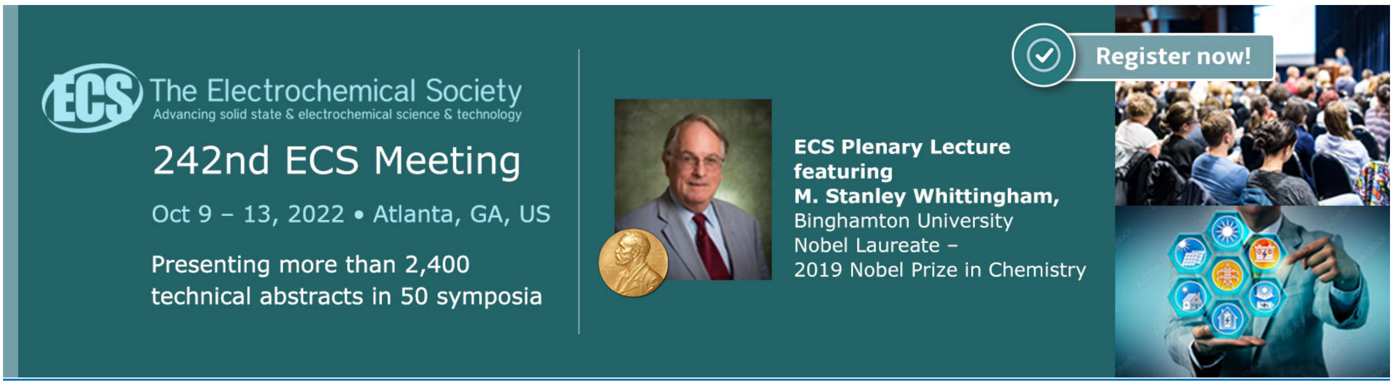
To cite this article: B Kiwan and N S Kalib 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1074** 012012



A review on the method for investigating carbon dioxide emissions in ASEAN

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Abstract. In the past, there was a strong positive correlation between gross domestic product (GDP) per capita and carbon dioxide (CO2) emissions worldwide. However, as the effects of climate change become more pronounced, particularly in ASEAN, it is crucial to assess the relationship between these two indicators. This paper provides a comprehensive overview of the applications of standard analyses: (i) decoupling and (ii) decomposition, which are applied to assess the relationship between the two indicators within ASEAN during 2017-2020. Malaysia, Thailand, the Philippines, Indonesia, and Vietnam were selected and studied as these five ASEAN sovereign states constitute Tiger Cub economies that reflect the geographical diversity of ASEAN. Two analyses were deemed necessary for the methodology of this study: (i) decoupling and (ii) decomposition. The Tapio model was found to be optimal for the decoupling analysis due to its sensitivity to GDP growth in classification. For decomposition, it was also found that the Kaya identity followed by the additive LMDI-I was recommended for decomposition, mainly because it provides physical values as opposed to indices. The methodology described would create a comprehensive database of selected decoupling and decomposition indicators for benchmarking amongst ASEAN sovereign states with these considerations and recommendations.

Keywords: CO_2 emission, Kaya identity, LMDI decomposition, Tapio decoupling, energy sector

1. Introduction

Since its emergence in the 1970s, the East Asia Miracle has been an object of intense scrutiny amongst analysts – such as in Joe Studwell's book 'How Asia Works' [1] and Joseph E. Stiglitz's essay '*Some Lessons from the East Asia Miracle*'[2]. What draws analysts to this phenomenon is the sustained high rates of increase of the gross domestic product (GDP) of many sovereign states of East Asia – including those in South-East Asia (ASEAN), caused by a general shift of labour from agriculture to manufacturing [3]. This phenomenon is the latest in many similar periods of the sustained high rates of GDP growth across the globe, as part of the general economic expansion and development after the Second World War. Even so, in these periods of GDP growth, global carbon dioxide (CO_2) emissions have been observed to increase sharply [4]. Therefore, a relationship between GDP increase and CO_2 emissions increase could be surmised.

However, the Glasgow Climate Pact [5] warns against ignoring such a relationship. It states that *'rapid, deep, and sustained reductions'* in global carbon dioxide emissions towards net zero emissions in 2050 are required to limit global warming to 1.5 °C. In the case of ASEAN, which '*will be one of the world's most vulnerable regions to climate change unless countries make dramatic cuts in greenhouse gas pollution*' [6], an unmitigated increase in CO_2 emissions threaten the economies ASEAN sovereign states, as resources would have to be diverted away from development, towards fire-fighting the impact of climate change. At the same time, the Glasgow Climate Pact also recognises that this reduction in CO_2 emissions needs to reflect *'common but differentiated responsibilities and respective capabilities in the light of different national circumstances and in the context of sustainable development and efforts to eradicate poverty*.' [5]. Therefore, to facilitate this effort to balance environmental sustainability with economic development, this paper aims to provide a comprehensive overview of two types of analyses used to assess the causal link between GDP growth and CO_2 emissions, namely (i) decoupling and (ii) decomposition analyses. From this overview, a standard methodology is proposed for use within ASEAN. The output from this standard methodology would be able to inform future national policies that in turn leads to a decoupling of CO_2 emissions from GDP growth – thereby contributing to sustainable growth in ASEAN and manifesting a paradigm shift in global human development towards mitigating and adapting to climate change.

2. Literature review

Decoupling and decomposition analyses have been identified as quantitative tools that make up this methodology to further study the link between growth in GDP and CO_2 emissions in ASEAN. This is so as it is important to assess CO_2 emissions at both the macro and micro levels, respectively - thereby providing the full gamut of data needed for ASEAN sovereign states to evaluate their current national policies and propose new ones with respect to CO_2 emissions and GDP growth.

A decoupling analysis is used to indicate how positively correlated economic growth is compared to environmental pressure. Organisation for Economic Co-operation and Development (OECD) [7], has enumerated 31 different decoupling indicators, amongst which that indicating total CO_2 emissions per unit of GDP and per capita has been found to be robust, conceptually sound and has available data from sovereign states from at least 1990. Conte Grand, [8], has analysed three different decoupling models used in examining CO_2 emissions and GDP growth and has concluded that all three decoupling models have limitations, and that decoupling per se is not the end goal However, upon closer inspection of the comparisons between the three analyses, the Tapio decomposition model is most able to identify states of decoupling that more accurately describes the states of CO_2 emissions and GDP growth to different degrees that are valid in both growing and declining economies. The Tapio decomposition model has been used by Xie et al. [9] has undertaken the decoupling analysis of total CO_2 emissions per unit of GDP from 1985 to 2016.

Meanwhile, a decomposition analysis is further undertaken to decompose the link studied by the decoupling analysis. de Boer at al. described two categories of decomposition analyses: index (IDA) and structural (SDA) – and each category has its additive and multiplicative methods [10]. Under IDA, there is the additive means divisia index (AMDI) as well as two logarithmic means divisia index

(LMDI): LMDI-I (based on logarithmic mean weight scheme) and LMDI-II (based on decomposition of differential quantity). From this, five analyses have been recommended: three multiplicative decomposition models (Fischer (SDA), Montgomery-Vartia (multiplicative LMDI-I), Sato-Vartia (multiplicative LMDI-II) and two additive decomposition models (Bennet (SDA), Montgomery (additive LMDI-I)). According to Ang, there are two salient considerations when selecting between multiplicative decomposition, and additive decomposition [11]. Firstly, multiplicative decomposition gives indexes, whereas additive decomposition gives physical quantities. Secondly, in considering data for benchmark years only, additive decomposition is superior to multiplicative decomposition in terms of convenience. Since the data for physical quantities and the flexibility to consider data for benchmark years are pivotal to this methodology, additive decomposition models are superior to that of multiplicative decomposition models. Out of the two additive models recommended by de Boer et al., the Montgomery (additive LMDI-I) model is recommended for its consistency in aggregation and its robustness in encountering zero values (by substituting for extremely small values). Although it is not change-in-sign robust (unlike Bennet), Montgomery's ease to programme as well as the nature of the methodology data not incorporating any changes in sign [10]. This preference is corroborated by Ang, in which eight models for LMDI are presented, and Model 1 (additive LMDI-I) is recommended for quantity aggregates. Upon review, this Model 1 from Ang is identical to that of Montgomery model presented by de Boer et al. This method has been used in similar studies undertaken by this methodology, further confirming it as a sound decomposition model [9] [12] [13].

For the decomposition analysis of CO_2 emissions, factors need to be defined to decompose the CO_2 emissions to aid more detailed analysis. These factors can be formulated by use of an identity. There are two identities that could be used to define factors: I=PAT and Kaya. I=PAT describes the environmental impact (I) of human activity, which is the product of population (P), affluence (A) and technology (T) [14]. Sandu et al. used the I=PAT identity is further dividing A and T into multiple factors [13]. However, the use of I=PAT is nebulous, owing to the fact that T is difficult to define and quantify, and in most analyses it becomes a residual value derived from I, P and A [14]. Therefore, the Kaya identity is a more concrete and mathematically consistent alternative, which equates CO_2 emissions to the product of population, GDP per capita, GDP energy intensity and energy carbon footprint. The Kaya identity is used extensively by the Intergovernmental Panel on Climate Change (IPCC) [15]. The Kaya identity has also been used in many other studies in defining factors for decomposition, thereby confirming it as a sound method to define factors [9] [12] [13] [16].

In utilising the decoupling and decomposition analyses, several studies have been done for many scopes. Xie et al. analysed the decoupling relationship between the CO_2 emission in the power industry and GDP in China for the years 1985-2016 [9]. Lisaba et al. analysed the drivers of CO_2 emission in the sovereign states of ASEAN for the years 2010-2017 [12]. Sandu et al. also analysed the drivers of CO_2 emission in the sovereign states of ASEAN, but for the years 1971-2016 [13]. Kim analysed the energy consumption in the Korean energy sector for the years 1991-2011 [17]. However, a niche has been identified in research, where there is no comprehensive analysis on the decoupling relationship between CO_2 emission and growth of GDP in ASEAN for the years 2017-2020. The forecast analysis is most significant, as the sovereign states of ASEAN continue to develop economically and have a greater collective diplomatic influence globally [18][19]. This diplomatic influence is especially true with the continuation of the China-USA trade wars [20].

3. Scope

Five sovereign states from ASEAN were selected to be studied: Thailand, Vietnam, Indonesia, the Philippines, and Malaysia. The rationale behind the selection of these sovereign states was to capture the geographical diversity within ASEAN – with Thailand and Vietnam representing Mainland ASEAN, Indonesia and the Philippines representing Maritime ASEAN, and Malaysia straddling between the two sub-regions [21]. Apart from Singapore, the chosen five sovereign states have the highest GDP in ASEAN [22]. This corresponds with the five largest middle-income economies in the region – dubbed the Tiger Cub economies [23]. Singapore was specifically excluded from the analysis, as it represents an outlier in the data – as a service-oriented city-state with an advanced economy [24].

Two time periods are to be studied: 2017-2020 and 2021-2025. These two periods are of interest as they represent periods before and after the emergence of the COVID-19 pandemic, respectively. The period 2017-2020 is also of interest as it coincides with the China-USA trade wars, which has significant positive and negative economic impacts on ASEAN sovereign states [20]. The year 2021 coincides with the 2021 United Nations Climate Change Conference [5], and 2025 coincides with the fulfilment of the ASEAN Community Vision 2025 [25] – both of which would have salient impacts on GDP growth and CO_2 emissions in the five sovereign states. The two periods also coincide with the implementation of the ASEAN Plan of Action for Energy Cooperation 2016-2025 [19].

The analysis on CO_2 emission is focussed on CO_2 emissions from electricity generation as this reflects CO_2 emissions from residential, commercial, and industrial sectors. This analysis is also extremely salient in considering the energy transition from fossil fuels to sustainable alternatives in the region, as governments of the five selected sovereign nations of ASEAN implement policies that would influence the use of renewable energy as well as overall energy efficiency [19][21].

Several data sources were considered: the two main ones are Our World in Data [22] and the World Bank [26]. Data for the latter is more stringent than the former, however the former is more comprehensive and accessible in its scope for data. This breadth of accessible data is what this methodology requires, and therefore the former is selected as the main source of data, whereas the latter is used as an auxiliary data set for benchmarking.

4. Methodology

Based on the justifications laid out in the previous sections, the proposed methodology can be summarised into two components – with the input being processed through two different analyses: (i) decoupling analysis and (ii) decomposition analysis. These two analyses then produce two sets of distinct, yet complementary outputs. This methodology is illustrated in the Figure 1 and is further elucidated upon in the subsequent subsection.

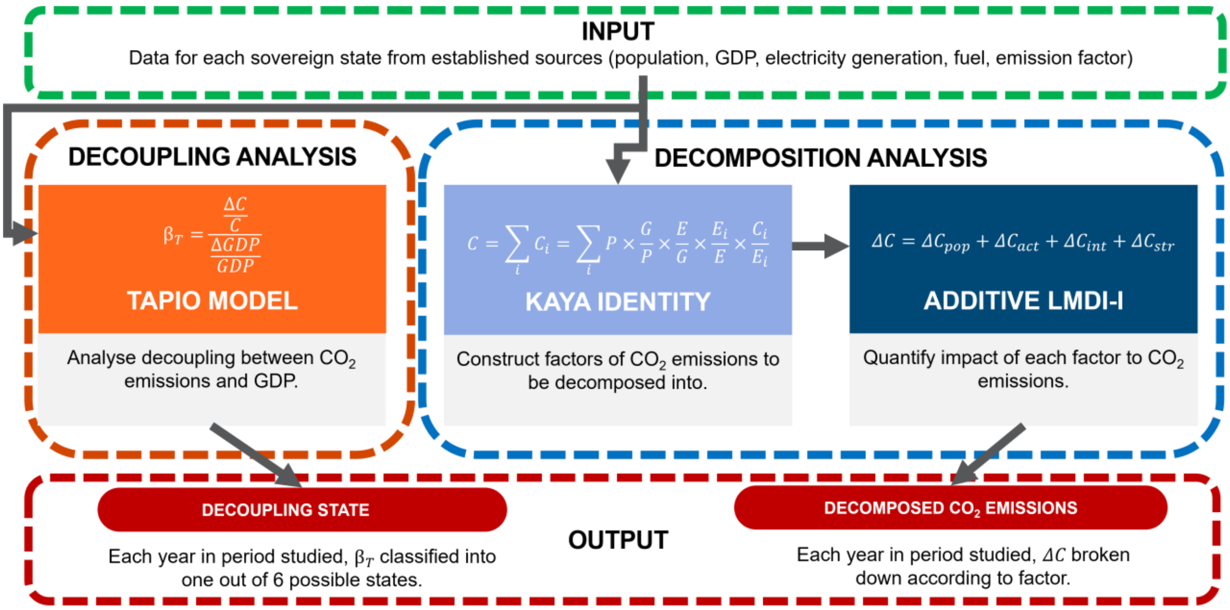

Figure 1. Overview of proposed methodology.

IOP Conf. Series: Earth and Environmental Science 1074 (2022) 012012 doi:10.1088/1755-1315/1074/1/012012

4.1. Input

The data sets for each sovereign state for the years 2017-2020 to be obtained are tabulated in Table 1 below (with their relevant units and abbreviations) were taken from Our World in Data [22]:

Table 1. List of data sets and associated abbreviations.

Data set	Abbreviation
Population	P
CO_2 emissions (tonnes)	C
GDP (2017 US$, PPP)	G
Total fuel consumption (TWh)	E
Share in energy mix for fuel type (TWh)	E_i

It must be noted, from here on out, all mentions of US$ would refer to the purchasing-power-parity (PPP) value of the US$ in the year 2017 to account for the effects of inflation and the variation in purchasing power of the currencies of each sovereign state.

The emission factor for each fuel type (EF_i) was then taken from [27]. The unit for EF_i would then be in kg / TJ, which would then need to be converted to tonne / TWh by multiplying the EF_i by a factor of 3.6, as shown in Equation (1):

$$\frac{[kg]}{[TJ]} = \frac{\frac{1}{1000}[tonne]}{\frac{1}{3600}[TWh]} = 3.6\frac{[tonne]}{[TWh]} \quad (1)$$

A spreadsheet is then created with the data sets, and the following formulae for decoupling and decomposition analysis also put in, to further facilitate the two analyses.

4.2. Decoupling analysis

For the decoupling analysis, the Tapio decoupling model is utilised, the decoupling elasticity index, β_T, is as seen in Equation (2):

$$\beta_T = \frac{\frac{\Delta C}{C}}{\frac{\Delta GDP}{GDP}} = \frac{\Delta C \times GDP}{C \times \Delta GDP} \quad (2)$$

where

β_T = Decoupling index from the subsequent year
C = CO_2 emission in the initial year (tonnes)
GDP = GDP in the initial year (US$)
ΔC = Change in CO_2 emissions in the subsequent year from the initial year (tonnes)
ΔGDP = Change in GDP in in the subsequent year from the initial year (US$)

From this, the values of β_T, $\frac{\Delta C}{C}$, and $\frac{\Delta GDP}{GDP}$ are then examined, and a decoupling state between CO_2 emissions and growth in GDP is interpreted from the data using Table 2 outlying the six possible decoupling types [9]:

Table 2. Table of decoupling states.

β_T	$\frac{\Delta C}{C}$	$\frac{\Delta GDP}{GDP}$	Decoupling state	Decoupling type
$\beta \geq 1$	> 0	> 0	Expansive negative decoupling	I
$0 < \beta < 1$	> 0	> 0	Weak decoupling	II
$\beta \leq 0$	< 0	> 0	Strong decoupling	III
$\beta \geq 1$	< 0	< 0	Recessive decoupling	IV
$0 < \beta < 1$	< 0	< 0	Weak negative decoupling	V
$\beta \leq 0$	> 0	< 0	Strong negative decoupling	VI

Type III indicates that economic growth has a correlation with CO_2 emissions, whereas type VI indicates that there is a strong correlation between economic growth and CO_2 emissions. In terms of declining CO_2 emissions, type III is most favourable in a growing economy, whilst type IV is most favourable for a declining economy.

4.3. Decomposition analysis

The Kaya identity is first used to decompose the annual CO_2 emissions for each sovereign state for the years 2017 to 2020 into several factors, as seen in Equation (3):

$$C = \sum_i C_i = \sum_i P \times \frac{G}{P} \times \frac{E}{G} \times \frac{E_i}{E} \times \frac{C_i}{E_i} = \sum_i P \times M \times I \times S_i \times EF_i \quad (3)$$

where:
C = Total CO_2 emissions (tonnes)
C_i = CO_2 emissions for fuel type (tonnes)
i = Fuel type
P = Population
G = GDP (US$)
E = Total fuel consumption (TWh)
E_i = Amount of fuel consumed for fuel type (TWh)
M = GDP per capita (US$)
I = Energy intensity (TWh / US$)
S_i = Share in energy mix for fuel type
EF_i = Emission factor for fuel type (tonne / TWh)

Using these factors, an additive LMDI-I decomposition model can then be constructed for each sovereign state for each period 2017-2018, 2018-2019, 2019-2020 – as seen in Equation (4):

$$\Delta C = \Delta C_{pop} + \Delta C_{act} + \Delta C_{int} + \Delta C_{str} \tag{4}$$

where pop = population, act = activity, int = intensity and str = structural. Each factor can be further determined for each sovereign state by the following Equations (5) – (8):

$$\Delta C_{pop}^{T} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnCI_i^0} ln\left(\frac{P^T}{P^0}\right) \tag{5}$$

$$\Delta C_{act}^{T} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnCI_i^0} ln\left(\frac{M^T}{M^0}\right) \tag{6}$$

$$\Delta C_{int}^{T} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnCI_i^0} ln\left(\frac{I^T}{I^0}\right) \tag{7}$$

$$\Delta C_{str}^{T} = \sum_{i} \frac{C_i^T - C_i^0}{lnC_i^T - lnCI_i^0} ln\left(\frac{S^T}{S^0}\right) \tag{8}$$

where:
C = Total CO_2 emissions (tonnes)
C_i = CO_2 emissions for each fuel type (tonnes)
i = Fuel type
P = Population
G = GDP (US$)
E = Total amount of fuel consumed (TWh)
E_i = Amount of fuel consumed for fuel type (TWh)
M = GDP per capita (US$)
I = Energy intensity (TWh / US$)
S_i = Share in energy mix for fuel type
EF_i = Emission factor for fuel type (tonne / TWh)
T = At subsequent year
0 = At initial year

Thus, the impact of the population, activity, intensity, and structural factors are then to be compared to understand which factors have contributed the most to CO_2 emissions.

4.4. Output

Each analysis finally provides one set of output for the years 2017-2020. The decoupling analysis defines the relationship between CO_2 emissions and GDP growth based on the six possible decoupling types, whereas the decomposition analysis zooms into the CO_2 emissions and quantifies the impact of each of the main factors (population, activity, intensity and structural) contributing to the decoupling relationship. These two sets of outputs are distinct, yet complementary in the analysis of CO_2 emissions – with the decoupling analysis looking at the macro level, whilst the decomposition analysis looking at the micro level.

5. Conclusion

A methodology was proposed to study the CO_2 emissions from electricity generation and growth in GDP of ASEAN sovereign states for the years 2017-2020 to provide an apples-to-apples comparison for benchmarking purposes. This methodology consists of two distinct, yet complementary analyses: decoupling and decomposition. It is proposed that this methodology can also forecast data for the years 2021-2025.

The decoupling analysis looks at the relationship between CO_2 emissions from electricity generation and GDP growth for each ASEAN sovereign state. The Tapio decomposition model was chosen for this analysis, as it can identify different decoupling states that best facilitates CO_2 emissions in both rising (that is, strong decoupling – type III) and declining economies (recessive decoupling – type IV). The output of the decoupling analysis is a set of decoupling states for each year within the given period.

The decomposition analysis looks at the factors that contribute to CO_2 emissions from electricity generation in each ASEAN sovereign state. The Kaya identity was chosen to identify the factors for decomposition due to its mathematical consistency. After that, the additive LMDI-I method is chosen to quantify the decomposition according to four factors, population, activity, intensity and structural. The additive LMDI-I method was chosen due to its use of a quantity indicator which shows absolute values, has consistency-in-aggregation, is robust in encountering zero values, and is the most straight-forward to program. The output of the decoupling analysis are the CO_2 emissions decomposed into four factors for each year within the given period.

With these two outputs, CO_2 emissions can be analysed macro-level via the decoupling analysis and micro-level via the decoupling analysis. These two levels thus allow for comprehensive benchmarking and thus inform future policy for ASEAN sovereign states to reduce CO_2 emissions from electricity generation. Further recommendations to expand the scope to apply the same methodology in analysing emissions of other greenhouse gasses and studying the CO_2 emissions from energy generation allow for a more comprehensive data set to inform ASEAN sovereign states to combat climate change.

6. Recommendations

After examining the period 2017-2020, projections can be made for the period 2021-2025 based on extrapolation from population, GDP growth and fuel growth projections. This would further be tempered by current policies implemented by each ASEAN sovereign state.

In addition to examining its defined scope, this methodology can be further expanded in terms of its application to encompass a greater scope of analysis for each ASEAN sovereign state studied.

An expansion into the analysis of emissions of other greenhouse gasses in electricity generation (particularly methane (CH_4) and nitrous oxide (N_2O)) is possible with this methodology by substitutions of emission factors. This analysis is important as one tonne of CH_4 has the same global warming potential (GWP) as 28 tonnes of CO_2 [27]. For one tonne of N_2O, the GWP value is equivalent to that of 265 tonnes of CO_2 [27]. With the GWP being one or two orders of magnitude compared to CO_2, the reduction of the emissions of these two greenhouse gasses are also important in combatting climate change.

In terms of general scope, this methodology can also be expanded to incorporate CO_2 emissions from total energy consumed. This can be done also by substitution of the emission factors. Although this methodology yields a less accurate output, as it uses a more general emission factor value – it can capture other sources of emissions, and in particular emissions due to transportation. This is especially important due to the significant increase in motor vehicle ownership relative to road capacity, whilst alternatives such as electrified transport and mass transit are still underdeveloped [19].

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