

Main Drivers of Carbon Dioxide Emissions in Vietnam Trajectory 2000-2011: An Input-Output Structural Decomposition Analysis

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Abstract

Vietnam's rapid economic growth has resulted in serious environmental concerns both at local and global scales. In-depth understanding of the key factors behind the rapid growth of CO₂ emissions is of great significance in the development of local and global climate policies. Furthermore, this provides insight into how emerging economies can develop a low emission future. Recent works have demonstrated the effectiveness of the input-output model and structural decomposition analysis in analyzing how changes in different socio-economic factors affect energy-based CO₂ emissions in the sectoral level using production and consumption-based perspectives. In the context of Vietnam's economy, such aspects have not been fully explored in previous literature. This study thus analyzes the driving forces responsible for the increase in CO₂ emissions in Vietnam from both production and consumption perspective during periods 2000 – 2007 and 2007 - 2011. The results using the production perspective indicate that during 2000 - 2011 the incremental change in CO₂ emissions in Vietnam is driven mainly by the consumption structure (100.5%) and consumption volume (219.4%) which are offset by the decline in technology (-132.7%) and production structure (-22.5%). Population (24.1%) had a small effect on total CO₂ emissions. Results using the consumption perspective show that even with large variations between the two periods, household, export and investment are the main drivers responsible for the sharp increase in CO₂ emissions. This is offset by the decrease in import factor. Policy implications indicate that improving technology, adjusting production and consumption structure, and optimizing international trade are important factors for alleviating CO₂ emissions in Vietnam.

Keywords: input-output analysis, structural decomposition analysis, driving forces, CO₂ emissions, Vietnam

1. Introduction

The impact of economic production activities on the environment has caused serious global problems such as global warming. Rising greenhouse gas (GHG) emissions, mainly CO₂ generation, from the continued consumption of fossil fuels remains a main contributor to global warming which has induced climate change. The World Bank (2010) reported that if anthropogenic activities continue to operate at usual conditions, this could result in a 5 °C increase in global temperature but timely and appropriate intervention may limit it within 2 °C. Thus, reducing GHG releases has become an emerging economic development research interest world-wide (Wang, Yin, Zhang, & Zhang, 2012).

Currently, Vietnam is in the last process of rapid industrialization and is expected to pass into an innovative stage of development (Maryzin, 2013). Since 2000, the Vietnamese economy has positively prospered with annual economic growth rates up to above 5% (PricewaterhouseCoopers, 2017). This rapid economic growth was accompanied by increased energy consumption (MNRE, 2014) and resulted in corresponding increases in GHG emissions from the energy sector. N. Nguyen, Ha-Duong, & Sandra (2009) reported that the projection of GHG generation from energy combustion will increase tremendously by up to 14% per year, reaching nearly 400 million tonnes of CO₂ in 2030. In order to mitigate the impact of climate change, the 1992 UN Framework Convention on Climate Change (UNFCCC) developed the Kyoto Protocol which required member countries to

promote environmental policies to reduce GHG emissions (UNFCCC, 1998). As a non-annex I country under Kyoto Protocol, Vietnam is not required to abate GHG emissions. It has however ratified the agreement to pursue efforts of reducing emissions in polluting sectors such as the energy, agriculture and transportation sectors (KEPA & GreenID, 2014). In light of this, Vietnam submitted an intended nationally determined contribution (INDC) to the 2015 United Nations Climate Change Conference (COP21), which commits to a 25 % reduction in GHG emissions by 2030 compared to the business-as-usual (BAU) levels (UNFCCC, 2015a; 2015b). H. Nguyen, Aviso, Le, Kojima, & Tokai (2018b) employed a high-level assessment of the potential effectiveness of mitigating GHG emissions by considering low-carbon measures including differentiated growth of sectors, shift to low-carbon energy mix, broad deployment of energy conservation measures for final consumption and use of low-carbon technologies in agriculture, transport and waste sectors. The results indicate that the targets of GHG emissions outlined in INDC are achievable if all the strategies outlined are implemented altogether. However, according to KEPA and GreenID (2014), in addition to technology factor and annual growth, there are many other socio-economic factors which impact the incremental changes in GHG emissions of an economy. In-depth understanding of these drivers may help in developing short-term and long-term sustainable energy emission mitigation strategies. In Vietnam, the main contributor to total GHG emissions is CO₂, which accounts for 48% (H. Nguyen et al., 2018b; MNRE, 2014) of the total. Thus, the effectiveness of GHG mitigation measures can be enhanced and maximized if the main drivers of CO₂ generation can be identified. In other words, uncovering these main drivers could be helpful in reaching reduction targets and projecting future low-emission scenarios (Shahiduzzaman & Layton, 2017; Guan, Hubacek, Weber, Peters, & Reiner, 2008).

Cansino, Roman, & Ordóñez (2016) indicated that decomposition analysis facilitates the identification of driving forces which are more crucial for mitigating CO₂ emissions. Liu and Wang (2013) proved that using decomposition method allows for the analysis of how different factors contribute to the changes of SO₂ emissions. Frequently used methods of decomposition analysis include the LMDI method (Shrestha, Anandarajah, & Liyanage, 2009; Cansino, Sánchez-Braza, & Rodríguez-Arévalo, 2015; Chen, Li, Zhou, Yang, & Chen, 2017), the IPCC method (IPCC, 2006), and the SIRPAT method (Fu et al. 2015; Shuai, Shen, Jiao, Wu, & Tan, 2017). Recently, the Kaya Index method was used for identifying the drivers of CO₂ emissions in Vietnam (A. Nguyen, 2012), for linking changes in GHG emissions in Baltic States (Štreimikienė & Balezentis, 2016), and for identifying the driving forces of CO₂ emissions from construction (Mavromatidis, Orehoung, Richner, & Carmeliet, 2016), to name a few. The advantage of these methods is the ability to examine the various factors which affect energy-based CO₂ emissions. They are later used to propose the differentiated measures which should be adopted for each region. However, these previous works have failed to provide a comprehensive analysis of how the connections between the different economic sectors and other economic structure factors affect emissions. To fill this gap, a hybrid input-output structural decomposition analysis (IO-SDA) method using economic input-output tables is applied to provide a more detailed assessment of economic structure changes over time (Xie, 2014). Furthermore, IO-SDA can show socio-economic factors from both production and consumption perspectives (Casino et al., 2016; Wang, Huang, Yang, & Yu, 2013). With decomposition on a sectoral scale, IO-SDA can analyze the driving factors for pollutants from high-polluting sectors (Cansino et al., 2016; Wang, Huang, Yu, Hu, & Xu, 2016)

Rose and Chen's (1991) seminal work using IO-SDA assessed the changes in the sectoral energy use in the U.S. while Rose and Casler (1996) later gave the basic principles to get equations for structural decomposition. A similar approach was implemented for optimizing supply chain network under water footprint constraints (Aviso, Tan, Culaba, & Cruz, 2011). IO-SDA model has been used successfully not only on a national scale (Huang & Wu 2013; Koh et al., 2016), but also on a city scale (Wang & Wang 2015, Wei et al., 2017). IO-SDA was also utilized in analyzing the emissions embodied in trade among countries (Xu & Dietzenbacher, 2014; Wang, Ang, & Bin Su, 2017) and in projecting the future emission scenarios (Shahiduzzaman & Layton, 2017).

There are few studies which have utilized decomposition analysis for analyzing the Vietnamese economy. A. Nguyen (2012) applied the Kaya Index to analyze CO₂ emission variability in Vietnam during 1986 - 2008, while Zimmer, Jakob, & Steckel (2015) used it for the period of 1975-2010. These authors were successful in evaluating the changes in CO₂ emissions using a macro-economic scale, but they failed to identify the changes in CO₂ emissions at the sectoral scale. T. Nguyen and Ishihara (2006a; 2006b) used IO-SDA to analyze the variation of energy flows in Vietnam from 1989 to 2000. These helped identify the changes in energy flows at the sectoral level, but they focused primarily on energy intensity and lacked analysis of other socio-economic drivers such as production structure, population and consumption structure to name a few.

To supplement this research gap, this paper used the IO-SDA to analyze the driving forces of CO₂ emissions looking at various perspectives over two categorical periods, 2000 - 2007 and 2007 - 2011. In light of this, more recent data on emissions, gross domestic product (GDP), population and IO tables are used in order to achieve the three fold objectives as follows:

- 1) Decompose the changes in CO₂ emissions from the production perspective with five socio-economic driving forces including technology, production structure, consumption structure, consumption volume and population growth.
- 2) Decompose the changes in CO₂ emissions from the consumption (final demand) perspective with different consumption categories including government, household, investment, import and export.
- 3) Propose policy recommendations for policy makers, manufacturers and relevant partners for reducing CO₂ emissions.

The rest of paper is organized as follows. The methodology is discussed in Section 2. Section 3 shows the dataset used. Results, discussion and policy implications are then mentioned in Section 4. Finally, conclusions and recommendations for future work are presented in Section 5.

2. Methods

The framework developed to achieve the objectives of the study is illustrated in Figure 1:

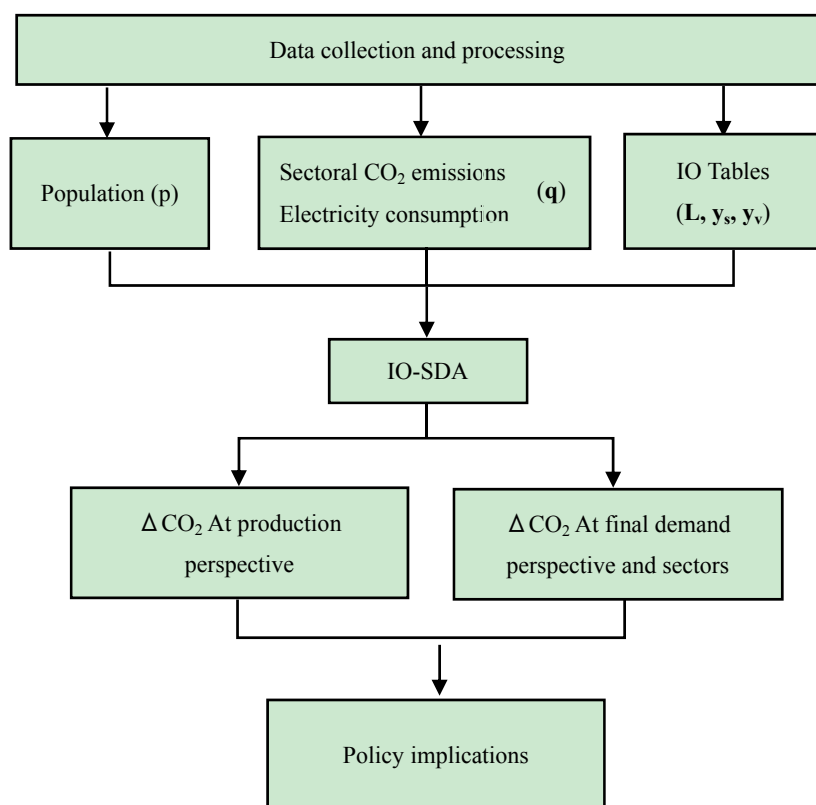


Figure 1. Research framework

2.1 Generic Input-Output (IO) Analysis

The IO framework has been conventionally used to describe the interrelationship between different economic sectors in an economy. Its basic formulation contains a system of linear equations where the total output of the system is equal to the amount consumed internally by the system as intermediate consumption plus the amount used by final customers (or final demand such as household and government consumption) (Leontief, 1936; 1986). For an economy with n sectors, x can denote the $n \times 1$ gross domestic output vector, y the $n \times 1$ final demand vector and Z the $n \times n$ input-output matrix. In matrix notation, the IO model can be written as follows (Miller & Blair, 2009):

$$x = Ze + y \tag{1}$$

where \mathbf{e} is column vector with all elements having a value of 1. \mathbf{A} denotes the $n \times n$ technology coefficient matrix with elements a_{ij} ($a_{ij} = Z_{ij} / x_j$) representing the amount of product from the i^{th} sector needed to produce one unit of output from the j^{th} sector. Based on this, Equation 1 can be converted as follows:

$$(\mathbf{I} - \mathbf{A})^{-1} \mathbf{y} = \mathbf{x} \tag{2}$$

where \mathbf{I} denotes an $n \times n$ identity matrix and $(\mathbf{I} - \mathbf{A})^{-1}$ is the $n \times n$ Leontief inverse matrix (\mathbf{L}) which expresses the requirements for an economy's production.

By adding environmental factors into the economic IO model, Environmental Input-Output (EIO) analysis may be used to account for environmental interventions of each sector. This method is discussed in detail in Miller and Blair (2009). The EIO model links environmental interventions with sector production and final demand consumption. Suh (2009) employed this model in accounting for CO₂ releases in a supply chain network to conduct sustainability assessment while Tan, Culaba, & Aviso, 2008; Tan, Ballacillo, Aviso, & Culaba (2009) applied the EIO for optimizing a multi-regional bioethanol supply chain network with the presence of multiple objectives. Wiedmann and Barrett (2011) used EIO to account for GHG generation embodied in goods and services purchased by Central Government. Recently, H. Nguyen, Aviso, Kojima, & Tokai (2018a) applied this model to analyze the inter-relationship between economic sectors and water pollution in Vietnam. In this case, CO₂ emissions contributed by economic sectors in Vietnam are considered as the environmental intervention. The amount of CO₂ emission of each sector is assumed to be proportional to the total output of that sector. Let \mathbf{q} represent a $1 \times n$ vector which contains the sectoral pollution intensity. The pollution intensity of a sector is equal to the amount of emissions generated by the sector divided by its gross output. Therefore, the quantity of CO₂ emissions can be expressed as follows:

$$\mathbf{Q} = \mathbf{q} \mathbf{L} \mathbf{y} \tag{3}$$

where \mathbf{Q} is the total CO₂ emission from all sectors.

2.2 Input-Output Structural Decomposition Analysis (IO-SDA)

IO-SDA is a method frequently applied to quantify the contribution of various factors to the total changes in economic and environmental flows using IO tables (Hoekstra & van den Bergh, 2002; Minx et al.; 2011; Xu, Li, Crittenden, & Chen, 2011). The IO-SDA framework is utilized in this study to analyze the variations of CO₂ emissions in categorical periods due to 5 factors including production structure (\mathbf{L}), pollution intensity (\mathbf{q}), population (p), consumption structure (\mathbf{y}_s) and consumption volume (\mathbf{y}_v).

Production structure is considered as the Leontief inverse matrix (\mathbf{L}). The changes in this factor express the changes in input requirement of each sector. Pollution intensity (\mathbf{q}) can reflect the improved energy efficiency or technology factor (energy consumption per unit output) when there is less emission per unit of energy output. To differentiate the contributions of various consumption components, final demand, \mathbf{y} , is decomposed into three components namely consumption structure, consumption volume and population as follows.

$$\mathbf{y} = \mathbf{y}_s \mathbf{y}_v p \tag{4}$$

where \mathbf{y}_s is a $n \times m$ matrix of consumption structure with m amount of consumption categories (in this study $m = 5$ (e.g. household, government, investment, export and import)). Assuming that \mathbf{F} is a $n \times m$ matrix of consumption flows, its element, F_{id} , denotes the amount of final demand of category d in the i^{th} sector. Thus, the consumption structure of final demand category d in response to the i^{th} sector is expressed as $y_s^{id} = \frac{F_{id}}{\sum_{i=1}^n F_{id}}$;

\mathbf{y}_v is a $1 \times m$ vector of consumption volume, its element, $y_v^d = \frac{\sum_{i=1}^n F_{id}}{p}$ represents the per capita final demand of category d ; and p is a scalar value representing the population. Therefore, Equation 4 can be rewritten as:

$$\mathbf{Q} = p \mathbf{q} \mathbf{L} \mathbf{y}_s \mathbf{y}_v \tag{5}$$

Over a given time period, any change in CO₂ emissions (ΔQ) in an economy can be indicated by Equation 6, where the five factors including emission intensity, population, production structure, consumption structure and consumption volume completely account for the increase or decrease in CO₂ emissions from the production perspective. Thus, Equation 5 can be written as:

$$\Delta Q = \Delta p \mathbf{q} \mathbf{L} \mathbf{y}_s \mathbf{y}_v + p \Delta \mathbf{q} \mathbf{L} \mathbf{y}_s \mathbf{y}_v + p \mathbf{q} \Delta \mathbf{L} \mathbf{y}_s \mathbf{y}_v + p \mathbf{q} \mathbf{L} \Delta \mathbf{y}_s \mathbf{y}_v + p \mathbf{q} \mathbf{L} \mathbf{y}_s \Delta \mathbf{y}_v \tag{6}$$

where Δp , $\Delta \mathbf{q}$, $\Delta \mathbf{L}$, $\Delta \mathbf{y}_s$ and $\Delta \mathbf{y}_v$ represent the changes of each factor in which each Δ is calculated when all other

factors are assumed to be constant. For example, Δy_s is change in consumption structure, and this term $(p\mathbf{q}L\Delta y_s, y_v)$ represents the change of total CO₂ emissions resulting from a change in consumption structure with population, CO₂ emission intensity, production structure and consumption volume staying constant.

In structural decomposition analysis, it is possible to compare various factors related to any point in time within a study period. According to Dietzenbacher and Los (1998), there are plenty of possible solutions of decomposition. If the number of decomposed factors is k , the number of possible decomposition equations is $k!$ (in this case $k=5$). Since the number of decision factors are excessively powerful to compute, this problem can be solved using the average of all possible first-order of decompositions for simplification (Koh et al., 2016). This work applies the structural decomposition analysis method proposed by Koh et al. (2016). For further details, see Appendix.

In consideration of IO-SDA for assessing the changes in CO₂ emissions from the final demand perspective, the formulas introduced by Peters (2008) can be applied to allocate the variations in CO₂ emissions to the appropriate final demand category d as follows:

$$\mathbf{Q}_d = \mathbf{q} \mathbf{L} \mathbf{y}_d \quad (7)$$

Based on Equation 7, the changes in CO₂ emissions using the consumption perspective, which includes household consumption, government consumption, investment, export and import, can be achieved. Note that the total change in CO₂ emissions from consumption (Equation 7) is equal to the change obtained using the production perspective (Equation 6). It can be understood that the changes from production perspective are obtained by analyzing directly the effect of socio-economic factors on the production of all economic sectors. Meanwhile, final demand perspective allows the analysis of changes in CO₂ emissions based on changes in final consumption. In fact, the impact of these socio-economic factors on the economy will also be reflected in its GDP (total final demand). For example, any change in population, or production structure among others, is reflected in GDP or final demand categories.

3. Data Collection

The necessary economic data utilized in this work were obtained from Vietnam IO tables for 2000, 2007 and 2011 which were published in the Vietnamese General Statistical Office (GSO) website (GSO, 2003; 2009; 2013). These contained the most recent information available. The 2000 IO table contains 112 sectors while IO tables 2007 and 2011 have 138 sectors. These IO tables were classified and aggregated into 18 main sectors as shown in Table 1. The classification of sectors was based on the classifications indicated for the IO table from GSO and according to the International Standard Industrial Classification version 3 (UN, 2018). Furthermore, these aggregated IO tables of 2007 and 2011 were converted from 2007 and 2011 prices, respectively, into 2000 constant price through the double deflation methods using each sector's producer price index as obtained from the Vietnamese statistical Yearbook (GSO, 2007; 2011). The Vietnamese IO data include five categories of final demand – households, government, investment, exports and imports. An example of the structure of the Vietnamese IO tables was shown in H. Nguyen et al. (2018a).

Table 1. Nomenclature of sectors

Sector code	Economic sectors
1	Agriculture, Fishery and Forestry
2	Mining and Quarrying
3	Food, Beverage and Tobacco
4	Textile, Wearing Apparel and Leather Industries
5	Manufacture of Wood and Wood products
6	Manufacture of Paper and Paper Products, Printing and Publishing
7	Manufacture of Industrial Chemicals and petro chemicals
8	Manufacture of Non-metallic Mineral Products
9	Basic Metal Industries
10	Manufacturing of Fabricated Metal Products, Machinery and Equipment
11	Other Manufacturing Industries

12	Electricity, Gas and Water
13	Construction
14	Trade and Repairing Services
15	Transportation and Communication
16	Finance, Real Estate and Business Services
17	Government Services
18	Personal, Community, and Household Services

CO₂ emissions by sector resulting from fuel combustion in Vietnam are obtained from the International Energy Agency (IEA, 2016). Since electricity produced by power and heat sectors is mainly used by other sectors, CO₂ generation from electricity should be allocated to all sectors based on their electricity consumption (Hsu & Chou, 2000). The data of electricity consumption by sector in Vietnam were obtained from IEA (2017). The sectoral CO₂ emissions for different years are shown in Figure 2 while the pollution intensity of sectors is given in Table A.2 in Appendix. The IEA database indicated that Vietnam’s energy-related CO₂ emissions resulting from economic activities increased by 108% (from 44,223 thousand tonnes (kt) to 91,969 kt) from 2000 to 2007 and increased by 80.8% from 2007 to 2011. In the period 2000 - 2007, Sector 11, Sector 15 and Sector 18 were the highest contributors to total direct CO₂ emissions (Figure 2). These sectors are considered as energy-intensive sectors. Meanwhile, other sectors which mainly consist of manufacturing sectors such as Sectors 3-10 contributed insignificantly. In contrast, in 2011, not only energy-intensive sectors (Sector 11, 15 and 18), but also manufacturing sectors such as Sector 8 and Sector 4 have high CO₂ emissions. The considerable increase in emissions in manufacturing sectors in 2011 was due to Vietnam’s accession to the World Trade Organization (WTO) since 2007, which has stimulated international trade between Vietnam and other countries (Le, 2017). Economic sectors, especially manufacturing sectors, were boosted to strongly develop to meet the demand of international trade.

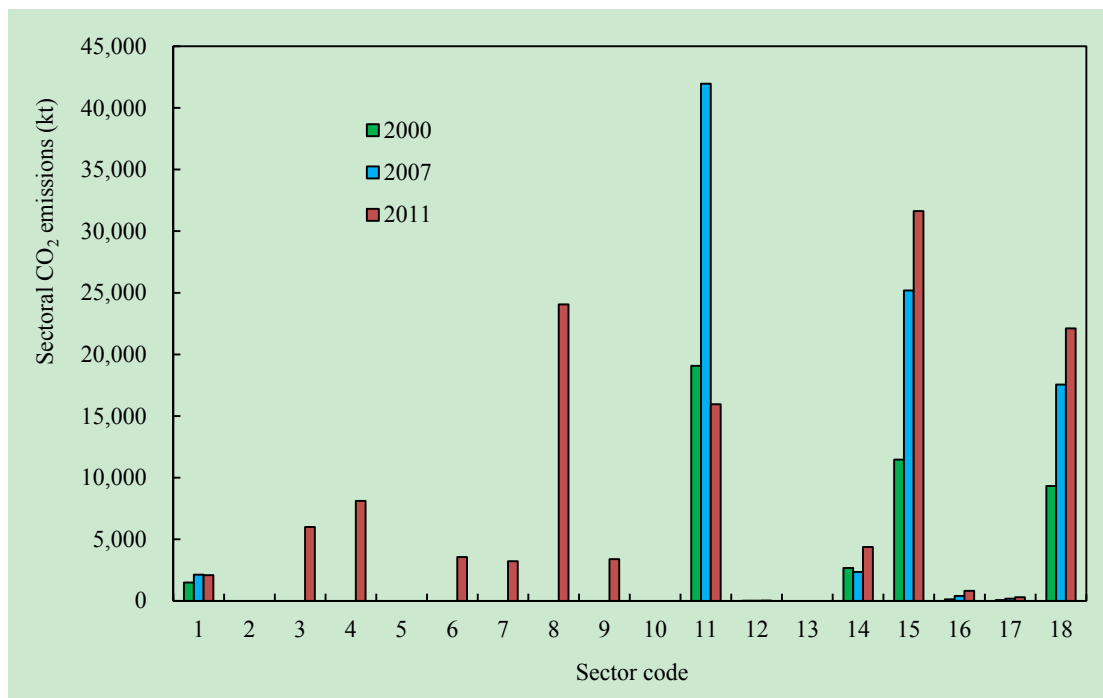


Figure 2. Sectoral CO₂ emissions in 2000, 2007 and 2011 (IEA, 2016)

4. Results

4.1 Analysis from the Production Perspective

Solving Equation 6 using decomposition methods discussed in the Appendix to account for any change in CO₂ emissions using the production perspective, the results indicate that in the 11 years from 2000 to 2011, Vietnam’s

energy-related CO₂ emissions increased by 188.8% (83,495 kt). The structural decomposition analysis for the year 2000, 2007 and 2011 reveals how different factors contribute to the change in CO₂ emissions (Figure 3). In light of this, three factors: (i) steady growth in population (24.1%, 10,660 kt); (ii) consumption structure (100.5%, 44,423 kt); and (iii) consumption volume triggered by per capita consumption (219.4%, 97,029 kt) acted as tremendous accelerators of CO₂ emission from 2000 until 2011. Meanwhile, the changes in production structure led to a slight decrease in CO₂ emissions (-22.5%, 9,927 kt), and the changes in improved energy efficiency (pollution intensity) resulted in a -132.7% (58,690 kt) decrease. Despite production structure and improved efficiency in production contributing to the decrease in CO₂ emissions, consumption structure, consumption volume and population contributes to the sharp increase of emissions. This led to accelerating tendency of CO₂ emissions in period 2000-2011. These findings are consistent with the analysis of changes in CO₂ emissions and energy consumption from 1986 to 2008 carried out by A. Nguyen (2012).

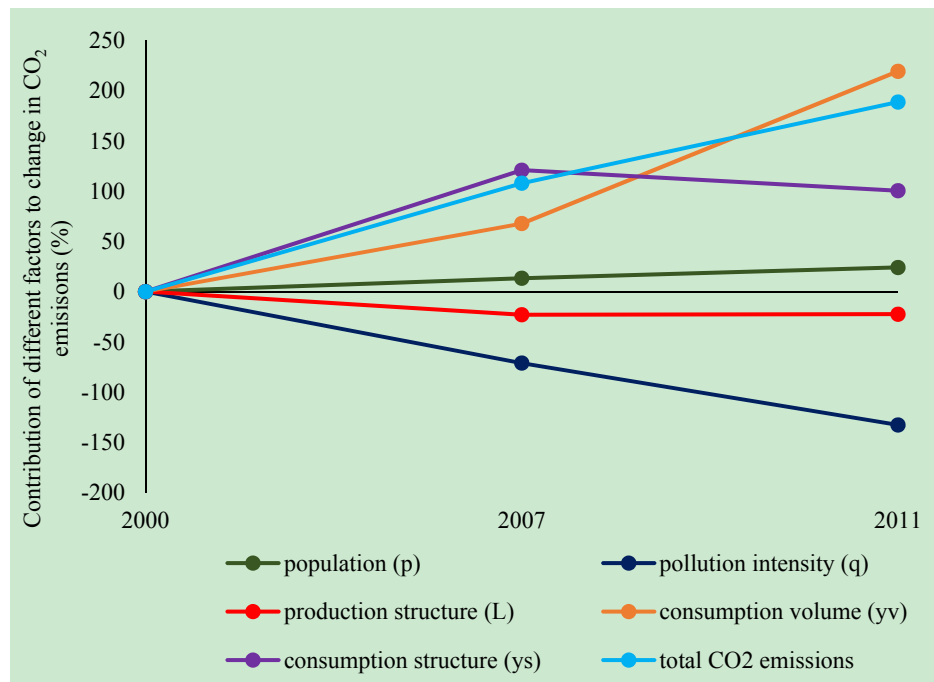


Figure 3. Contributions of driving factors to changes in Vietnamese CO₂ emissions between 2000 and 2011

Figure 4 shows which factors dominated within the shorter periods of 2000 - 2007 and 2007 - 2011. During 2000 - 2007, population growth, increased consumption volume and increased consumption structure increased CO₂ emissions by 202% (89,343 kt) (13.3%, 5,894 kt; 67.8%, 29,982 kt; and 120.9%, 53,467 kt, respectively) (Figure 4). However, production structure (-23%, 10,160 kt) and pollution intensity (-71.1%, 31,436 kt) were two factors which offset the incremental change in CO₂ in the same period. Overall, the CO₂ emissions increased significantly by 108% (47,747 kt) between 2000 and 2007. In the period of 2007 - 2011, population (10.8%, 4,766 kt) and consumption volume (151.6%, 67,047 kt) exerted upward influence on CO₂. This was offset by an improvement in efficiency (-61.6%, 27,253 kt) and consumption structure (-20.5%, 9,044 kt), which led to an actual increase in total CO₂ generation of 80.8% (35,748 kt). Meanwhile, changes in production structure remained almost constant.

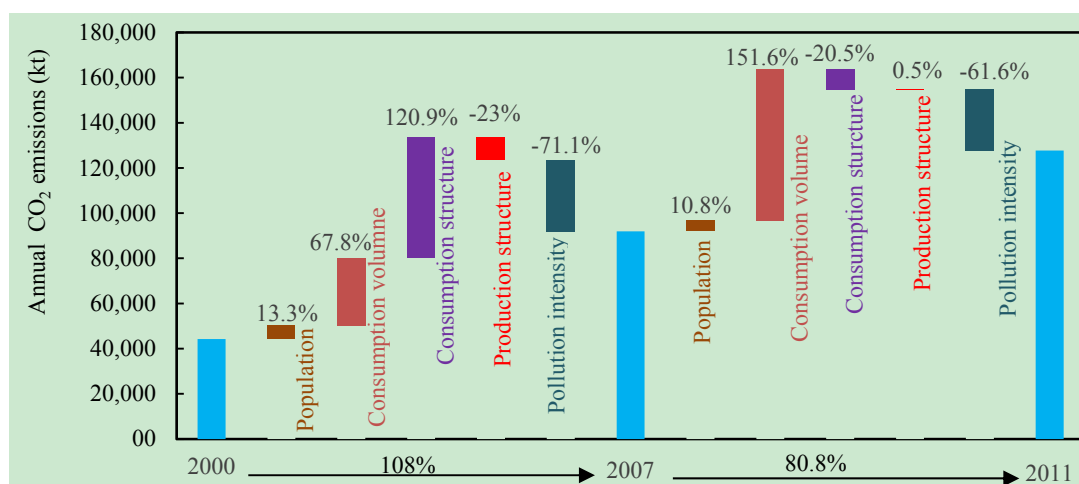


Figure 4. Contributions of different factors to Vietnam's CO₂ emission change based on two periods 2000-2007 and 2007-2011

From these results, it can be stated that notable improvement in efficiency for both periods contributes to offsetting the increment in CO₂. This was reasoned by Dinh and Lin (2014) and Zimmer et al. (2015). First, the production of Vietnam's economic industries mainly depended on imported oil, meanwhile the international oil prices rose significantly in the 21st century. This urged the implementation of advanced energy-saving and the improvement of energy-efficient technologies (Andrei, 2007). Second, Vietnam shifted from fossil fuel into a fuel mix which increased the consumption of natural gas to partially replace coal. Furthermore, the consumption of biofuel and waste for power generation was also a main contributor to CO₂ emission reduction.

Consumption volume was a main factor contributing to the sharp increase. Meanwhile, the consumption structure varied between two periods. During 2000 - 2007, consumption structure contributes to an increase of 120.9% while this number decreased to -20.5% between 2007 and 2011. The drastic variation as explained by Le (2017) is that Vietnam's accession to WTO since January 2007 strongly affected trade liberalization and improved market access for the new member country's exports and imports (Le, 2017). As a result, trade activities, especially import, increased sharply during 2007 - 2011, which significantly contributed to the reduction of CO₂ emissions. Thus, accession to WTO increased emissions in consumption volume due to an increase of production activities and consumptions but they had positive effect on CO₂ mitigation in terms of consumption structure due to the sharp decrease of CO₂ in import factor. The next section discusses the allocation of total emissions to different final demand categories.

4.2 Analysis from the Consumption Perspective

Analyzing the changes of CO₂ emissions from the consumption (final demand) perspective could uncover underlying driving factors in the whole supply chain network (Liu et al., 2012; Wang et al., 2013; Peters, Weber, Guan, & Hubacek, 2007). In this paper, Equation 7 is used to account for this. The allocation of CO₂ emissions into the different final demand categories is shown in Table 2 and analysis results of economic sectors are given in Table 3 and Tables A.3 and A.4 in the Appendix.

Table 2. Contribution of different consumption categories to CO₂ emissions (kt)

Categories	Period	
	2000-2007	2007-2011
Household	29,756	27,021
Government	3,675	1,069
Investment	-3,033	30,385
Export	23,908	46,665
Import	-8,740	-69,334

Table 3. Allocation of CO₂ emission changes (kt) during 2000 - 2011 by different consumption categories and sectors

Sector code	Categories	HHs.	Govt.	Total I	Export	Import
	Consumption	Consumption	Consumption			
1		68	6	125	823	-434
2		0	0	0	0	0
3		4,707	34	-2,629	5,614	-1,736
4		3,591	48	-1,503	14,344	-8,373
5		0	0	0	0	0
6		4,474	295	430	4,846	-6,485
7		9,346	340	3,312	12,179	-21,960
8		7,950	325	21,240	13,662	-19,119
9		10,874	257	22,115	20,440	-50,305
10		0	0	0	0	0
11		-15,999	-1,554	-17,529	-12,198	44,162
12		11	1	6	13	-17
13		0	0	0	0	0
14		64	-47	-504	1,228	965
15		18,819	704	1,920	9,796	-11,069
16		729	39	96	265	-442
17		83	145	0	1	-1
18		12,061	4,150	273	-439	-3,260

Changes in household consumption caused 29,765 kt and 27,021 kt increases in CO₂ emissions during the first and second period, respectively (Table 2). Changes in household were analyzed by sector during 2000 - 2011 and are shown in Table 3 and Figure 5. Meanwhile, the contribution of government to changes in CO₂ was not considerable (Figure 6).

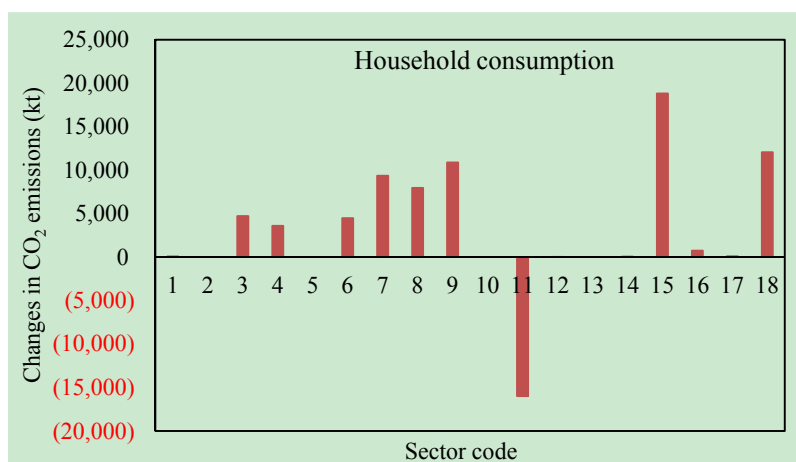


Figure 5. Allocation of CO₂ emission changes (kt) during 2000 - 2011 by household consumption

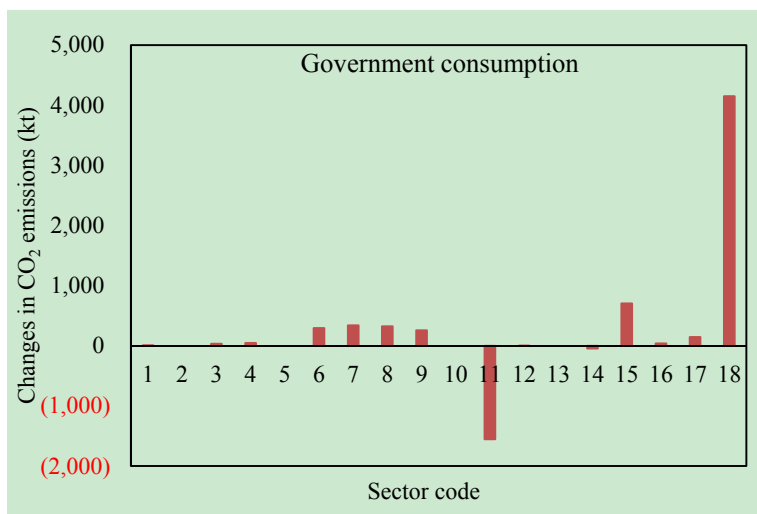


Figure 6. Allocation of CO₂ emission changes (kt) during 2000 - 2011 by government consumption

The changes in investment followed an irregular path for both periods. In the first period, there was a slight decrease in CO₂ emissions from investment, but it sharply increased up to 30,385 kt in the second period. This was explained that there was an increase in FDI during 2006 - 2010 compared to 2001 - 2005 (Ngo, Dao, H. T. Nguyen, & Dao, 2017) which was mainly used for the expansion of manufacturing production (Dinh & Lin, 2014). As a result, CO₂ emissions from manufacturing industries sharply changed during 2006 - 2011 (see Figure 1). Figure 7 indicates the increase and decrease in CO₂ emissions in various sectors resulting from investment. Under which, Sector 8 (manufacture of non-metallic mineral products, 21,240 kt) and Sector 9 (basic metal industry, 22,115 kt) were the main contributors in the increase of CO₂ emissions. In contrast, Sector 11 (Other Manufacturing Industries) was the main sector in the reduction of CO₂ emissions (-17,529 kt). These results are consistent with information mentioned by Dinh and Lin (2014). According to Dinh and Lin (2014), the investment in Sectors 8 and 9 resulted in the increase in emissions because these sectors require intensive-energy for their production. Meanwhile, emissions in Sector 11 reduced because investment was used for both economic growth and environmental protection, (e.g. application of cleaner and more efficient production activities and/or end-of-pipe treatment technologies in factories).

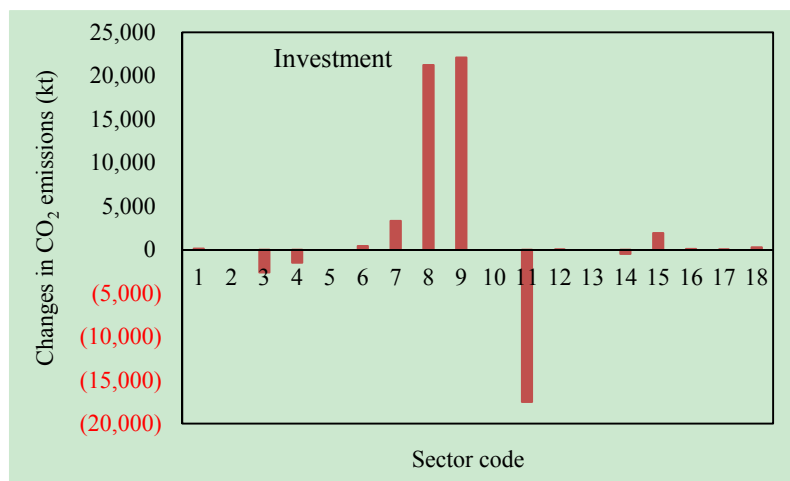


Figure 7. Allocation of CO₂ emission changes (kt) during 2000 - 2011 by investment

Export was also a key driving force of CO₂ emission incremental change during both periods. Changes in export caused a sharp increase from the first period (23,908 kt) to second period (46,665 kt). The analysis by sector is shown in Figure 8.



Figure 8. Allocation of CO₂ emission changes (kt) during 2000 - 2011 by export

Import activities were main drivers in CO₂ reduction with -8,740 kt during 2000 - 2007 and -69,334 kt during 2007 - 2011. Since the CO₂ emissions in this paper was estimated as production-based emissions, the increase in production of domestic products for different purposes such as household, government and export normally causes the increment in pollution for Vietnam, but the increase in the importation of goods and services produced from other countries may help this country avoid emissions. The analysis by sector in terms of import is given in Figure 9. From these results, it can be stated that the accession to WTO from 2007 helped improve import and export between Vietnam and other countries. This greatly affected the economic development and environmental pollution in Vietnam from the year of 2007 onwards.



Figure 9. Allocation of CO₂ emission changes (kt) during 2000 - 2011 by import

4.3 Policy Implications for Mitigating CO₂ Emissions

As a result of rapid industrialization and modernization, especially after accession to WTO, the Vietnamese economy has positively prospered through the expansion of manufacturing industries and the increase in international trade activities with other countries. These led to increasing energy consumption induced CO₂ emissions. Thus, the appropriate identification of driving factors related to increase in CO₂ emissions is significant in developing policies.

4.3.1 From the Production Perspective

Using the production perspective, the consumption volume, consumption structure and pollution intensity are the main driving forces which influence CO₂ emissions in Vietnam. Meanwhile, population growth, had a small effect on the increase in CO₂ release, but the rapid population growth in the future especially in big cities such as

Hanoi and Ho Chi Minh may affect environmental-social-economic development. Thus, implementing the policies to encourage birth rate reduction is of significance for emission reduction. Pollution intensity or technical factor is a strong factor in offsetting CO₂ generation in all other factors considered in this paper. According to KEPA and GreenID (2014), there is still significant potential for further improving energy use efficiency by varying fuel mix use (i.e., increasing natural gas use and decreasing coal and oil uses), replacement of fossil fuels by clean and renewable energy such as wind energy, solar energy and bio-gas, and carbon capture and sequestration. Furthermore, policies for encouraging continued energy conservation should be given. In addition to technology improvement, strong regulations are required to capture other potentials to mitigate emissions through economic structural adjustment and optimization in both production and consumption sides. In the whole observed time period, Vietnam's CO₂ emissions were 22% lower due to improvement in production structure. These emissions due to production structure can be further lowered through increased resource efficiency such as reducing highly pollutive inputs, recycling products and waste.

4.3.2 From the Consumption Perspective and Sectors

From deeply analyzing using the consumption perspective, household, investment, export and import are key driving factors to the changes in CO₂ emissions. The growth of CO₂ emissions relative to household consumption is driven by a combination of increased consumption of urban household and urbanization (DEA, 2017). Therefore, to reduce emissions from household consumption, there is a need to shift structure toward using more environmental friendly products or reducing the use of energy-intensive products (i.e., appliances and electricity).

Investments are important for economic development in Vietnam, but the downside is the increase in emissions from the production of heavy manufacturing such as cement, steel, glass, etc. However, if investments are channeled towards improving the efficiency of technologies or implementing cleaner technologies, Vietnam can further reduce its emissions. These may also stimulate the enterprises toward low-CO₂ production.

International trade including import and export has been an important driving force for Vietnam's economic development. Table 2 has shown that trade activities may contribute to the decrease in CO₂ emissions by promoting import. However, this may result in high emissions in original countries where products are produced. Thus, to reduce global pollution problem, there is need to import goods from countries that can produce more efficiently. Furthermore, there is a need to optimize trade structures between Vietnam and other countries. Reducing the import of highly-pollutive materials also help reduce emissions for domestic production.

Taking into account CO₂ emissions from various economic sectors, it can be seen that Sector 15 (transportation and communication) and Sector 18 (personal, community, and household services) and the manufacturing sectors (Sector 3-11) are main contributors to CO₂ emissions in Vietnam. To reduce emissions in Sector 18, there is a need to shift economic structure toward using more environmental friendly goods and services or reducing the consumption of energy-intensive products. To decrease emissions in Sector 15 the most logical option for Vietnam is to invest in traffic infrastructure to develop public transportation and reduce private vehicles. Using energy-efficient vehicles to replace traditional ones is also helpful. For manufacturing sectors (Sector 3-11), the best option to reduce pollution is by using cleaner technologies, improving process efficiency and waste treatment systems, and replacing highly pollutive raw materials with less pollutive inputs.

5. Conclusions and Recommendations

This paper uses IO-SDA model to analyze underlying driving forces for the changes in energy-based CO₂ emissions in Vietnam during two periods 2000 - 2007 and 2007 - 2011. This model is more useful than traditional SDA methods because it can highlight any change of pollutant resulting from different socio-economic factors at both macro-economic and sectoral levels. This method makes use of available IO tables in 2000, 2007 and 2011 and other socio-economic data to indicate the variation of CO₂ emissions contributed by economic activities using both production perspective (technology, production structure, consumption structure, consumption volume and population growth) and final demand perspective (government, household, investment, import and export). Such analysis is helpful for decision makers, manufacturers and relevant partners to know the structural dynamics of CO₂ generation. These can be used to formulate effective and sustainable emission mitigation strategies and management protocols for short and long-term plans.

The results from the production perspective indicate that the overall energy-related CO₂ emissions in Vietnam from 2000 to 2011 increased by 188.8% (83,495 kt). Consumption structure and consumption volume were the main drivers responsible for this incremental change in CO₂ emissions, while CO₂ pollution intensity and production structure were two main factors which offset this increase. However, population growth had a small effect on the increase in CO₂ generation during this period, but it may have significant effect if population

growth rate increased rapidly in the future. From the final demand perspective, household, export and investment are the key drivers responsible for the sharp increase in CO₂ emissions between 2000 and 2011, while import factor contributes to the abatement of CO₂ emissions. Government had inconsiderable effect on the growth in CO₂ emissions. Between these two periods, different factors contributed differently to the increase and decrease in CO₂. Consumption structure has the largest variation with an increase of 120.9% during 2000 - 2007 and a decrease of 20.5% between 2007 and 2011. This was due to the increase in import activities in the second period resulting from the accession to WTO in 2007. In consideration of CO₂ changes by sector, Sector 11 (other manufacturing industries), Sector 15 (transportation and communication) and Sector 18 (personal, community, and household services) were energy-intensive sectors which contributed greatly to the total CO₂ emissions during 2000-2007. In contrast, between 2007 and 2011, besides the energy-intensive sectors mentioned above, manufacturing sectors such as Sector 9 (basic metal industry), Sector 8 (manufacture of non-metallic mineral products), Sector 7 (manufacture of industrial chemicals) and Sector 4 (textile, wearing apparel and leather industries) also have high CO₂ emissions and strongly impacted the changes in CO₂ emissions in this period. These results suggest that the mitigation of domestic CO₂ emissions in Vietnam can be obtained by CO₂ pollution intensity reduction, structural adjustment and optimization of production and final demand activities. Furthermore, optimizing international trade is greatly significant for the abatement of national and global CO₂ generation.

This research is especially developed for the Vietnam context, but the same methods can be easily adapted for analyzing other economies using existing IO table and pollution data. Furthermore, these methods can be applied for analyzing the structural changes of any kind of pollutant induced by various economic sectors, once the data are available. The limitation of this study is that it just focuses on CO₂ emissions from energy sectors, while CO₂ emissions from remaining sectors are not considered. Future work can develop a model to evaluate the changes in CO₂ pollution intensity as the industrial and manufacturing sectors apply more advanced treatment and cleaner technology. Furthermore, a model should be developed in the future to see the effect of reduced birth rate in CO₂ emission. In addition, tools for handling data uncertainty can be coupled in this model to result in more robust analysis.

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Appendix

Structural decomposition method

As presented in Methods, the changes of CO₂ emissions are decomposed into five terms and each term expresses the contribution of the changing factor to total CO₂ emissions. According to Koh et al. (2016), Eq. 6 is rewritten as follows:

$$\Delta Q = w^p \Delta p + w^q \Delta q + w^L \Delta L + w^{y_s} \Delta y_s + w^{y_v} \Delta y_v \tag{A.1}$$

where w^p, w^q, w^L, w^{y_s} and w^{y_v} are called weight or coefficient for each the change of factor (Δ factor) population, pollution intensity, production structure, consumption structure and consumption volume, respectively. Due to no unique solution for the decomposition, Dietzenbacher and Los (1998) suggested to use the average of all the k! ($5! = 120$) decomposition equations. The calculation of Δ factor and weight or coefficient were given in detail in Koh et al. (2016). In light with this, assuming that in each given period, the changing factor is calculated from base year (t-1) to the target year (t). Therefore, each “w” attached to the Δ factor in Eq. A.1 can be expressed, for example:

$$w^p \Delta p = \frac{1}{120} [(24 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t-1)} \cdot y_{s(t-1)} \cdot y_{v(t-1)}) + (6 \cdot \Delta p \cdot q \cdot L_{(t-1)} \cdot y_{s(t-1)} \cdot y_{v(t-1)}) + (6 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t)} \cdot y_{s(t-1)} \cdot y_{v(t-1)}) + (6 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t-1)} \cdot y_{s(t)} \cdot y_{v(t-1)}) + (6 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t-1)} \cdot y_{s(t-1)} \cdot y_{v(t)}) + (4 \cdot \Delta p \cdot q_{(t)} \cdot L_{(t)} \cdot y_{s(t-1)} \cdot y_{v(t-1)}) + (4 \cdot \Delta p \cdot q_{(t)} \cdot L_{(t-1)} \cdot y_{s(t)} \cdot y_{v(t-1)}) + (4 \cdot \Delta p \cdot q_{(t)} \cdot L_{(t-1)} \cdot y_{s(t-1)} \cdot y_{v(t)}) + (4 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t)} \cdot y_{s(t)} \cdot y_{v(t-1)}) + (4 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t)} \cdot y_{s(t-1)} \cdot y_{v(t)}) + (4 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t)} \cdot y_{s(t)} \cdot y_{v(t)}) + (6 \cdot \Delta p \cdot q_{(t-1)} \cdot L_{(t)} \cdot y_{s(t)} \cdot y_{v(t)}) + (6 \cdot \Delta p \cdot q_{(t)} \cdot L_{(t-1)} \cdot y_{s(t)} \cdot y_{v(t)}) + (6 \cdot \Delta p \cdot q_{(t)} \cdot L_{(t)} \cdot y_{s(t-1)} \cdot y_{v(t)}) + (6 \cdot \Delta p \cdot q_{(t)} \cdot L_{(t)} \cdot y_{s(t)} \cdot y_{v(t-1)}) + (24 \cdot \Delta p \cdot q_{(t)} \cdot L_{(t)} \cdot y_{s(t)} \cdot y_{v(t)})]$$

Similarly, the other terms can be obtained using Table A.1

Table A.1 Subscripts for the components of Δ factors and their weights.

Subscript for the components in the of Δ factors				weight
Order of factors				
first	second	third	fourth	
t-1	t-1	t-1	t-1	24
t	t-1	t-1	t-1	
t-1	t	t-1	t-1	6
t-1	t-1	t	t-1	
t-1	t-1	t-1	t	
t	t	t-1	t-1	
t	t-1	t	t-1	4
t	t-1	t-1	t	

t-1	t	t	t-1	
t-1	t	t-1	t	
t-1	t-1	t	t	
t-1	t	t	t	
t	t-1	t	t	6
t	t	t-1	t	
t	t	t	t-1	
t	t	t	t	24

Table A.2 Sectoral pollution intensity (IEA, 2016)

Sector code	q (kgCO ₂ /million VND)		
	2000	2007	2011
1	9.196	9.064	6.443
2	0.000	0.000	0.000
3	0.000	0.000	13.256
4	0.000	0.000	32.043
5	0.000	0.000	0.000
6	0.000	0.000	107.767
7	0.000	0.000	23.804
8	0.000	0.000	283.077
9	0.000	0.000	58.349
10	0.000	0.000	0.000
11	917.003	512.650	102.207
12	0.202	0.180	0.181
13	0.000	0.000	0.000
14	31.664	17.696	16.974
15	402.866	151.956	98.525
16	2.990	4.122	3.350
17	2.990	5.038	4.375
18	115.645	254.782	217.159

Table A.3 Contribution of different final demand categories to CO₂ emissions (kt) during 2000-2007

Sector code	Categories				
	Household	Government	Investment	Export	Import
1	352	12	133	838	-702
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
6	0	0	0	0	0
7	0	0	0	0	0
8	0	0	0	0	0
9	0	0	0	0	0

10	0	0	0	0	0
11	6505	-516	-7891	20537	4250
12	10	0	2	5	-10
13	0	0	0	0	0
14	-732	-34	-57	-467	968
15	15196	755	4594	4364	-11175
16	317	21	56	55	-170
17	24	91	0	0	-1
18	8083	3346	130	-1423	-1900
Sum	29,756	3,675	-3,033	23,908	-8,740

Table A. 4 Contribution of different final demand categories to CO₂ emissions (kt) during 2007-2011

Sector code	Categories				
	Household	Government	Investment	Export	Import
1	-284	-5	-8	-15	268
2	0	0	0	0	0
3	4707	34	-2629	5614	-1736
4	3591	48	-1503	14344	-8373
5	0	0	0	0	0
6	4474	295	430	4846	-6485
7	9346	340	3312	12179	-21960
8	7950	325	21240	13662	-19119
9	10874	257	22115	20440	-50305
10	0	0	0	0	0
11	-22505	-1037	-9638	-32735	39912
12	1	0	4	8	-8
13	0	0	0	0	0
14	795	-13	-447	1695	-3
15	3623	-51	-2674	5432	106
16	412	18	40	210	-272
17	59	54	0	0	0
18	3978	804	143	985	-1359
Sum	27,021	1,069	30,385	46,665	-69,334

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