

Jaruwan Chontanawat; Wiboonchutikula, Paitoon; Atinat Buddhivanich

Article

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An LMDI decomposition analysis of carbon emissions in the Thai manufacturing sector

Jaruwan Chontanawat^{a,*}, Paitoon Wiboonchutikula^b, Atinat Buddhivanich^c

^a *Department of Social Sciences and Humanities, School of Liberal Arts, King Mongkut's University of Technology Thonburi, 126 Prachu-Uthit Rd., Thungkru, Bangkok 10140, Thailand*

^b *Faculty of Economics, Chulalongkorn University, 254 Phayathai Rd, Pathumwan, Bangkok 10330, Thailand*

^c *Iron and Steel Institute of Thailand, 1st-2nd Fl., Bureau of Industrial Sectors Development, Soi Trimitr, Rama IV Road, Prakanong, Klong-Toey, Bangkok 10110, Thailand*

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Abstract

During the last two decades CO₂ emissions increased rapidly along with the growth of production and energy use in the industrial sector in Thailand. We use the Logarithmic Mean Divisia Index (LMDI) method to decompose the source of changes of CO₂ emission level and CO₂ emission intensity of the sector for the period 2005–2017. The results show that during this period, on average the amount of CO₂ emissions and the CO₂ emission intensity increased annually. The structural change effect helped reduce both the amount of CO₂ emissions and the emission intensity. However, the increased energy intensity of individual industries led to an increase in the amount of CO₂ emission and CO₂ emission intensity. The study thus calls for policies to reduce energy intensity of firms in the manufacturing sectors in order for Thailand to benefit from industrial growth without having to incur greater polluting emissions.

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Keywords: CO₂ emissions; LMDI decomposition; Manufacturing industries; Thailand

1. Introduction

Thailand is a newly industrialized country with the manufacturing sector growing rapidly from the late 1980s. As a result of industrialization both energy consumption and carbon dioxide (CO₂) emissions have grown in line with the expanded industrial activity. In the past two decades, particularly after the mid-2000s, the manufacturing sector was the one which released the most CO₂. The sector's rising energy consumption increased its CO₂ emission. During the period, the energy consumption grew at 5% a year, leading the CO₂ emission to increase by 6%. It is, therefore, crucial to make efforts to reduce CO₂ emissions in Thailand's industries in order to address the problem

* Corresponding author.

E-mail address: jaruwan.cho@mail.kmutt.ac.th (J. Chontanawat).

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of climate change. CO₂ emissions can be decreased by directly reducing the amount of CO₂ emissions of individual industries or by reducing each industry's emission intensity (CO₂ emissions per unit of production). Our study aims to contribute to the literature on the source of the change of both the amount of carbon emissions and the carbon emission intensity of manufacturing industries in developing countries, focusing on the case of Thailand. We first measure the CO₂ emission intensity and the CO₂ emission level of manufacturing industries in Thailand during the period (2005–2017). Then we decompose both the change of the CO₂ emission level and the change of CO₂ emission intensity.

2. Methodology

2.1. CO₂ emission intensity

To analyze the source of annual change of CO₂ emission intensity from the base year we decompose the change of the CO₂ emission intensity into two components namely, the structural change effect and the intensity effect. The structural change effect is due to the shift of production composition among sub-sectors which have different levels of CO₂ emission intensity. The intensity effect comes from the ability of individual sub-sectors to change their CO₂ emission intensity effect. In our study we follow Ang [1,2] and use the logarithmic mean Divisia decomposition index (LMDI) in multiplicative form to investigate annual changes of CO₂ emission intensity in Thailand's manufacturing industry for the periods 2005–2017. LMDI is a worldwide method and has been widely accepted among scholars for the decomposition analysis for both energy and CO₂ emissions in either aggregate or disaggregate levels, Ang and Zhang [3], Xu and Ang [4], Chontanawat et al. [5], Moutinho et al. [6], Shahiduzzaman et al. [7] and Roinioti and Koroneos [8]. The most recent work on decomposition analysis of carbon emissions in industry are Hammond and Norman [9], Jeong and Kim [10], Yan and Fang [11], Lin and Long [12], Pappas et al. [13] and Li et al. [14].

The aggregated industrial CO₂ emission intensity can be defined in Eq. (1) as below.

$$CI = \frac{C}{Y} \quad (1)$$

where

CI = CO₂ emission intensity (kton/billion Baht)

C = CO₂ emissions in manufacturing industry (kton)

Y = Value-added of manufacturing output at constant 2002 prices (billion Baht)

The change of the above CO₂ emission intensity is decomposed into two main components namely, structural changes of manufacturing production, and the CO₂ emission intensity changes of individual manufacturing sub-sectors.

The decomposition can be expressed in the following forms and the computation is done using the method as shown in Eqs. (2) to (6).

$$D_{tot} = D_{str} \times D_{int} = \frac{CI_t}{CI_0} \quad (2)$$

$$D_{str} = \exp \sum_i^n \left[\frac{L[w_{i,t}, w_{i,0}]}{\sum_i^n L[w_{i,t}, w_{i,0}]} \ln \left[\frac{S_{i,t}}{S_{i,0}} \right] \right] \quad (3)$$

$$D_{int} = \exp \sum_i^n \left[\frac{L[w_{i,t}, w_{i,0}]}{\sum_i^n L[w_{i,t}, w_{i,0}]} \ln \left[\frac{CI_{i,t}}{CI_{i,0}} \right] \right] \quad (4)$$

$$L[w_{i,t}, w_{i,0}] = \frac{w_{i,0} - w_{i,t}}{\ln \left[\frac{w_{i,0}}{w_{i,t}} \right]} = \frac{\frac{C_{i,0}}{C_0} - \frac{C_{i,t}}{C_t}}{\ln \left[\frac{\frac{C_{i,0}}{C_0}}{\frac{C_{i,t}}{C_t}} \right]} \quad (5)$$

$$S_i = \frac{Y_i}{Y} \quad (6)$$

where

D_{tot} = Total change of CO₂ emission intensity in year t relative to the reference year

D_{str} = Change of total CO₂ emission intensity due to the structural change effect

D_{int} = Change of total CO₂ emission intensity due to the change of CO₂ emission intensity of individual sub-sectors.

S_i = Ratio of output of sub-sector i to the aggregate manufacturing output.

L = L function representing the logarithmic average of $w_{i,0}$ and $w_{i,t}$, where w 's are the CO₂ emissions of individual subsectors in different time periods.

2.2. CO₂ emission level

In addition to analyzing the sources of the change of the CO₂ emission intensity, we also use the decomposition analysis to identify the source of the change of the amount of CO₂ emissions in Thailand's manufacturing industries. The computed results will be helpful for further identifying the main areas where CO₂ emission intensity needs to be reduced. The decomposition method followed Ang [2].

Let

$$CI_i = \frac{C_i}{Y_i} \quad (7)$$

$$S_i = \frac{Y_i}{Y} \quad (8)$$

$$I_i = \frac{E_i}{Y_i} \quad (9)$$

$$M_{ij} = \frac{E_{ij}}{E_i} \quad (10)$$

$$U_{ij} = \frac{C_{ij}}{E_{ij}} \quad (11)$$

where

C = CO₂ emissions in manufacturing industry (kton)

E = Energy consumption in manufacturing industry (ktoe)

Y = Value-added of manufacturing output at constant 2002 prices (billion Baht)

Q = Total industrial activity level (billion Baht)

S_i = Ratio of output of subsector i to the aggregate output

I = Energy intensity (ktoe/billion Baht)

M_{ij} = Energy-mix of j th energy type of i th subsector

U_{ij} = CO₂ emission factor (kton/ktoe) of j th energy type of i th subsector

The change of the CO₂ emissions level can be decomposed into five components namely, total production in the manufacturing sector (activity effect), composition (structural production change effect), subsectoral energy intensity (energy intensity effect), subsectoral energy composition (energy-mix effect), and CO₂ emission factors (emission-factor) effect. The decomposition of CO₂ emissions of the manufacturing sector in our study is expressed in the following form (Eqs. (12) to (19)):

$$D_{tot} = D_{act} \times D_{str} \times D_{int} \times D_{mix} \times D_{emf} = \frac{C_t}{C_0} \quad (12)$$

$$D_{act} = \exp \sum_{ij}^n \left[\frac{L[w_{ij,t}, w_{ij,0}]}{\sum_i^n L[w_{i,t}, w_{i,0}]} \ln \left[\frac{Q_t}{Q_0} \right] \right] \quad (13)$$

$$D_{str} = \exp \sum_{ij}^n \left[\frac{L[w_{ij,t}, w_{ij,0}]}{\sum_i^n L[w_{i,t}, w_{i,0}]} \ln \left[\frac{S_{i,t}}{S_{i,0}} \right] \right] \quad (14)$$

$$D_{int} = \exp \sum_{ij}^n \left[\frac{L[w_{ij,t}, w_{ij,0}]}{\sum_i^n L[w_{i,t}, w_{i,0}]} \ln \left[\frac{I_{i,t}}{I_{i,0}} \right] \right] \quad (15)$$

$$D_{mix} = \exp \sum_{ij}^n \left[\frac{L[w_{ij,t}, w_{ij,0}]}{\sum_i^n L[w_{i,t}, w_{i,0}]} \ln \left[\frac{M_{ij,t}}{M_{ij,0}} \right] \right] \quad (16)$$

$$D_{emf} = \exp \sum_{ij}^n \left[\frac{L[w_{ij,t}, w_{ij,0}]}{\sum_i^n L[w_{i,t}, w_{i,0}]} \ln \left[\frac{U_{ij,t}}{U_{ij,0}} \right] \right] \quad (17)$$

$$L[w_{i,t}, w_{i,0}] = \frac{w_{i,0} - w_{i,t}}{\ln \left[\frac{w_{i,0}}{w_{i,t}} \right]} = \frac{C_{i,0} - C_{i,t}}{\ln \left[\frac{C_{i,0}}{C_{i,t}} \right]} \quad (18)$$

$$L[w_{ij,t}, w_{ij,0}] = \frac{w_{ij,0} - w_{ij,t}}{\ln \left[\frac{w_{ij,0}}{w_{ij,t}} \right]} = \frac{C_{ij,0} - C_{ij,t}}{\ln \left[\frac{C_{ij,0}}{C_{ij,t}} \right]} \quad (19)$$

where

D_{tot} = Total change of CO₂ emissions in year t relative to the reference year

D_{act} = Change of total CO₂ emissions due to activity effect

D_{str} = Change of total CO₂ emissions due to the structural change effect

D_{int} = Change of total CO₂ emissions due to the change of energy intensity of individual sub-sectors

D_{mix} = Change of total CO₂ emissions due to the subsectoral energy mix effect

D_{emf} = Change of total CO₂ emissions due to the emission factor effect

Sources of data are from Department of Alternative Energy Development and Efficiency (DEDE) [15], Energy Policy and Planning Office (EPPO) [16], and Office of the National Economic and Social Development Council (NESDB) [17].

3. Results

The CO₂ emissions from the manufacturing sector come directly from the use of energy in the form of fossil fuels namely oil, coal and natural gas and indirectly from the use of electricity which in turn uses the above fossil fuels in its production process. During 2005 to 2017 the industries which emitted the most amount of CO₂ were non-metallic mineral products, food and beverages, chemicals and chemical products. In terms of growth, the industries with the highest growth of CO₂ emissions were food and beverages, paper and paper products, miscellaneous products, chemicals and chemical products. In Thailand, the industries which emitted the most CO₂ were not necessarily the ones with the largest production volume.

The industries with the largest production volumes which did not emit the most CO₂ were machinery and equipment comprising of the production of electronic and electrical equipment and transport equipment. Meanwhile, capital-intensive industries such as the non-metallic mineral products, which emitted a large amount of CO₂, maintained their relatively small share of production in the total manufacturing sector. Since the largest industries in terms of production size were not the ones which emitted the most CO₂, it is beneficial to measure CO₂ emissions per unit of output (CO₂ emission intensity) across industries in order to examine the side effects of each industry's production on environmental problems.

The CO₂ emission intensity of the manufacturing industry in Thailand increased rapidly in the first half of the 1990s before the 1997 economic crises but was on a declining trend up to 2007. During 2007 to 2017, the trend reversed and was on the rise again. This is because although the production of industries with high CO₂ emission intensity particularly, nonmetallic mineral products, metal products, paper and paper products grew much slower than the industries with low CO₂ emission intensity, their CO₂ emission intensity grew much faster than the rest. It implies that while the structural change of production helped reduce the amount of CO₂ emission of the manufacturing sector, the increased CO₂ emissions intensity of industries with high CO₂ emission dominated the benefit of production structural change on the CO₂ emission reduction. Therefore, in order to find factors leading to CO₂ emission reduction in the manufacturing sector, we need to analyze the change of CO₂ emission intensity by its source, structural change effect and CO₂ emission intensity effect.

The decomposition of the change of the CO₂ emission intensity of Thailand's manufacturing sector in Fig. 1 shows that in each year during the period of 2005 to 2017, the CO₂ emission intensity increased at the average rate of 2.6% compared to the base year of 2005. However, on the basis of individual years, the change of CO₂ emission intensity fluctuated. In the years with a reducing CO₂ emission intensity before 2011, the structural change effect

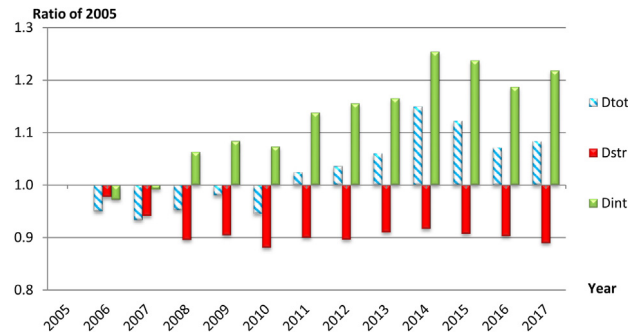


Fig. 1. Decomposition of CO₂ emission intensity of manufacturing industry during 2005–2017.

dominated the intensity effect. For the rest of the years the intensity effect was so strong that it was not possible for the structural change effect to offset it and consequently, the CO₂ emission intensity of the whole manufacturing sector increased compared to the base year. If wanting to reduce the CO₂ emission intensity of the sector, efforts should be made to reduce the CO₂ emission intensity of individual industries (intensity effect), particularly the ones with high CO₂ emission intensity.

Our study also analyzed the source of the change of CO₂ emission in terms of level shown in Fig. 2. The amount of CO₂ emissions in Thailand's manufacturing sector increased almost every year compared to the base year of 2005. The increase was small during the years with low manufacturing production growth but became greater when the growth of the sector picked up. The increases in CO₂ emissions came from five sources namely, activity effect, structural effect, energy intensity effect, energy mix effect and emission factor effect. Among these sources the yearly increase of the CO₂ emissions came mostly from the growth of manufacturing production, followed by the increases of energy intensity. The energy mix and emission factor effects all had little impact. In contrast, the structural change effect helped decrease the CO₂ emissions in almost all years. However, their beneficial effects could not offset the detrimental effects of the increased energy intensity of most industries. As a result, CO₂ emissions increased as the manufacturing sector grew. The increased energy intensity of individual industries came from the increasing use of coal, oil and natural gas. Therefore, without an attempt to effectively increase the efficiency of the use of each of the fossil fuels above, it would be difficult to reduce the energy intensity of manufacturing sector and balance the industrial growth with environmental deterioration in Thailand.

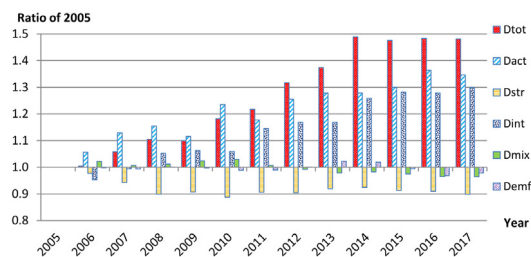


Fig. 2. Decomposition of CO₂ emission of manufacturing industry during 2005–2017.

4. Conclusion

Our computed results show that during the whole period (2005–2017), both the amount of CO₂ emissions and the CO₂ emission intensity increased annually. The structural change effect helped reduce both the CO₂ emission intensity and the amount of CO₂ released from the manufacturing sector. However, the energy intensity which increased steadily during 2008–2017 increased the CO₂ emissions. This explains why the CO₂ emission intensity of the manufacturing sector increased during the study period. The findings call for policies to reduce energy intensity of individual industries at the firm level in order to reduce the amount of CO₂ emissions and the CO₂ emission intensity and for Thailand to have high industrial growth with reduced carbon emissions.

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