International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2017, 7(2), 26-33.

A Study of Energy Efficiency and Mitigation of Carbon Emission: Implication of Decomposing Energy Intensity of Manufacturing Sector in Taiwan

Yu-Kai Huang[1], Jyh-Yih Hsu[2]*, Lih-Chyun Sun[3]

[1]Department of Agricultural Economics, Texas A&M University, College Station, Texas, USA, [2]Center for Industrial Development Research, National Chung Hsing University, Taichung, Taiwan, [3]National Policy Foundation, Taipei, Taiwan.
*Email: cidrnchu01@gmail.com

ABSTRACT

This paper applies the logarithmic mean divisia index (LMDI) approach to examine aggregate energy intensity of the manufacturing sector in Taiwan from 1982 to 2014. We decompose aggregate energy intensity into three effects, which are the fuel mixed effect, the sectoral energy intensity effect, and the substructural effect. The results show that aggregate energy intensity is highly correlated with carbon intensity in Taiwan. Moreover, the aggregate energy intensity is mainly driven by sectoral energy intensity effect. The influence of the substructural effect and fuel mixed effect on improving the aggregate energy intensity has become larger in the recent years. The policy implication of study results suggests that internalizing the costs of carbon emission, creating incentives to invest energy-saving technology, establishing a fair and efficient electricity market are needed in Taiwan.

Keywords: Logarithmic Mean Divisia Index, Energy Intensity, Carbon Intensity, Structural Change, Fuel Mixed Effect
JEL Classifications: O1, O2, Q4, Q5

1. INTRODUCTION

The IPCC (2007) shows that there is a significant relationship between greenhouse gas (GHG) emission and climate change. There are some previous studies (IEA, 2012; IEA, 2008), which further point out that GHGs are mainly emitted from energy. Thus, many countries realized the importance of understanding how effectively energy was consumed in their economies and how to improve energy efficiency (Ang, 2006). Therefore, most countries have set efficient energy improvement as an important policy goal for tackling the problem of climate change. For example, the European Union (EU) intends to save 20% energy consumption by 2020 and 27% or greater by 2030. The US also has called for doubling energy efficiency by 2030. Group of Twenty has set different targets for improving energy efficiency in certain industries (IEA, 2014). In addition, Taiwan, whose its carbon emission level ranks 21st in the world (IEA, 2015), is not a member of the United Nations Framework Convention on Climate Change (UNFCCC). To reduce its emission, the government of Taiwan sets a policy target[1] for improving energy efficiency more than 20% in 2015 against the level of 2005 and improving at least 50% in 2025. In order to achieve the above policy objective, it is important and necessary to examine energy intensity and its underlying factors.

The aim of this paper is to identify the variation trend of energy intensity of the manufacturing sector in Taiwan from 1982 to 2014; we decompose energy intensity into the following factors: (1) Fuel mixed effect that captures the impact of the energy structure, which hasn't been examined in previous Taiwanese studies; (2) sectoral energy intensity effect, which captures the impact of energy efficiency in the manufacturing sector; and (3) substructural effect, which captures the impact from changes in the manufacturing subsector. Lastly, we conclude with corresponding policy implication and strategic measures for improving energy efficiency and mitigating emission.

1 The target is based on "sustainable energy policy framework" issued in 2008.

The following sections of this paper are organized as a literature review and background introduction in Taiwan in Section 2. The methodology of the multiplicative index decomposition analysis (IDA) model in Section 3. Description of data is shown in Section 4. The result and discussion are shown in Section 5. Lastly, conclusion and policy implication is in Section 6.

2. LITERATURE REVIEW AND BACKGROUND OF TAIWAN

2.1. IDA Relevant Literature Review

To decompose the energy intensity, there are two methodologies that can be utilized, which are structural decomposition analysis (SDA) and IDA. The former is based on input-output theorem, and the latter is based on index number theory. Hoekstra and van der Bergh (2003) summarize the fundamental differences between these two approaches. First of all, since SDA uses the input-output framework, and IDA uses aggregate sector information, one merit of IDA is a lower data requirement which, however, causes it to have a less detailed decomposition of the economic structure than SDA. Furthermore, SDA can capture indirect and direct demands, while IDA can only assess the impact of the direct effects. Thirdly, SDA is able to assess a range of technological effects and final demand effects which are not available for IDA. Nevertheless, IDA is more suitable, when analyzing data at any level of aggregation in term of time series, which is what this study focuses.

The evolutions of IDA in the previous research can be traced back prior to 1990. Ang (2015) states that most decomposition analysis studies were based on the concept of Laspeyres index before 1990. Thereafter, divisia index was the mainstream method for the IDA studies. Prior to 2000, arithmetic mean divisia index proposed by Boyd et al. (1988) was the major approach applied in decomposition research; however, currently logarithmic mean divisia index (LMDI) has been the most popular method.

Ang (2004) points out there are two main merits of LMDI: (1) LMDI doesn't leave an unexplained residue, so it can be perfectly decomposed; and (2) LMDI can deal with the zero data which is an important nature for empirical study (Ang and Liu, 2007). Due to these benefits, the LMDI method has been used widely in decomposition relevant research recently. Besides the above advantages of LMDI, there are also some comparative studies pointing out that LMDI is the superior method to apply in decomposing intensity indicators (Liu and Ang, 2003; Ang et al., 2010; Ang, 2015).

There are several studies using LMDI to decompose carbon emission, energy consumption, carbon intensity and energy intensity in a single country or across countries. The LMDI method was applied to analyze energy and CO_2 intensity in industrial sectors in Thailand (Bhattacharyya and Ussanarassamee, 2004; Bhattacharyya and Ussanarassamee, 2005). Vinuya et al. (2009) applied LMDI to decompose CO_2 emission in the USA between 1990 and 2004. González and Martinez (2012) analyzed the carbon intensity from 1965 to 2010 in Mexico. Hasanbeigi et al. (2012) utilized LMDI to analyze the energy intensity of California industries. Zhang and Guo (2013) identified the factors contributing to the change in rural residential and commercial energy consumption in China by LMDI. Marrero and Ramos-Real (2013) used LMDI to decompose energy intensity in EU-15 countries (except Luxembourg) during 1991-2005. Emodi and Boo (2015) decomposed CO_2 emission from electricity generation in Nigeria by LMDI. Obadi and Kor (2015) investigated driving forces of energy consumption in EU-28 by LMDI decomposition technique.

Recent studies have focused on the energy consumption structure (i.e. the fuel mixed effect). Shahiduzzaman and Alam (2013) analyzed the variation of energy intensity in Australia and separated underlying factors, such as the sectoral energy intensity effect, the structural effect, and the fuel mixed effect. Lescaroux (2008) discussed the decomposition of energy intensity in manufacturing industries in the USA by the above three effects during 1974-1998 as well. Ma and Stern (2008) applied the same approach to analyze the variation of energy intensity in China from 1980 to 2003.

IDA has also been applied to empirical cases in Taiwan. Hsu and Hsu (1998) applied the simple average divisia index to decompose variation of energy intensity by considering the sectoral energy intensity effect and the structural effect during 1961-1990. Huang and Tsao (2005) analyzed the variation of energy consumption in transport sector during 1990-2003. The divisia index also was applied to identify the key factors influencing Taiwan's CO_2 emission changes of the industrial sectors (Lin et al., 2006), and of highway vehicles (Lu et al., 2007). Nevertheless, none of the above literature applied the LMDI methodology to examine the variation of energy intensity of the manufacturing sector in Taiwan by the three decomposition factors (i.e. the fuel mixed effect, the sectoral energy intensity effect, the subsectoral effect).

Previous studies didn't separate the fuel mixed effect from the sectoral intensity effect. In the sense of neoclassical economics, the fuel mixed effect, which captures substitution among different energy sources, presents a move along a production isoquant. On the other hand, the sectoral intensity effect, which captures technological change, presents a shift in the entire isoquants (Ma and Stern, 2008). The underlying reason of separating fuel mixed effect and sectoral intensity effect is that green energy technology and climate policy have unprecedentedly evolved in the recent years in Taiwan. To distinguish the effect influenced by these changes, separating the fuel mixed effect from the sectoral intensity effect is needed.

Hence, the unique contribution of this paper is not only to fill the above gap but also to provide the latest corresponding strategy for improving energy efficiency and mitigating emission.

2.2. Background Statement for Taiwan

2.2.1. Gross domestic product (GDP), the growth rate of economic, energy consumption, and the population in Taiwan

The GDP per capita, the economic growth rate, the energy consumption and the population are illustrated in Figure 1. It indicates that the annual economic growth rate stayed around 4%

on average, with exception of the years 2001 and 2009. Thus, the GDP per capita increased gradually over the study period. The annual growth rate of energy consumption had a similar pattern with economic growth rate. In addition, the population growth rate declined gradually during the sample period, and it has been almost close to zero in the latest decade.

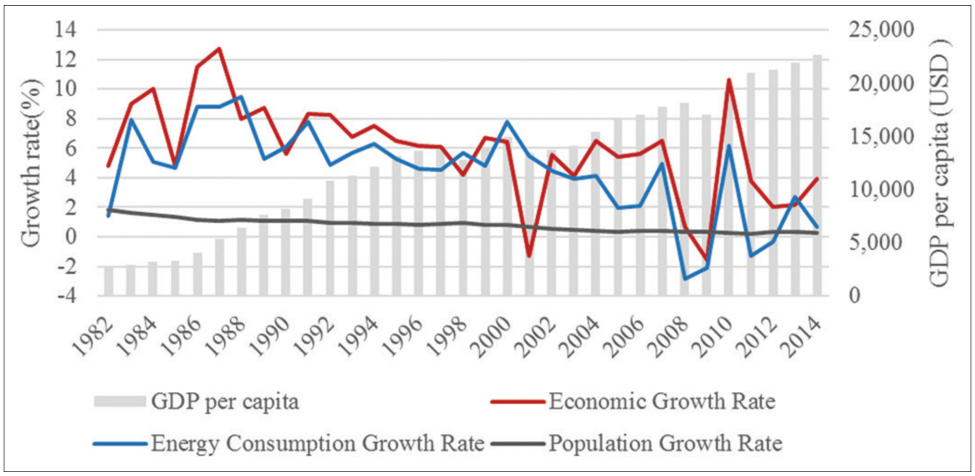
2.2.2. Structural GDP share in Taiwan

Table 1 shows that the economic structure over the study period in Taiwan. The GDP share of the agricultural and the transportation sectors had decreased continuously. In contrast, the service sector had risen gradually during the first two decades and remained at around 60% during rest of the study period. The share of the industrial sector declined in the 90's and raised up again after 2000. In terms of the subsectors level in the manufacturing sector, we can find out that the output share of the "electrical, electronic machinery and precision instruments subsector" grew from 2.7% in 1982 to 14.9% in 2014, which is the most significant increase among all the subsectors during 1982-2014. On the other hand, the GDP share of the most energy-consuming subsector, "petroleum, coal and associated products," is relatively small, around 0.9-2.1%. Another energy-consuming subsector, "chemical materials," has a GDP share around 1.5-2.1% over the study period.

2.2.3. Sectoral energy consumption share in Taiwan

The share of final energy consumption by the different subsectors and sectors is illustrated in Table 2. The industrial sector, the focus in this paper, had the largest share of energy consumption,

Figure 1: The gross domestic product per capita, the growth rate of economic, the energy consumption and the population



Source: DGBAS (2015), Bureau of Energy (2015)

Table 1: The GDP share in the sectors and major subsectors (Unit - %)

Sector	1982	1987	1992	1997	2002	2007	2012	2014
Agricultural	8.0	5.5	3.6	2.5	1.8	1.5	1.7	1.9
Industrial	44.7	47.5	39.1	34.1	32.1	33.9	33.7	35.6
Chemical materials	2.1	2.8	1.8	1.9	1.9	1.9	1.5	1.5
Non-metallic mineral products	1.6	1.4	1.7	1.1	0.8	1.0	1.0	0.7
Electrical, electronic machinery and precision instruments	2.7	4.0	3.8	5.6	8.8	12.5	13.2	14.9
Petroleum, coal and associated products	1.3	2.1	1.7	1.6	1.6	1.7	0.9	0.9
Electricity and gas supply	4.3	4.0	2.9	2.5	2.2	1.2	1.1	1.8
Transportation	4.4	4.6	4.5	4.4	4.1	3.2	3.0	2.9
Service	42.9	42.4	52.8	59.0	62.0	61.4	61.6	59.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Directorate General of Budget, Accounting and Statistics (2015). GDP: Gross domestic product

Table 2: The share of energy consumption in the sectors and major subsectors (Unit - %)

Sector	1982	1987	1992	1997	2002	2007	2012	2014
Agricultural	3.4	3.4	2.4	2.0	1.5	0.9	0.9	0.9
Industrial	65.1	63.4	59.6	59.2	61.8	65.0	65.3	65.8
Chemical materials	6.3	7.8	7.9	7.8	10.0	11.1	10.4	10.1
Non-metallic mineral products	9.8	7.7	7.0	5.2	3.7	3.1	3.1	2.8
Electrical, electronic machinery and precision instruments	1.1	1.8	1.9	2.8	5.1	7.0	8.7	9.1
Petroleum, coal and associated products	19.8	18.1	15.7	16.5	20.0	23.9	24.0	24.9
Electricity and gas supply	1.71	3.42	2.87	3.75	3.76	3.58	3.11	3.11
Transportation	12.4	13.3	16.4	16.2	14.1	12.4	12.3	12.1
Service	19.0	19.9	21.6	22.7	22.6	21.8	21.5	21.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Bureau of Energy (2015)

approximately two-thirds of the total, during the past 33 years. In the subsector level, the "petroleum, coal and associated products subsector" consumed around 15.7-24.9% of total energy consumption which was the largest energy consumption subsector. The second large subsector was the "chemical materials subsector," which consumed around 6.3-11.1% during the study period.

2.2.4. Sectoral energy consumption share in Taiwan

The share of final energy consumption by the different energy sources as shown in Figure 2. Note that the energy sources shown in Figure 2 are recalculated by breaking down the electricity term into its fuel components. The renewable energy shown in Figure 2 includes geothermal, solar photovoltaic, wind, conventional hydro, biomass and waste. The hydro illustrated in Figure 2 represents pumped hydro. The largest consumption share was from petroleum, but it had decreased continuously from 69% to 39.8%. Meanwhile, coal and natural gas grew gradually. The former one ascended from 12.2% to 31.5%, the latter one was more fluctuated but generally increased from 3.8% to 17.5%. It is important to address here that the consumption of nuclear energy had decreased from 19.8% to 8.1%.

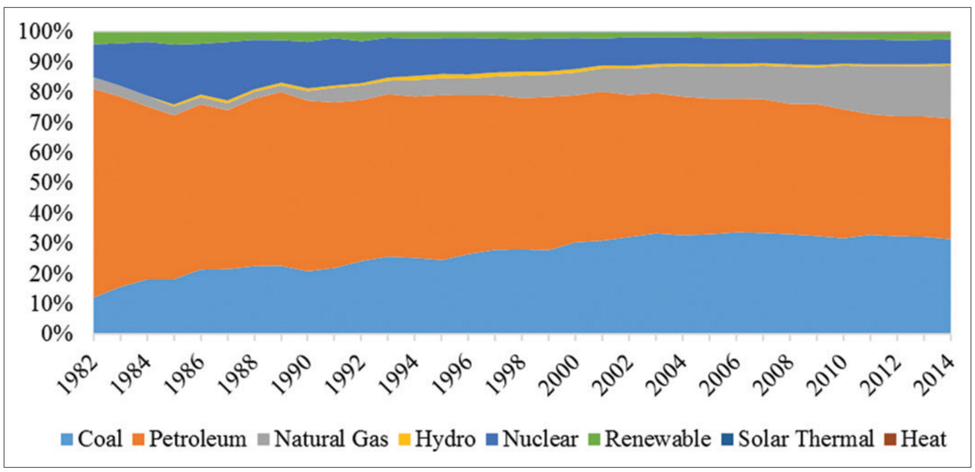
2.2.5. The relationship between energy intensity and GHG intensity

Ang et al. (2010) point out that improving energy efficiency is helpful to reduce GHG. To reexamine this claim in our study, we probed the relationship between energy intensity and GHG intensity during 1990-2013, and the result is shown in Figure 3. The trends of these three intensity indicators (energy intensity, CO_2 intensity, and GHG intensity) were highly correlated. The correlation coefficient between energy intensity and GHG intensity is 0.9630; on the other hand, the correlation coefficient between energy intensity and CO_2 intensity is 0.9726. This outcome not only echoes the statement of Ang et al. (2010), but also indicates that improved energy efficiency, i.e. decreased energy intensity, is an effective way to improve GHG intensity in Taiwan.

2.2.6. The cross countries energy intensity comparison

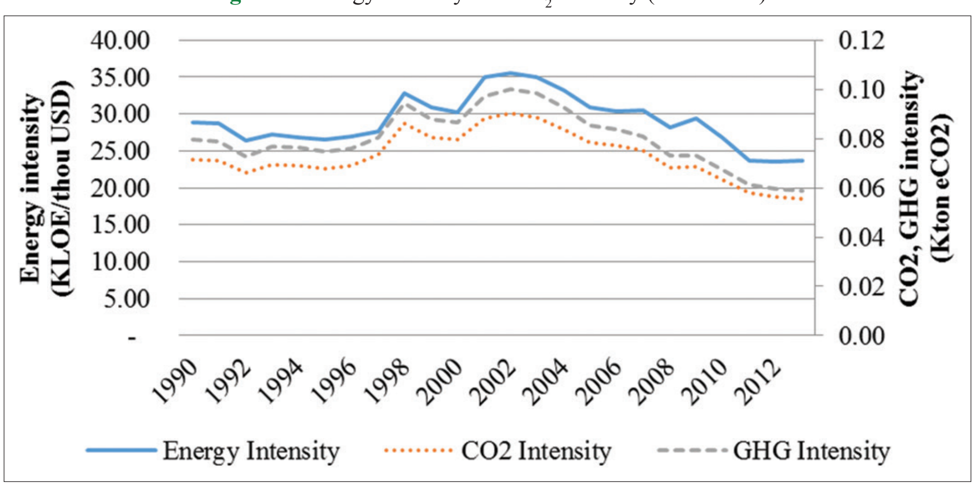
Figure 4 shows energy intensity comparison among the US, the UK, Germany, France, Japan, South Korea and Taiwan. The energy intensity had descended continuously in these selected countries. The UK, Germany, France and Japan have relatively low energy intensity, which is around 0.09 to 0.16 (toe/thousand USD) over the study period. On the other hand, the US and South Korea

Figure 2: Share of the final energy use (1982-2014)



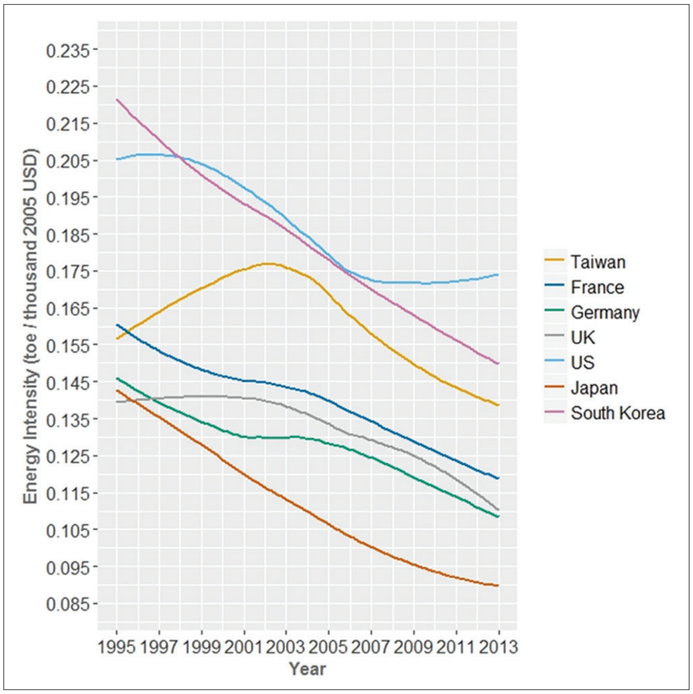
Source: Bureau of Energy (2015)

Figure 3: Energy intensity and CO_2 intensity (1990-2013)



Source: CO_2 data is from International Energy Agency (2015)

Figure 4: Energy intensity cross countries comparison



Source: Bureau of Energy (2015)

Note: (1) Energy intensity is total primary energy supply/gross domestic product (GDP) (purchasing power parity); (2) GDP is in 2005 USD

have relatively high energy intensity, which is around 0.15-0.22 (toe/thousand USD). The energy intensity in Taiwan was between these two groups.

3. METHODOLOGY

Since LMDI is commonly viewed as the preferred method among the variety of IDA methods (Ang, 2004), this study applies LMDI as the methodology for decomposing energy intensity. We decompose energy intensity into the following factors: (1) Fuel mixed effect, which captures the impact from the energy structure; (2) sectoral energy intensity effect, which captures the impact from energy efficiency in the manufacturing sector; and (3) substructural effect, which captures the impact from changes in the manufacturing sector.

The formulation of multiplicative LMDI-I[2] with the three decomposition terms (i.e. the fuel mixed effect, the sectoral energy intensity effect, and the substructural effect) is expressed as follows:

$$I = \frac{E}{Y} = \sum_m \sum_i \frac{E_{im}}{Y} = \sum_m \sum_i \frac{E_{im}}{E_i} \cdot \frac{E_i}{Y_i} \cdot \frac{Y_i}{Y} = \sum_m \sum_i F_m \cdot I_i \cdot S_i \quad (1)$$

Equation (1) indicates that aggregate energy intensity (I) is able to express as the ratio of energy consumption (E) and the overall GDP (Y). E_{im} denotes the consumption amount of fuel m in manufacturing subsector i; Y_i denotes the GDP in manufacturing subsector i; F_m denotes the share of fuel m in the total energy consumption; I_i denotes the energy intensity in manufacturing subsector i; S_i denotes the GDP share of manufacturing subsector i to the total GDP in the manufacturing sector.

The multiplicative of the change of energy intensity (D_{tot}) can be obtained as:

$$D_{tot} = \frac{I_t}{I_0} = D_{fm} \cdot D_{eff} \cdot D_{str} \quad (2)$$

Which represents that the change rate of aggregate energy intensity (D_{tot}) from time 0 to time t is equal to product of the change rate of fuel mixed effect (D_{fm}), the change rate of sectoral energy intensity effect (D_{eff}), and the change rate of substructural effect (D_{str}). Each change rate of effects can be calculated by follows:

$$D_{fm} = \exp\left[\sum_m \sum_i \ln\left(\frac{F_m^t}{F_m^0}\right) \frac{L\left(\frac{E_{im}^t}{Y^t}, \frac{E_{im}^0}{Y^0}\right)}{L\left(I^t, I^0\right)}\right]$$

$$D_{eff} = \exp\left[\sum_m \sum_i \ln\left(\frac{I_i^t}{I_i^0}\right) \frac{L\left(\frac{E_{im}^t}{Y^t}, \frac{E_{im}^0}{Y^0}\right)}{L\left(I^t, I^0\right)}\right]$$

$$D_{str} = \exp\left[\sum_m \sum_i \ln\left(\frac{S_i^t}{S_i^0}\right) \frac{L\left(\frac{E_{im}^t}{Y^t}, \frac{E_{im}^0}{Y^0}\right)}{L\left(I^t, I^0\right)}\right]$$

Where $L\left(\frac{E_{im}^t}{Y^t}, \frac{E_{im}^0}{Y^0}\right) / L\left(I^t, I^0\right)$ consists of a weight function in terms of logarithmic mean weight function. The logarithmic mean weight function can be calculated by

$$L(\alpha, \beta) = \frac{\beta - \alpha}{\ln \beta - \ln \alpha} = \frac{\beta - \alpha}{\ln\left(\frac{\beta}{\alpha}\right)} \quad (3)$$

Where $\forall$ $\alpha, \beta > 0, \alpha \neq \beta$

4. DESCRIPTION OF DATA

The GDP and the energy balance sheet in Taiwan are utilized in this study. The detail descriptions of these data are elaborated as below.

4.1. GDP Data

The source of GDP data is from the Directorate General of Budget, Accounting and Statistics (DGBAS). It is the yearly data from 1982 to 2014. The real GDP used in this study is based on the constant price of 2011. In order to easily compare the cross-country data with other research in the future, we exchange the currency unit from the New Taiwan dollar to the US dollar by the annual average exchange rate which is also from DGBAS.

2 Details of the LMDI approach can refer to Ang (2005)

4.2. Energy Consumption Data

Taiwan's energy balance sheet, regularly issued by the Bureau of Energy, is based on the same statistic approach as the Organization for Economic Cooperation and Development and the International Energy Agency. Columns of the energy balance sheet present the main end-used energy sources and the associated sub-sources. The main end-used energy sources which are used in this study include seven categories: "Coal and associated products," "crude oil and associated products," "natural gas," "biomass and waste," "electricity," "solar thermal," and "heat." Rows of the energy balance sheet are sorted by different subsectors. The manufacturing sector data is used in this study. The kiloliter of oil equivalent is applied as the unit of our energy consumption data, and the duration is as same as that of the GDP data from 1982 to 2014.

5. RESULTS AND DISCUSSION

This section presents the decomposition results of energy intensity in the manufacturing sector and then elaborates on corresponding policy implications from our results.

5.1. Decomposition of Aggregate Energy Intensity and Correlation Analysis

The decomposition result is shown in Figure 5 which indicates that the fuel mixed effect has a relatively trivial influence on aggregate energy intensity in the manufacturing sector, but its effect becomes more apparent in the last 10 years. The larger fuel mixed effect than before could be caused by the increase in use of natural gas and the decrease in the use of petroleum in the recent years in Taiwan (Figure 2). This almost neutral fuel mixed effect outcome is similar to previous studies (Ma and Stern, 2008; Shahiduzzaman and Alam, 2013).

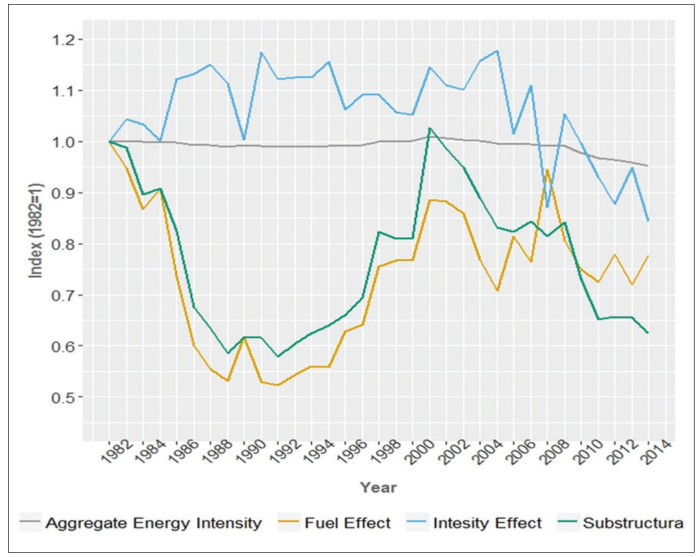
On the other hand, the sectoral energy intensity effect is the major factor affecting aggregate energy intensity. It decreased quickly during the 1980s and remained stable in the early 1990s. Thereafter, due to the Asian financial crisis, the Dot-com bubble, and the subprime mortgage crisis, there were deteriorations of the sectoral energy intensity effect in 1997, 2001 and 2008.

In view of the substructural effect, since the substructural effect captures more detailed information in the industrial structure, it performed more sensitively. The decreasing trend of the substructural effect has occurred since 2005. As shown in Tables 1 and 2, it can be caused by the higher increasing GDP share and relatively lower energy consumption share in the electrical, electronic machinery and precision instruments sector.

5.2. Policy Implication and Discussion

According to our decomposition results and high correlation outcome between energy intensity and GHGs intensity (Figure 3), we interpret the relevant implication and suggest a corresponding strategy for improving energy efficiency and mitigating emissions in this subsection.

Figure 5: Decomposition of aggregate energy intensity (1982-2014)



Source: Estimated by authors

Note: (1) Indices: 1982=1; (2) If index is smaller 1 which indicates that the energy intensity is less than the base year (i.e. energy efficiency is improved; and *vice versa*)

5.2.1. The role of the fuel mixed effect

The fuel mixed effect has a trivial influence on the aggregate energy intensity in our results and some previous studies (Ma and Stern, 2008; Shahiduzzaman and Alam, 2013). However, there are some plausible reasons to pay more attention to reducing energy intensity further by the fuel mixed effect in the future in Taiwan. First, the economic perspective in Taiwan is less likely to be as good as the growth rate in the 1980s, so the attribution of improving energy intensity from the sectoral intensity effect will be limited; second, the economy structure is hard to adjust in the short-term so that the improvement of energy intensity from substructural effect would not have a significant change in the short-run. Hence, the fuel mixed effect has relatively more room to be improved given some appropriate incentives compared with other effects in Taiwan.

Nevertheless, there is a critical challenge to adjust the fuel structure in Taiwan. The government of Taiwan is committed to achieving a "zero nuclear policy" by 2025. From Figure 2, we can find out that the ratio of nuclear energy has declined gradually since the mid-1980s; however, if the Taiwanese government would like to fulfill the commitment of the "zero nuclear policy," improve energy intensity, and mitigate emission of carbon, the fuel structure needs to switch to natural gas and renewable energy.

To achieve this objective, one of the feasible and effective policies is internalizing the cost of emission of carbon. To encourage the manufacturing sector, especially electricity generation, to use less-carbon-intensity fuels, cap and trade scheme should be implemented as soon as possible. To do so, the government of Taiwan should accelerate improvement at the emission report and monitor system, develop a carbon emission market in Taiwan, and connect with international carbon trading markets. This measurement can provide more economic incentives to level up energy efficiency and also replace coal-fired power plants with natural gas-fired or cogeneration power plant. In addition, decentralizing the electricity industry and establishing a fair and efficient electricity dispatching system can help to integrate more decentralized energy resources (small solar and wind turbine power).

5.2.2. Provide economic incentives to stimulate energy-saving technological innovation

The sectoral intensity effect played a key role in improving aggregate energy intensity in the manufacturing sector during the study period. However, when the economy is in recession, the aggregate energy intensity gets deteriorated. It shows that the energy-saving technology hasn't developed enough so that the economic growth can't decouple with energy consumption in Taiwan.

In order to make economic growth and energy consumption decoupling, it's necessary to increase investment in energy-saving technology. The energy costs, such as electricity, gas, and petroleum, are very low (Bureau of Energy, 2016). Thus, there's no strong incentive to introduce energy-saving technology. To enhance implementation of energy-saving technology, energy prices should reveal the externality cost of climate change by imposing a carbon or energy tax. Therefore, there will be more firms which are willing to involve in altering their production process to a less-carbon-intensity way.

5.2.3. Transformation of the industrial structure

Figure 6 shows the current industrial structure distribution sorted by energy consumption and the GDP. It illustrates that "petroleum and coal associated product," "chemical materials," "basic metal" and "electricity and gas supply" are the main high energy intensity subsectors in the industrial sector. Due to the essentially different characteristics among these subsectors, a policy-maker cannot apply the same standard of energy intensity to evaluate these distinct subsectors. However, we still can improve the energy efficiency from the above energy-intensive subsectors through implementing appropriate measures:

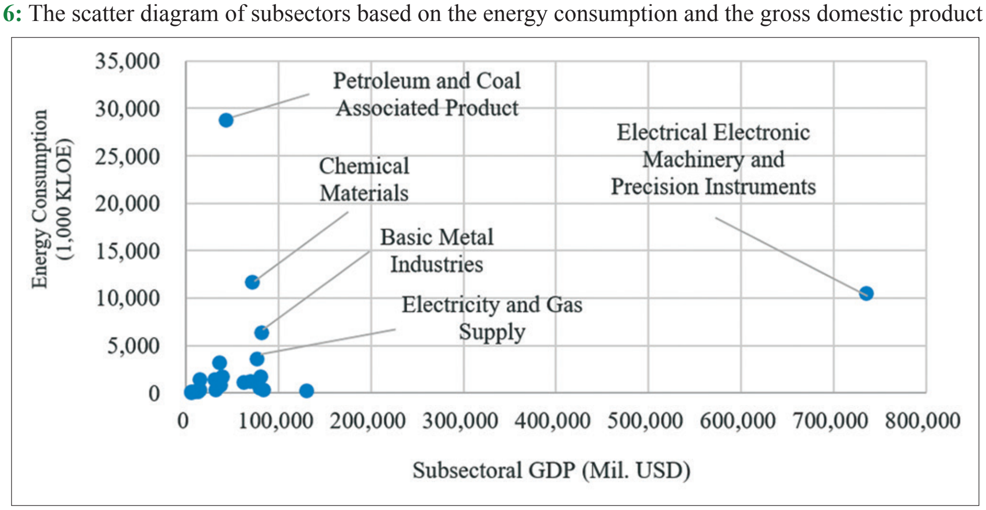
First of all, in order to manage the total amount of emission effectively, the above energy-intensive subsectors should be included in the cap and trade scheme. Secondly, the electricity and gas supply firms can increase its added-value by utilizing valuable energy usage data and coordinating with other industries, such as the retail market, transportation sector, and residential sector. Thirdly, the "electrical electronic machinery and precision instruments subsector" which is a vital subsector for economic growth and international trade in Taiwan is a highly competitive industry across countries. To maintain and enhance high-tech industries competitiveness, the government should create a friendly investment environment through establishing a fundraising platform which can share innovative ideas to potential investors. Thus, Taiwan can cultivate more high-added-value and innovative start-up companies and make the high-tech industry, a less energy-intensive industry, larger and stronger.

6. CONCLUSION

This paper concludes that how different factors influence the energy intensity in the manufacturing sector by LMDI approach during 1982-2014 in Taiwan, which is not a member of the UNFCCC and also needs to reveal its climate policy relevant information and experience. The corresponding policy implication and the strategic measures are discussed in this study.

The decomposition results show that the sectoral energy intensity effect is the major factor affecting the aggregate energy intensity. In addition, the substructural effect is more sensitive and fluctuated, and its impact on improving the aggregate energy intensity has gradually become larger recently. Likewise, the fuel mixed effect has a relatively slight impact on the aggregate energy intensity during first two decades of our study period, but its influence has become larger in recent years. Moreover, our correlation analysis indicates a highly correlated relationship between energy intensity and GHG intensity, and the similar pattern occurs between energy intensity and CO_2 intensity. It demonstrates that reducing the energy intensity is an effective way to improve the GHG intensity in Taiwan.

Figure 6: The scatter diagram of subsectors based on the energy consumption and the gross domestic product in 2014



Source: DGBAS (2015), Bureau of Energy (2015)

According to our results, the policy recommendations are as follows:

- Internalize the cost of emission of carbon by carrying out the cap and trade scheme in the major energy-intensive subsectors.
- Decentralize the electricity industry and establish a fair and efficient electricity dispatching system.
- Create incentives to increase investment in energy-saving technology through imposing carbon or energy levy or tax.
- Increase the added-value of traditional utility companies via utilizing their energy data with other industries, such as bundling with retail market, the transportation sector, and residential sector.
- Establish a fundraising platform which can share innovative ideas to potential investors and cultivate more high-added-value and innovative start-up companies.

This study provides analytical framework which combines more delicate decomposition analysis with the fuel mixed effect in the manufacturing sector in Taiwan, which is not a member of the UNFCCC, but its emission level cannot be neglected. Hence, the empirical results and the corresponding policy implication in Taiwan can effectively ease the international carbon leakage problem. In addition, the corresponding policy implication provided by this study are not only helpful to trace and examine the trajectory of energy efficiency performance in Taiwan, but also useful to compare the evolution of energy intensity with other countries.

7. ACKNOWLEDGMENTS

We wish to thank the Ministry of Science and Technology (Project No. 105-2221-E-005-067) for financial support.

REFERENCES

Ang, B.W. (2004), Decomposition analysis for policymaking in energy: Which is the preferred method? Energy Policy, 32(9), 1131-1139.

Ang, B.W. (2005), The LMDI approach to decomposition analysis: A practical guide. Energy Policy, 33, 867-871.

Ang, B.W. (2006), Monitoring changes in economy-wide energy efficiency: From energy - GDP ratio to composite efficiency index. Energy Policy, 34(5), 574-582.

Ang, B.W., Liu, N. (2007), Handling zero values in the logarithmic mean divisia index decomposition approach. Energy Policy, 35, 238-246.

Ang, B.W. (2015), LMDI decomposition approach: A guide for implement. Energy Policy, 86, 233-238.

Ang, B.W., Mu, A.R., Zhou, P. (2010), Accounting frameworks for tracking energy efficiency trends. Energy Economics, 32, 1209-1219.

Bureau of Energy. (2015), Energy Balances in Taiwan. Ministry of Economic Affairs. Taiwan: Executive Yuan

Bureau of Energy. (2016), Energy Statistical Annual Reports. Ministry of Economic Affairs, Executive Yuan, Taiwan.

Bhattacharyya, S.C., Ussanarassamee, A. (2004), Decomposition of energy and CO_2 intensities of Thai industry between 1981 and 2000. Energy Economics, 26, 765-781.

Bhattacharyya, S.C., Ussanarassamee, A. (2005), Changes in energy intensities of Thai industry between 1981 and 2000: A decomposition analysis. Energy Policy, 33, 995-1002.

Boyd, G.A., Hanson, D.A., Sterner, T. (1988), Decomposition of changes in energy intensity: A comparison of the Divisia index and other methods. Energy Economics, 10, 309-312.

Directorate General of Budget, Accounting and Statistics. (2015), Taiwan: National Statistics, Executive Yuan.

Emodi, N.V., Boo, K.J. (2015), Decomposition analysis of CO_2 emissions from electricity generation in Nigeria. International Journal of Energy Economics and Policy, 5(2), 565-573.

González, D., Martinez, M. (2012), Changes in CO_2 emission intensities in the Mexican industry. Energy Policy, 51, 149-163.

Hasanbeigi, A., Can, S.R., Sathaye, J. (2012), Analysis and decomposition of the energy intensity of California industries. Energy Policy, 46, 234-245.

Hoekstra, R., van der Bergh, J.C.J. (2003), Comparing structure and index decomposition analysis. Energy Economics, 25(1), 39-64.

Hsu, J.Y., Hsu, A.C. (1998), Analysis of variation trend of energy intensity in Taiwan. Quarterly Journal of Taiwan Bank, 49(1), 156-196.

Huang, Y.K., Tsao, S.M. (2005), Decomposition analysis of transportation energy consumption in Taiwan. Journal of the Chinese Institute of Transportation, 17(2), 175-208.

IEA. (2008), Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis. Paris, France: International Energy Agency (IEA).

IEA. (2012), CO_2 Emissions from Fuel Combustion Highlights. Paris, France: International Energy Agency (IEA).

IEA. (2014), Energy Efficiency Policies and Measures Database. Paris, France: International Energy Agency (IEA).

IEA. (2015), Key World Energy Statistics. Paris, France: International Energy Agency (IEA).

IPCC. (2007), Climate Change 2007: Mitigation of Climate Change. Working Group III Contribution to the IPCC Fourth Assessment Report: Summary for Policymakers. Intergovernmental Panel on Climate Change.

Lescaroux, F. (2008), Decomposition of US manufacturing energy intensity and elasticities of components with respect to energy prices. Energy Economics, 30(3), 1068-1080.

Lin, S.J., Lu, I.J., Lewis, C. (2006), Identifying key factors and strategies for reducing industrial CO_2 emissions from a non-Kyoto protocol member's (Taiwan) perspective. Energy Policy, 34, 1499-1507.

Liu, F.L., Ang, B.W. (2003), Eight methods for decomposing the aggregate energy-intensity of industry. Applied Energy, 76, 15-23.

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, 3226-3235.

Ma, C., Stern, D.I. (2008), China's change energy intensity trend: A decomposition analysis. Energy Economics, 30(3), 1037-1053.

Marrero, G.A., Ramos-Real, F.J. (2013), Activity sectors and energy intensity: Decomposition analysis and policy implications for European countries (1991-2005). Energies, 6, 2521-2540.

Obadi, S.M., Kor, M. (2015), Investigation of driving forces of energy consumption in EU 28 countries. International Journal of Energy Economics and Policy, 5(2), 422-432.

Shahiduzzaman, M., Alam, K. (2013), Changes in energy efficiency in Australia: A decomposition of aggregate energy intensity using logarithmic mean divisia approach. Energy Policy, 56, 341-351.

Vinuya, F., DiFurio, F., Sandoval, E. (2009), A decomposition analysis of CO_2 emissions in the United States. Applied Economics Letters, 17, 925-931.

Zhang, M., Guo, F. (2013), Analysis of rural residential commercial energy consumption in China. Energy, 52, 222-229.