Taiwan's changing energy intensity trend

- A decomposition analysis

By

Wei-Hong Hong[1*] Fu-Kuang Ko[2]

Abstract

After Industrial Revolution, due to fast progressing of technology and the life style changing, the world energy consumption exponentially grew and accompanied with large amount of greenhouse gas (GHG) emissions in decades. The increasing of GHG emissions makes global warming which results in intensification of weather and climate extremes, so almost all country positively promote many policies and measures to reduce GHG emissions. According to IEA (2015), emissions reductions from efficiency improvements in the end-use sectors accounts for 38% of total reductions higher than renewables and other technologies. In 2008, Taiwan also passed the Sustainable Energy Policy Guideline. In the guideline, the goal is to improve energy efficiency by more than 2 % per annum, so compared with the level in 2005, energy intensity will decrease 20% by 2015. Therefore, this study uses multilevel-hierarchical index decomposition analysis based on Shapley/Sun method to analyze the trend of Taiwan's changing energy intensity (EI) from 2002 to 2013. We also explore the impact of "Sectoral EI change" and "Structural Change" on total EI in past few years and provide some directions for improving EI in the future.

[1] Technician in Center of Energy Economics and Strategy Research, Institute of Nuclear Energy Research (INER)

[*] Corresponding Author, Phone: 886-3-4711400#2726, E-mail: Charlie@iner.gov.tw

[2] Researcher and Deputy Director of Center of Energy Economics and Strategy Research, INER

The results show that total EI decreasing (-21.1%), excluding the structure effect (-24.2%), over the past few years in Taiwan is mainly due to the effect of “pure EI change”, including industrial sector (-14.4%), transport sector (-4.3%), residential sector (-3.4%), and etc. We also find that Electronic Parts Manufacturing (-3.2%), Basic Metal Industries (-3%), Chemical Materials Manufacturing (-2.1%) are major subsectors contributed to the pure industrial EI change. While low-EI manufacturing industry grew quickly over the past years in Taiwan, service sector transforming to industrial sector have made the EI deteriorate. Therefore, the overall structural change effect (3.15%) makes little contribution to the total EI change.

In addition, this study also estimates the marginal contribution of EI for sub-sector assuming the industry structure keep constant. We found improving energy efficiency of high-EI and high energy consumption industry is the most effective measure to decrease total EI in Taiwan. In summary, we suggest that government should not only focus on improving energy efficiency of high-EI industry but also keep tracking high energy-consuming industry and supervising its energy efficiency improvement. In addition, the GDP structure should be transformed from Industry Sector to service sector, Service-oriented Manufacturing Industry and other low-EI industry, so that the total EI will continue to improve to meet the policy target.

Key words: decomposition analysis, energy intensity, industry structure

1. Introduction

After Industrial Revolution, due to fast progressing of technology and the life style changing, the world energy consumption exponentially grew and accompanied with large amount of greenhouse gas (GHG) emissions in decades. The increasing of GHG emissions makes global warming which results in intensification of weather and climate extremes, so almost all country positively promote many policies and measures to decrease GHG emissions. According to IEA (2015), emissions reductions from efficiency improvements in the end-use sectors accounts for 38% of total reductions higher than renewables (30%), CCS development (13%) and other technology.

More than 98% primary energy use depends on import every year in Taiwan and the expenditure on importing energy is up to 13.25% of GDP in 2013, so energy supply and demand is especially a crucial issue in Taiwan. We have to use the energy more efficiently to lower the impact from the deficit of energy source. In 2008, the congress of Taiwan also passed the energy policy: Taiwan's Sustainable Energy Policy. In the policy, the goal is to improve energy efficiency by more than 2 % per annum, so that when compared with the level in 2005, energy intensity will decrease 20% by 2015.

Energy intensity is one of the most common concepts to describe the energy efficiency which is defined as

Energy input into a process/ Useful output of a process.

However, the above description is still an abstract concept so a quantitative indicator needs to be created. According to different measurable unit usage, four kinds of indicator are able to use including Thermodynamic Indicator, Physical-Thermodynamic Indicator, Economic-Thermodynamic Indicator and Economic indicator (Bor, 2008). In addition, there are two ways to inspect the energy efficiency in general in past research. Some studies use bottom-up method by examining the progress of all production process and equipment efficiency to integrate and evaluate the total energy intensity improvement in the industry. The Thermodynamic Indicator and Physical-Thermodynamic Indicator are usually used for its convenience when bottom-up method is adopted. It is easier to get precise results of real energy efficiency changing and investigate the reason of improvement through bottom-up method (Yang, 2012； Huang et al., 2013), but it is difficult to compare energy efficiency cross industries due to different measurable physical quantity of useful output. If the technology make great progress, it is also hard to track the energy efficiency trend of specific technique for long time. Therefore, other studies replace physical unit with monetary unit for the useful output and adopt top-down method to do energy intensity research. The total energy intensity trend can be easy to inspect through top-down method then look deeper into every industry to analysis how their energy intensity changing affect total energy intensity. This study will focus on tracking Taiwan's energy intensity trend so we adopt top-down methods.

Index decomposition analysis (IDA) is the most common method to do top-down study including issues of energy intensity, electricity demand, CO_2 emission and etc. (Subhes C et al., 2005; Steenhof, 2006; Cian et al., 2014; Xu et al., 2014; Boonkham et al., 2015). Generally, the total energy intensity at a specific level is often decomposed to give the contribution of factors linked to activity structure shifts and energy efficiency improvement. We refer to the IDA studies conducted at a specific level as those using single level decomposition models. It is pointed out in the IDA studies that the energy intensity effect estimated at a finer level gives a better proxy for energy efficiency change. However, when the structure effect is studied using a single-level decomposition model, a finer level may lead to a higher degree of cancellation among sub-category effects (Ang, 1993). As a result, some compromise is needed in determining the “right” level to give representative estimates of the structure and energy intensity effects in a single-level study. This makes the single-level analysis decomposition results somewhat specific. Therefore, Xu & Ang (2014) provide comprehensive multilevel-hierarchical methodology to overcome above limitations. In the multilevel-hierarchical decomposition model, we can inspect structure effect at different level in the same time so that a better understanding of relationship between energy efficiency improvement and activity structure shifts can be achieved. In the decomposition analysis, Divisia index and Laspeyres index are most widely used and there is no preference of index selection. However a desirable index still has to satisfy factor-reversal, time-reversal, proportionality, and aggregation tests. (Ang, 2004) In addition, it is also concerned with ease of result interpretation and saving of computation-time so this study adopt refined-Laspeyres index of additive form (Shapley/Sun method) to calculate the decomposition results.

There are many studies focusing on tracking Taiwan energy intensity from top-down in the past(胥愛琦及許志義,1992；Huang and Wang,1996；吳銘峰及張四立,2003；Bor, 2008；Huang et al., 2014；黃韻勳, 2015) but almost all the studies lacked of finer comparison among different level due to using single-level decomposition. While Bor (2008) give special contributing weight factor to complete multilevel decomposition analysis of Taiwan's energy intensity, their methodology is too special to investigate how the activity structure shifts put impact on total energy intensity. Therefore, in order to elaborately research structure effect and intensity effect at different level, this study uses multilevel-hierarchical index decomposition analysis based on Shapley/Sun method to analyze the trend of Taiwan's changing energy intensity (EI) from 2002 to 2013.

2 Literature review

胥愛琦 and 許志義 (1992) applied Divisia index and Laspeyres index decomposition method to investigate the trend of energy consumption, energy intensity and contribution of factors linked to intensity effect and structure effect of Industry Sector from 1961 to 1990 in Taiwan. They found that the growing of high energy intensity industry made the total EI deteriorate before 1973 but the total EI was improved after 1979 due to intensity effect decreasing fast. Huang and Wang (1996) also applied Divisia index decomposition to examine the trend of energy intensity from 1981-1993 in Taiwan Manufacturing Sector and they got similar conclusion with 胥愛琦 and 許志義 (1992). 吳銘峰 and 張四立(2003) compared different Divisia index and Laspeyres index methods by analyzing the trend of energy intensity from 1981 to 2001 in Taiwan Manufacturing Sector. They found that using different index could get similar results if the residual term is small enough to ignore. In addition, the intensity effect kept decreasing and structure effect was fluctuating with little contribution to total EI changing during this period. Bor (2008) first time applied multi-level decomposition to compare the contribution of all sectors to total EI changing through special weight factor from 1992 to 2008 in Taiwan. The result showed the deterioration of energy efficiency in Chemical Material Manufacturing made the total energy worse in this period of time. However the contribution of activity structure shifts is hard to inspect in this method and the conclusion is quite different from other studies duo to different definition of real GDP. Huang et al. (2014) and 黃韻勳 (2015) applied Logarithmic Mean Divisia Method Index (LMDI) to investigate the trend of energy intensity from 1962-2013 in Taiwan and get similar results with other studies. In summary, the Taiwan's EI was improving over past decades due to fast-decreasing intensity effect and structure effect only made little contribution in this few years. However, how the structure of activity shifts made so little contribution in Taiwan? What is the contribution of intensity effect of different sector in Taiwan? How can we use the decomposition results to find the key industry for improving the energy intensity efficiently in the future? These issues are not well examined in the previous studies.

3. Methodology

In order to investigate the contribution of intensity effect and structure effect at different level of industry to total energy intensity changing, we build a hierarchical structure of industry as Table 1 and Fig. 1. The first level is composed of agriculture sector, industrial sector, service sector, Transport Sector and Residential Sector. Each sector can be disaggregated into sub-sectors in Level 2 such as manufacturing is one of sub-sectors of industrial sector. The disaggregation at finer level can be done with same rule. This study ultimately divides the industry into 4 levels in Taiwan. The energy intensity changing at each level can be disaggregated into intensity effect and structure effect of next level so the contribution of sectoral intensity effect at any level to total energy intensity can be calculated by using Shapley/Sun method.

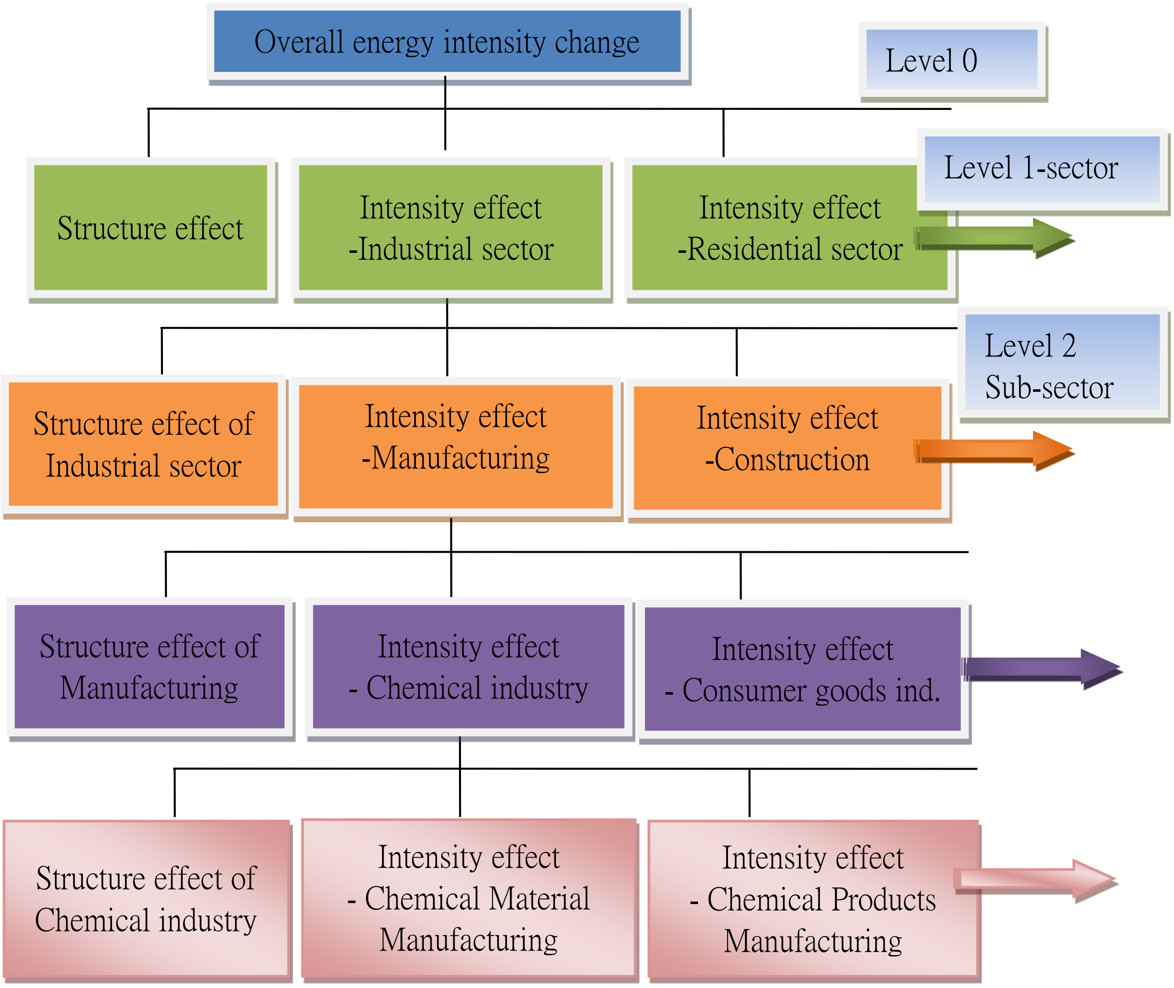

Fig. 1

Hierarchical decomposition structure of Taiwan.

Data source: depicted by author

We define

$$\text{Sectoral energy intensity} = \frac{\text{Energy comsumption of Sector}}{\text{GDP of Sector}} = A_i \tag{1}$$

$$\text{GDP share} = \frac{\text{GDP of Sector}}{\text{Total GDP}} = B_i \tag{2}$$

$$\text{Total energy intensity} = \mathrm{I} = \sum_{i=0}^{n} I_i = \sum_{i=0}^{n} A_i\, B_i \tag{3}$$

$$I_i = \frac{\text{Energy comsumption of Sector}}{\text{Total GDP}} \tag{4}$$

When time changes from 0 to T, the total energy change $\Delta \mathrm{I}$ can be represented as

$$\begin{aligned}\Delta \mathrm{I} = \mathrm{I}^T - \mathrm{I}^0 &= \sum_{i=0}^{n}(I_i^T - I_i^0) = \sum_{i=0}^{n}(A_i^T B_i^T - A_i^0 B_i^0) = \sum_{i=0}^{n}((A_i^0 + \Delta A_i)(B_i^0 + \Delta B_i) - A_i^0 B_i^0) \\ &= \sum_{i=0}^{n}(\Delta A_i\, B_i^0 + \Delta B_i A_i^0 + \Delta A_i \Delta B_i) = \sum_{i=0}^{n}((B_i^0\, \Delta A_i + 1/2 \Delta A_i \Delta B_i) + (A_i^0 \Delta B_i + 1/2 \Delta A_i \Delta B_i)) \\ &= \sum_{i=0}^{n}(\Delta A_i (B_i^0 + 1/2 \Delta B_i) + \Delta B_i (A_i^0 + 1/2 \Delta A_i)) = (\sum_{i=0}^{n} \Delta I_{int,i}) + (\Delta I_{str})\end{aligned} \tag{5}$$

$$\Delta I_{int,i} = \Delta A_i (B_i^0 + 1/2 \Delta B_i) \tag{6}$$

According to the second raw of formula (5), we find that total energy change $\Delta \mathrm{I}$ is affected by Sectoral energy intensity change $\Delta \mathrm{A}_i$, GDP share shifts $\Delta \mathrm{B}_i$, and interaction term $\Delta \mathrm{A}_i \Delta \mathrm{B}_i$, and we divide the interaction term equally to all the factors linked to Sectoral energy intensity change and GDP share shifts by applying Shapley/Sun method. Therefore, the Sectoral intensity effect $\Delta \mathrm{I}_{int,I}$ related to $\Delta \mathrm{A}_i$ and the structure effect $\Delta \mathrm{I}_{str}$ related to $\Delta \mathrm{B}_i$ is calculated and single-level decomposition is done. We can decompose the Sectoral energy intensity change in the similar way by replacing $\Delta \mathrm{I}$ with $\Delta \mathrm{A}_i$ in the formula (5). In this way, Sectoral energy intensity change $\Delta \mathrm{A}_i$ is combined with sub-sectoral intensity effect $\Delta \mathrm{I}_{sub\text{-}int,j}$ related to sub-sectoral energy intensity change $\Delta \mathrm{a}_j$ and sub-structure effect $\Delta \mathrm{I}_{sub\text{-}str}$ related to GDP share of A sector shifts $\Delta \mathrm{b}_j$ as formula (7)

$$\begin{aligned}\Delta A_i &= \sum_{j=0}^{m}(\Delta a_j (b_j^0 + 1/2 \Delta b_j) + \Delta b_i (a_j^0 + 1/2 \Delta a_j)) \\ &= (\sum_{j=0}^{m} \Delta I_{sub-int,j}) + (\Delta I_{sub-str})\end{aligned} \tag{7}$$

So far we complete single-level decomposition at level 2. In order to investigate how sub-sector affects total energy intensity, we adopt multilevel-hierarchical decomposition as formula (8) by combining formula (6) and formula (7).

$$\begin{aligned}\Delta I_{int,i} &= \Delta A_i (B_i^0 + 1/2 \Delta B_i) = (\sum_{j=0}^{m}(\Delta a_j (b_j^0 + 1/2 \Delta b_j) + \Delta b_j (a_j^0 + 1/2 \Delta a_j)))(B_i^0 + 1/2 \Delta B_i) \\ &= ((\sum_{j=0}^{m} \Delta I_{sub-int,j}) + (\Delta I_{sub-str}))(B_i^0 + 1/2 \Delta B_i) = (\sum_{j=0}^{m} \Delta I_{sub-int,ij}) + (\Delta I_{sub-str,i})\end{aligned} \tag{8}$$

$$\Delta I_{sub-int,ij} = \Delta I_{sub-int,j} (B_i^0 + 1/2 \Delta B_i) \tag{9}$$

From formula (8) we show a multiplicative weigh factor can connect two single-level decompositions at hierarchical level and we can keep decomposing into finer level by following same procedure until the whole multilevel-hierarchical decomposition is completed.

4 Results and Discussion

4.1 Taiwan's energy intensity trend

Table 1 shows the accumulated rate of energy intensity change in 2013 from base year 2002 and contribution of intensity effect and structure effect at different levels of industry by applying multilevel-hierarchical energy intensity decomposition in Taiwan. The average rate of EI improvement is 1.92% close to 2% of government's target from 2002 to 2013. The result from first level decomposition shows the intensity effect of industrial sector is the main reason of total EI improvement but the structure effect worsen the EI. However, when we look deeper into finer levels, the intensity effect of industrial sector mainly results from interior structure effect of Manufacturing. If all the structure effects at different levels are summed up, the total structure effect is only 3.15% far less than structure effect of first level. The result implies the activities towards low energy intensity grew in the manufacturing but activities between Sectors moved in opposite direction so the overall structure effect made little contribution to the total EI change. It is also pointed that the intensity effect improvement is still influenced by physical energy efficiency improvement and internal activities shifts. Therefore, EI effect should subtract all the internal structure effect in order to get better representation of physical Energy efficiency improvement. Figure 2 shows the trend of Taiwan's changing energy intensity including the overall structure effect and pure intensity effect. According to the trend, the EI goal of 2015 might be achieved successfully. The result also shows the total structure effect always made little contribution over the past years as previous studies found. The pure intensity effect (-24.2%), including industrial sector (-14.4%), transport sector (-4.3%), residential sector (-3.4%), and etc. is still the main factor to decrease the total EI and Electronic Parts Manufacturing (-3.2%), Basic Metal Industries (-3%), Chemical Materials Manufacturing (-2.1%) are major subsectors contributed to the pure intensity effect of industrial sector.

Table 1 Taiwan's energy intensity hierarchical decomposition in 2013 from base year 2002: intensity effect and structure effect in different level of industry.

Overall EI change in Taiwan (-21.08%)	Agriculture Sector (-0.45%)	Agriculture, Forestry and Animal Husbandry (0.09%)		
		Fishing (-0.7%)		
		Structure effect in Agriculture Sector (0.16%)		
	Industrial Sector (-23.54%)	Gas Supply (-0.15%)		
		Electricity Supply (-1.06%)		
		Mining and Quarrying (0.05%)		
		Water Supply and Remediation Services (-0.12%)		
		Construction (-0.09%)		
		Manufacturing (-25.7%)	Consumer goods ind. (-1.84%)	Food, Beverage and Tobacco (-0.33%)
				Textile, Wearing Apparel and Accessories (-0.63%)
				Wood, Bamboo products and Furniture (0%)
				Non-metallic Mineral Products (-0.94%)
				Other Manufacturing (-0.06%)
				Structure effect in Comsumer Goods Ind. (0.12%)
			Chemical industry (-0.3%)	Leather, Fur and Related Products (0.01%)
				Pulp, Paper and Paper Products (-0.17%)
				Printing and Reproductiom of Recorded Media (-0.03%)
				Chemical Material (-2.08%)
				Petroleum and Coal Products (-1.38%)
				Chemical Products (-0.48%)
				Rubber Products (-0.07%)
				Plastic Products (0.23%)
				Pharmaceuticals and Medicinal Chemical Products (-0.1%)
				Structure effect in Chemical Industry (3.77%)
			Metal and mechanical ind. (-0.36%)	Basic Metal (-2.99%)
				Fabricated Metal Products (0.28%)
				Machinery and Equipment (-0.17%)
				Transport Equipment (0.21%)
				Electrical Equipment (-0.02%)
				Structure effect in Metal and Mechanical Ind. (2%)
			Information and electronic ind. (-5.68%)	Computers, Electronic and Optical Products (-1.07%)
				Electronic Parts and Components (-3.23%)
				Structure effect in Information and Electronic Ind. (-1.05%)
			Structure effect in Manufacturing (-17.53%)	
		Structure effect in Industrial Sector (3.54%)		
	Service Sector (-1.62%)	Wholesale and Retail Trade (-0.45%)		
		Accommodation and Food Services (0.08%)		
		Transport Services; Warehousing and Storage (0.05%)		
		Information and Communication (-0.13%)		
		Finance, Insurance and Real Estate (-0.07%)		
		Public Administration and Defence (-0.09%)		
		Business Services, Social and Personal Services and others (-0.9%)		
		Structure effect in Service Sector (-0.12%)		
	Transport Sector (-4.64%)	Air Transportation (-0.22%)		
		Land Transportation (-3.64%)		
		Water Transportation (-0.43%)		
		Structure effect in Transport Sector (-0.35%)		
	Residential Sector (-3.44%)			
	Structure Effect (12.61%)			

Data source: author's calculation

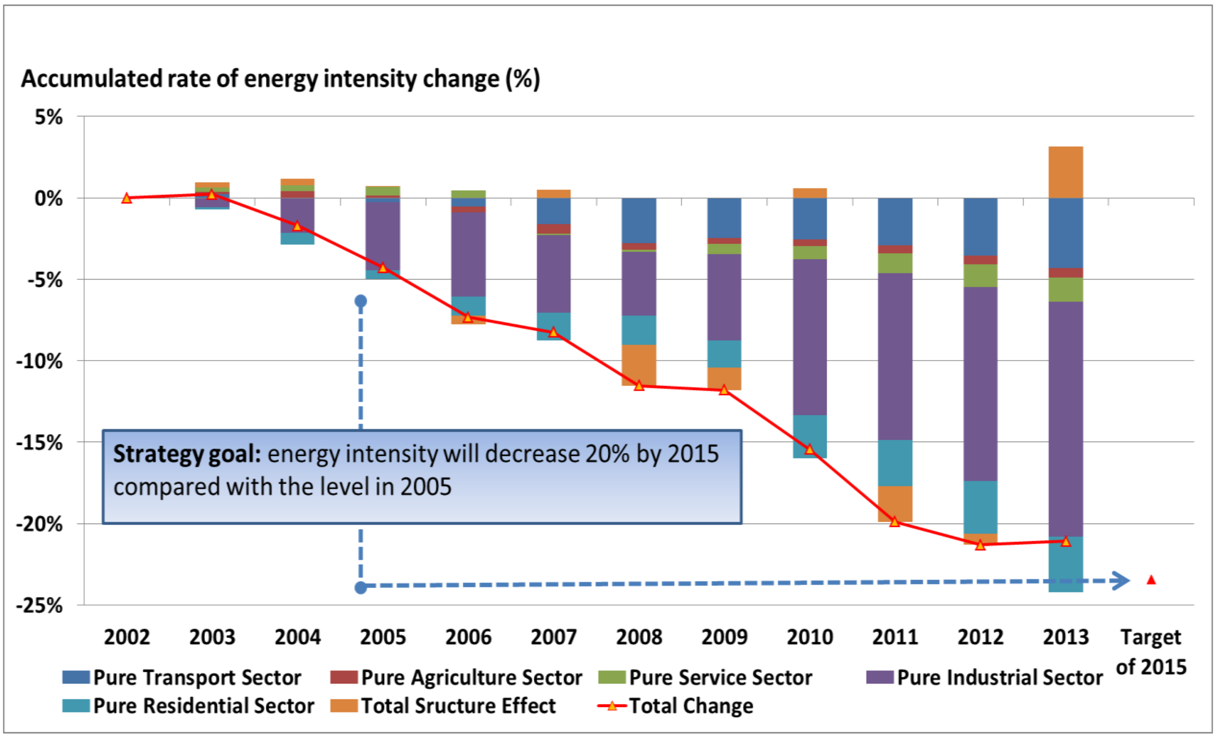

Fig. 2 Taiwan's changing energy intensity trend (base year 2002)

P.S.

1. The pure intensity effect of each sector in the figure is a result of subtracting interior structure effect from intensity effect of each sector.
2. Total structure effect is summation of all the structure effects in Table
3. Data source: author's calculation

4.2 The impact of Structure activity shifts on energy intensity

When we examine the structure effect at the first level, we found the GDP share of industrial sector increase by 7.6% and that of service sector decrease by 6.5% over the past years in Taiwan. The changing of activities with higher EI will make great contribution to the structure effect so growing of industrial sector worsens structure effect shown as Fig. 3. On the other hand, the industry in the manufacturing transformed towards information and electronic industry from other high EI manufacturing so the internal structure effect of manufacturing improved a lot shown as Fig. 4. In summary Taiwan's high-tech-export-oriented policy makes lower EI manufacturing industry growing but also decreases GDP share of industry in service sector so the contribution of structure effect is limited.

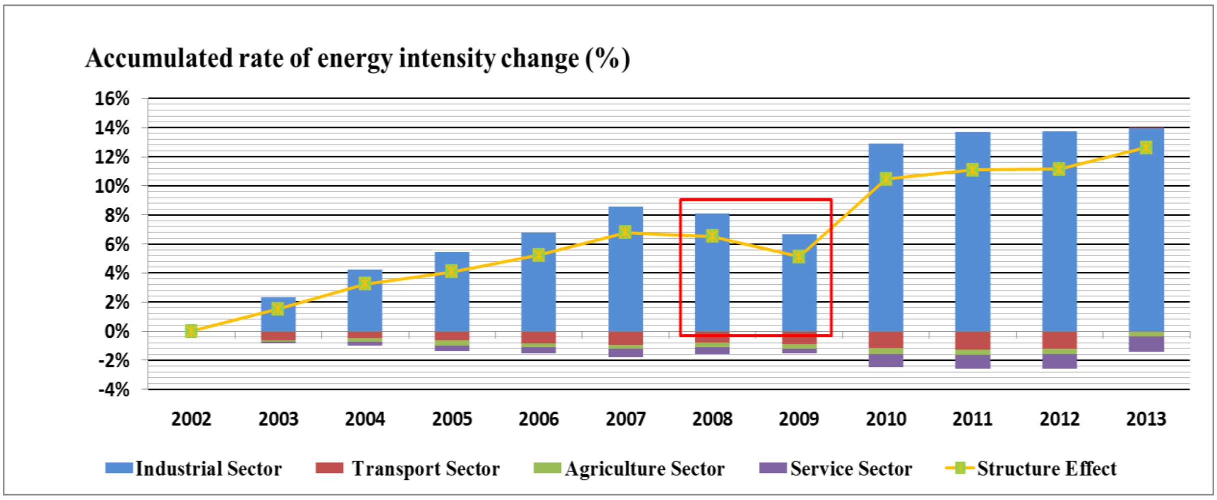

Fig. 3 The influence of GDP structure adjustment to energy intensity

Data source: author's calculation

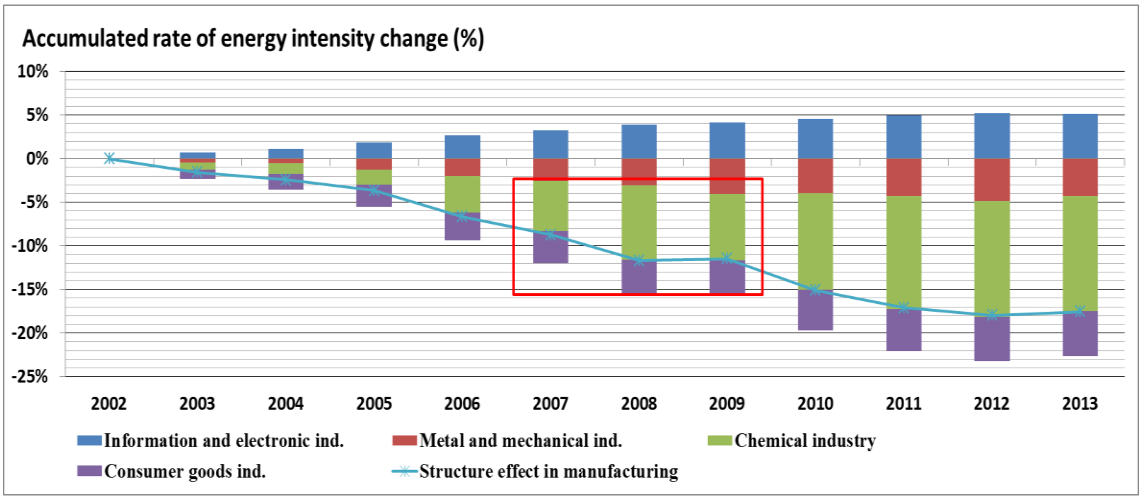

Fig. 4 The influence of GDP structure in the manufacturing adjustment to energy intensity

Data source: author's calculation

4.3 Marginal analysis

4.3.1 Marginal analysis of energy intensity

The above discussion is inspecting the contribution of intensity effect and structure effect at different level over the past years in Taiwan. We can use the data to further investigate which industry may play important role in improvement of EI in the future. In order to check the potential of EI improvement of each industry, we do the marginal analysis of EI. We decrease the energy intensity of all industry by 1% and calculate contribution of each industry to the improvement of total EI assuming the structure of industry stay unchanged. The result in the table 2 shows Chemical Material Manufacturing (0.3%), Land Transportation (0.11%) and Residential Sector (0.11%) will be top 3 factors to the contribution of improvement of total EI in the short term. In addition, we also find that not only energy efficiency changing of high EI industry but high energy-consumption industry (e.g. Electronic Parts and Components and Computers, Electronic and Optical Products) make great impacts on the total EI.

Table 2 The marginal contribution of energy intensity changing to total energy intensity

Industry	Impact	Industry	Impact
Chemical Material	0.299%	Fishing	0.005%
Land Transportation	0.114%	Machinery and Equipment	0.005%
Residential Sector	0.106%	Transport Services; Warehousing and Storage	0.004%
Basic Metal	0.065%	Agriculture, Forestry and Animal Husbandry	0.004%
Electronic Parts and Components	0.061%	Rubber Products	0.003%
Business Services, Social and Personal Services and others	0.057%	Information and Communication	0.003%
Petroleum and Coal Products	0.035%	Water Supply and Remediation Services	0.003%
Non-metallic Mineral Products	0.033%	Finance, Insurance and Real Estate	0.002%
Computers, Electronic and Optical Products	0.032%	Construction	0.002%
Electricity Supply	0.031%	Water Transportation	0.001%
Textile, Wearing Apparel and Accessories	0.016%	Mining and Quarrying	0.001%
Public Administration and Defence	0.016%	Printing and Reproductiom of Recorded Media	0.001%
Fabricated Metal Products	0.015%	Other Manufacturing	0.001%
Accommodation and Food Services	0.015%	Electrical Equipment	0.001%
Pulp, Paper and Paper Products	0.013%	Pharmaceuticals and Medicinal Chemical Products	0.001%
Plastic Products	0.013%	Wood, Bamboo products and Furniture	0.001%
Food, Beverage and Tobacco	0.011%	Gas Supply	0.001%
Wholesale and Retail Trade	0.011%	Air Transportation	0.001%
Transport Equipment	0.010%	Leather, Fur and Related Products	0.001%
Chemical Products	0.008%	**Total**	**1.000%**

Data source: author's calculation

4.3.2 Marginal analysis of structure effect

Analyzing the marginal test of EI is helpful for focusing on specific industry to improve total EI in the short term. However structure effect still should make comparable contribution in the long time so the marginal test of structure effect should be examined at the same time. We increase the GDP share of one industry 1% to examine how the total EI change in the test, provided that the EI stay constant in the all industry. We find out that the decreasing the share of high-EI industry is much more influential on total EI than increasing the share of low-EI industry due to asymmetrical contribution shown as table 3. Therefore in order to improve the total EI, the adjustment of high EI industry (e.g. Chemical Material Manufacturing) is a crucial problem to solve in the future

Table 3 The marginal contribution of GDP share changing to total energy intensity

Industry	Impact
Chemical Material	17.000%
Land Transportation	7.251%
Non-metallic Mineral Products	4.757%
Pulp, Paper and Paper Products	3.931%
Petroleum and Coal Products	2.368%
Plastic Products	2.282%
Electricity Supply	2.034%
Basic Metal	2.011%
Textile, Wearing Apparel and Accessories	1.789%
Chemical Products	1.045%
Fishing	1.035%
Rubber Products	0.643%
Fabricated Metal Products	0.209%
Computers, Electronic and Optical Products	0.127%
Leather, Fur and Related Products	0.117%
Transport Equipment	0.065%
Food, Beverage and Tobacco	-0.069%
Accommodation and Food Services	-0.251%
Gas Supply	-0.303%

Industry	Impact
Wood, Bamboo products and Furniture	-0.394%
Pharmaceuticals and Medicinal Chemical Products	-0.421%
Printing and Reproduction of Recorded Media	-0.475%
Water Supply and Remediation Services	-0.540%
Machinery and Equipment	-0.549%
Water Transportation	-0.555%
Mining and Quarrying	-0.611%
Transport Services; Warehousing and Storage	-0.623%
Agriculture, Forestry and Animal Husbandry	-0.672%
Business Services, Social and Personal Services and others	-0.688%
Electronic Parts and Components	-0.702%
Air Transportation	-0.785%
Other Manufacturing	-0.786%
Public Administration and Defence	-0.792%
Electrical Equipment	-0.825%
Construction	-0.938%
Information and Communication	-0.956%
Wholesale and Retail Trade	-1.128%
Finance, Insurance and Real Estate	-1.151%

Data source: author's calculation

5. Conclusion and Suggestions

This study applies multilevel-hierarchical index decomposition analysis to elaborately investigate the possible cause of improvement of EI over the past 11 years in Taiwan. It is the first time to study how the activity shifts at different levels to influence the energy intensity in detail in Taiwan. We find that pure intensity effect of industrial sector is still the most important factor just as previous studies discovered. However, we also find that Electronic Parts Manufacturing, Basic Metal Industries, Chemical Materials Manufacturing are major subsectors contributed to the pure

industrial EI change. Besides, service sector transformed to industrial sector has made the EI deteriorate while low-EI manufacturing industry grew quickly over the past years in Taiwan. Therefore, this overall structural change effect makes little contribution to the total EI change.
In addition, this study also found improving energy efficiency of high-EI and high energy consumption industry is the most effective measures to decrease total EI in Taiwan by estimating the marginal contribution of EI for sub-sector. The result from marginal test of structure effect reveals decreasing the GDP share of high EI industrial might be important in the future. The marginal analysis of EI and structure effect should be inspected periodically to make sure all key industries under control. In summary, we suggest that government should not only focus on improving energy efficiency of high-EI industries but also keep tracking high energy-consuming industries and supervising its energy efficiency improvement. Besides, the GDP structure should be transformed from industry Sector to service sector, service-oriented manufacturing industry and other low-EI industries, so that the total EI will continue to improve to meet the policy target. However, there are still limits in our study. For instance, using GDP as output of process is subject to vary due to unstable price so the physical improvement of energy intensity might not be reflected completely using Economic-Thermodynamic Indicator. Therefore, finding a method to combine Physical-Thermodynamic Indicator and Economic-Thermodynamic Indicator could be an important issue to understand real change of energy efficiency. In addition, the improvement of energy efficiency doesn’t guarantee the improvement of total factor productivity so figuring out the relationship between them could be needed in the future.

Reference

1. 胥愛琦、許志義，1992，台灣能源密集度變動之因素分解，國立政治大學經濟學系研究所碩士論文

2. 吳銘峰、張四立，2003，製造業能源效率指標的台灣實證研究，國立台北大學資源管理研究所碩士論文

3. 黃韻勳，2015，影響我國能源密集度之關鍵因素，工研院產經中心：節約能源與效率提升發展策略研究計畫(1/3)

4. Bureau of Energy, Taiwan, 2014, Energy Balance Sheet

5. Bureau of Energy, Taiwan, 2014, Energy Statistical annual Reports

6. Bureau of Energy, Taiwan, 2014, Energy Statistical Quarterly Reports

7. B.W. Ang, 1993, Sector disaggregation, structural effect and industrial energy use: an approach to analyze the interrelationships, Energy 18, 1033–1044.

8. B.W. Ang,1995, Multilevel decomposition of industrial energy consumption ,Energy Economics, Volume 17, Issue 1, Pages 39–51

9. B.W. Ang,2004, Decomposition analysis for policymaking in energy: which is the preferred method? ,Energy Policy, Volume 32, Issue 9, Pages 1131–1139

10. Chi-Feng Huang, I-Te Huang, Tzu-Yar Liu, 2013, Factor Analysis of Energy Consumption Change in Basic Metal Industry, Journal of Taiwan Energy, Volume 1, NO. 1, pp. 105-118

11. Directorate-General of Budget, Accounting and Statistics, Executive Yuan,Taiwan,2014,Gross Domestic Product by Kind of Activity and Implicit Price Deflators (SNA93)

12. Enrica De Cian, Michael Schymura, Elena Verdolini, Sebastian Voigt, 2014, Energy intensity developments in 40 major economies: Structural change or technology improvement?, Energy Economics, Volume 41, Pages 47–62

13. International energy agency (IEA), 2015, Energy Technology Perspectives 2015

14. Jin-Hua Xu, Ying Fan, Song-Min Yu, 2014, Energy conservation and CO2 emission reduction in China's 11th Five-Year Plan: A performance evaluation, Energy Economics, Volume 46, Pages 348–359

15. Paul A. Steenhof, 2006, Decomposition of electricity demand in China's industrial sector, Energy Economics, Volume 28, Pages 370–384

16. P. Boonkham and N. Leeprechanon, 2015, Decomposition Analysis of Changes in Energy Intensity of the Thai Manufacturing Sector during 1991-2013, International Journal of Materials, Mechanics and Manufacturing, Vol. 3, No. 3, pp.152-156

17. Subhes C. Bhattacharyya, Arjaree Ussanarassamee, 2005, Changes in energy intensities of Thai industry between 1981 and 2000:a decomposition analysis, Energy Policy, Volume 33, Pages 995–1002

18. Yang, Chin-Wen,2012, Measurement of Energy Efficiency and Its Linkage to Environmental Policy Instruments, Taipei Economic Inquiry, Department of Economics, National Taipei University, 48:2, pp.287-317

19. Ta Wei Huang, King Min Wang, 1996, Analysis of energy intensity and total factor productivity in the Taiwan Manufacturing Sector, Chung-Hua Institution for Economic Research, Taiwan

20. Yu-Kai Huang, Lih-Chyun Sun, Jyh-Yih Hsu, 2014, Analysis on Changes of Energy Consumption and Intensity in Different Stages of the Taiwan Economic Development, Chinese Association for Energy Economics, Taiwan

21. Yunchang Jeffrey Bor, 2008, Consistent multi-level energy efficiency indicators and their policy implications, Energy Economics 30, 2401– 2419

22. X.Y. Xu , B.W. Ang, 2014, Multilevel index decomposition analysis: Approaches and application, Energy Economics, Volume 44, Pages 375–382