Tracing and Quantifying Influences of Fossil Fuels in Thailand's Economic Structure Using Multiplier and Structural Path Analysis

Nattapong Puttanapong

Faculty of Economics, Thammasat University, Thailand

Thailand has pledged the Nationally Appropriate Mitigation Action (NAMA), which includes the sector-specific reduction of Greenhouse Gases (GHGs) emission. Based on this plan, the insight of economic structure, especially the roles of high GHGs emitting sectors within the economy, is among important fundamentals. Hence, this study aims at examining how adjustments originated from high GHGs emitting activities propagate throughout the economy. This study uses official input-output tables of 1995, 2000, 2005 and 2010 which are the most updated official data. The computation of Leontief backward and forward multipliers is conducted to examine each production activity's propagation magnitude to other sectors. In addition, Structural Path Analysis (SPA) is applied to further quantify the degree of economic linkages of high GHGs emitting sectors along their supply chains. Interestingly, the multiplier analysis shows that the group of sectors having the highest values of backward and forward multipliers has been unchanged since 1995, and the refinery activity has been among these sectors having the highest forward multipliers. This indicates the significant role of fossil-based energy in Thai economy since 1995. The result from SPA also illustrates and quantifies that refinery is among the most influential sectors of origins, functioning as the starting point of many supply chains. These results indicate two important facts for developing the national GHGs reduction plan. Firstly, the fossil fuel has been the backbone of Thailand's economic structure since 1995. Therefore, the action to alter the fossil-based production network has to be very influential to reshape this persisting structure. Secondly, the refinery sector, considered as one of main GHGs emitters, is the major upstream activity playing a very significant role in supplying most important paths of production chains. Hence, the adjustment of the refinery sector will inevitably propagate throughout all connecting supply chains and subsequently incur the high abatement cost of GHGs reduction.

Keywords: Structural Path Analysis, Input-Output Models, Supply Chain, Thailand, Greenhouse Gases, Mitigation, Carbon Tax

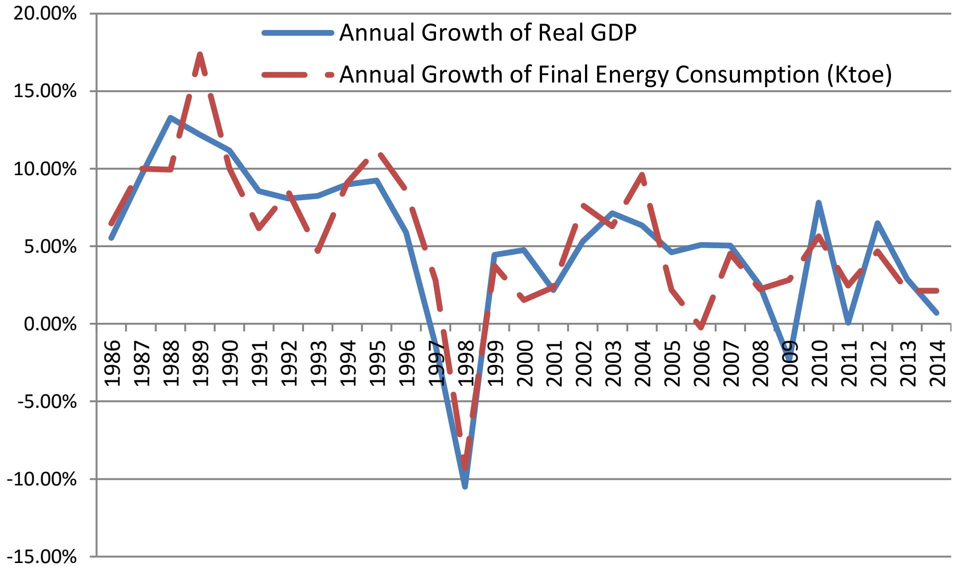
JEL Classification: Q43, Q56, R15

Corresponding author: Nattapong Puttanapong (nattapong@econ.tu.ac.th)

1. Introduction

Since the implementation of the first National Economic Development Plan in 1961, the economy has continuously progressed toward industrialization with the deepening connection to the global production network. The explicit evidence of this evolution is shown in the recent proportion of GDP. Specifically, during 2005-2015, the average share of agricultural production is approximately 10% of total GDP, while the rest is the combined contribution of manufacturing and service activities[1]. With this continuous transformation, the role of energy sector has been expanding in the structure of Thai economy. As illustrated on Figure 1, the total demand for energy has been highly correlated with the GDP growth. This energy demand is mainly supplied through import, which is most the crude oil, and the proportion of the energy import has been growing over time, as exhibited on Figure 2.

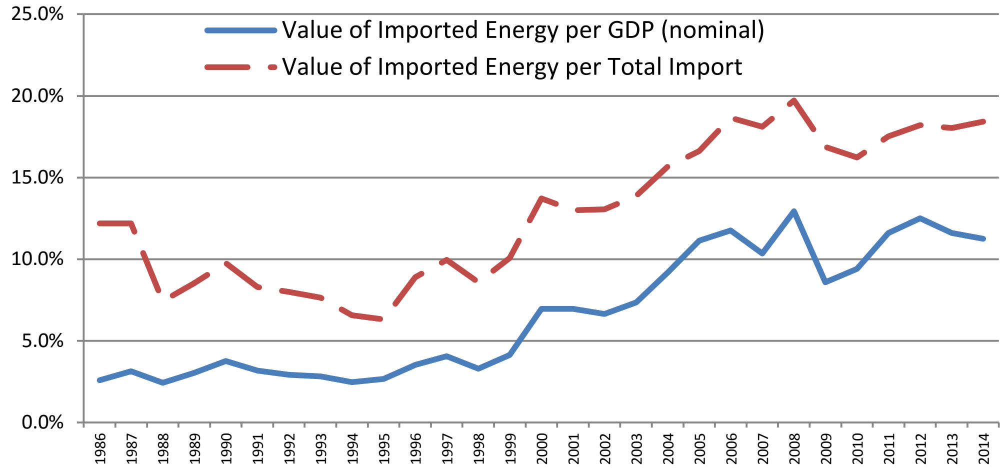
Figure 1: Annual growth of real GDP and Final Energy Consumption during 1986-2014



Source: Energy Policy & Planning Office, Ministry of Energy, Thailand

1 National Economic and Social Development Board (www.nesdb.go.th)

Figure 2: Ratios of value of imported energy per GDP and total import



Source: Energy Policy & Planning Office, Ministry of Energy, Thailand

Interestingly, the role of energy on Thai economy has been growing. Figure 3 shows that the energy use (kilograms of oil equivalent per capita) has been increasing while the similar measure in the unit of kilograms of oil equivalent per $1,000 GDP[2] has stable since 2000 (as shown on Figure 4). With this trend of energy use, the CO2 emissions (metric tons per capita) have been rising as illustrated on Figure 5. Figure 6 shows the measure of CO2 emissions in the alternative approach, which is kilogram per kilogram of oil equivalent energy use, and indicates that the emission ratio has been increasing during 1971 – 1997 and steady since then. These empirical evidences clearly indicate the significant role of energy in the development path of Thai economy. Concurrently, with the substantial domination of fossil fuel as the main source of energy, the CO2 emissions have been continuously rising.

Figure 3: Energy Use (kg. of oil equivalent per capita)

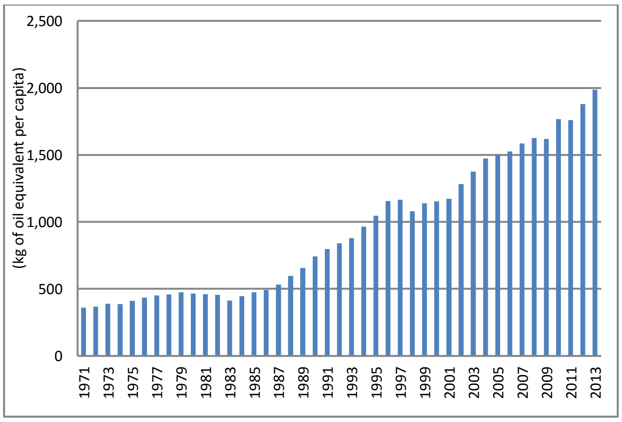
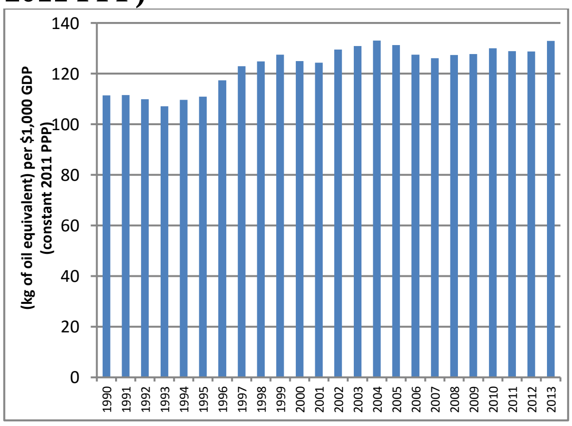


Figure 4: Energy Use (kg. of oil equivalent) per $1,000 GDP (constant 2011 PPP)



Source: World Development Indicator (World Bank (2016))

[2] The value of GDP adjusted by2011 Purchasing Power Parity (PPP).

Figure 5: CO2 emissions (metric tons per capita)

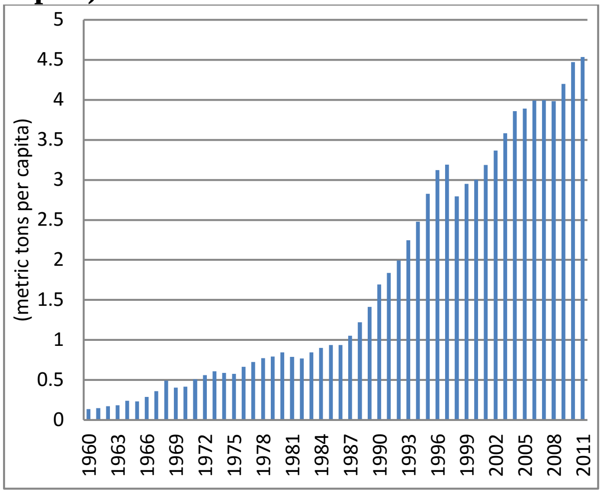
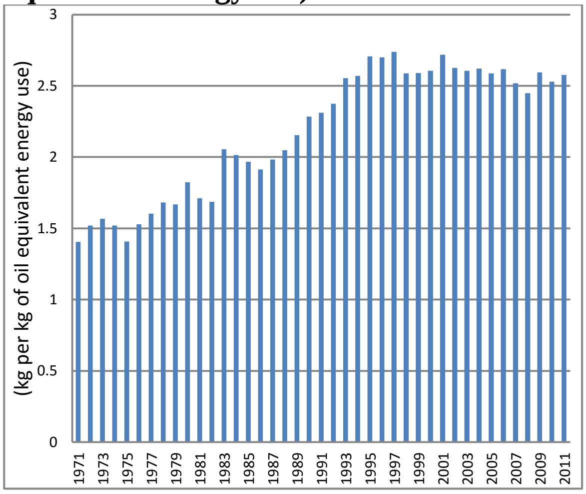


Figure 6: CO2 Intensity (kg. per kg. of oil equivalent energy use)



Source: World Development Indicator (World Bank (2016))

Regarding the national policies aiming toward the reduction of CO2 emissions, the Energy Efficiency Development Plan (EEDP), formulated by Ministry of Energy, has been introduced and targeted the 25% reduction in Energy Intensity (EI) in year 2030[3]. Also, for GHGs reduction, United Nations Framework Convention on Climate Change (UNFCCC) Parties has approved Thailand's pledge on Nationally Appropriate Mitigation Actions (NAMAs) in November 2014. Based on this voluntary scheme, Thailand will reduce its GHGs emissions in the range of 7% - 20% below the business as usual (BAU) in 2020.

With these officially announced plans of EI and GHGs reductions, it is challenging for Thai policy makers to further formulate action plans and undertake implementations without lowering the country's international competitiveness and retarding the potential growth path. The persisting structure of energy consumption is the main mechanism of Thai economy underpinning the high dependency on fossil fuel. Hence, this study aims at examining the detailed roles of fossil fuel on Thai economy by using the official Input-Output tables and Structural Path Analysis. Specifically the main objectives of this study are the following;

(1) conducting the structural analysis on Thailand's Input-Output tables of 1995, 2000, 2005 and 2010 to prioritize and quantify the major linkages of fossil fuels functioning as the origin of supply chains.
(2) comparing and classifying the structures of linkages connecting fossil fuel to serve main economic activities.
(3) examining the inter-temporal variation of fossil fuel's contribution and structural linkages to Thai economy.

---

3 The EEDP targets 25% reduction of EI from 15.6 ktoe/billion baht (the rate of 2010) to 11.7 ktoe/billion baht.

The obtained result would be supportive information for formulating the future specific action plans on major sectors and supply chains, which would lead to an effective outcome of EI and GHGs reduction policies.

This paper is structured as follows. The second section discusses the surveyed literature related to analyses of energy and economic structure. The third part elaborates the analytical techniques applied to Thailand's Input-Output tables, and their results are shown and discussed in the fourth section. The last part concludes main findings and suggests policy recommendations.

2. Literature review

2.1 Energy and economy

Since the introduction of the analysis of Input-Output table by Leontief (1936), many studies in the field of economics have applied the technique to examine the structure of the economy. Particularly the quantification and exploration of linkages among agents and activities are the main topics. In the field of energy economics, the concept of Input-Output table and related computations has revealed the role of energy in the economy as conducted by Bina and Dowlatabad (2005) in the case of US, and Lenzena et al.(2004) in the case of Australia. Also the studies of Cohena et al.(2005), Chunga et al.(2009) and Mukhopadhyay (2005) used the national Input-Output table to examine the energy demand and related issues, such as emissions and infrastructure expansion, in the case of Brazil, South Korea and India, respectively. In addition, the methodology based on Input-Output table was extended by Jan (2012) to decompose of embodied energy content in the production activities of Indian economy. Liang and Zang (2011) utilized the Input-Output table and calculated the direct and indirect demand for energy and related CO2 emissions in the case of Jiangsu Province in China. The analysis based on the Input-Output table was also furthered to the projection of energy demand. Ryo et al.(2009) applied this technique to the case of Japan, and Lua and Leib (2011) used the likewise methodology to the case of China.

2.2 Economy-wide propagation originated by energy sectors

The deeper insight on the issue of economy-wide impacts originated by energy sector has been conducted in the recent decade, mostly influenced by the issue of carbon tax. As formerly introduced in Goulder (1992), the Input-Output data and related calculations have been the main methodology for tracing the nationwide propagation originated by changes in prices of fossil fuels and related taxes. Gonne(2012), González(2015), Benavides et al.(2015), Callana et al. (2008) and Nápoles (2012) explored the effects in the case of Belgium, Spain, Chile, Italy and Mexico, respectively. Also the impacts on households classified by income classes were examined by Callana et al.(2008), Gough et al.(2012) and Mathur and Morris (2012) in the case of Ireland, UK and USA, respectively.

2.3 Structural Path Analysis and energy

As introduced by Defourny and Thorbecke(1984), the Structural Path Analysis (SPA) enables the deeper examination of impact transmissions among agents within Input-Output table. Specifically this computational technique decomposes the Leontief multiplier and reveals both direct and indirect paths which are components of a particular multiplier. Recently this calculation has been applied to the analysis of energy economics and shows details of linkages starting from energy sectors to other activities within the economy. Hong et al.(2016) and Liua et al.(2012) used SPA to the case of China and show the decomposed paths of energy contents within production chains. Likewise Acquaye et al.(2011) and Yang (2015) applied the same computation to trace the CO2 emissions along the supply chains in the case of EU and China, allowing the more specific quantification of carbon footprint of each production stage.

In the case of Thailand, Kofoworola and Gheewala (2008) used the Input-Output table to analyze the energy requirement and Greenhouse Gases emission. However, since then, there is a lack of study using the latest versions of official Input-Output tables to examine the structural influences of energy in Thai economy. Hence, this study will apply the multiplier computation and SPA to the four latest official Input-Output tables of Thailand. Details of analyses are discussed in the subsequent sections.

3. Data

This study uses the latest four official Input-Output tables of Thailand, produced by the National Economic and Social Development Board (NESDB). Each table represents the economy-wide transaction of 1995, 2000, 2005 and 2010, respectively. All tables are publicly available[4] with the format of Use table[5]. Details of all 58 sectors of productions and services of Input-Output table are listed on Table 1. All tables contained the transaction computed at purchaser price. The structure of the Input-Output used in this analysis is shown in Figure 7.

---

4 http://www.nesdb.go.th/nesdb_en/main.php?filename=national_account

5 The matrix representing economy-wide transactions can be formatted in either Supply or Use table. The Supply format shows details of costs of production of each sector. On the other hand, the Use format illustrates details of demand for output of each sector and also its production and value-added.

Table 1: List of sectors on the Input-Output table

Sector	Description		Sector	Description
1	Paddy		30	Petroleum Refineries and Coal
2	Maize		31	Rubber Products
3	Cassava		32	Plastic Wares
4	Beans and Nuts		33	Cement and Concrete Products
5	Vegetables and Fruits		34	Other Non-metallic Products
6	Sugarcane		35	Iron and Steel
7	Rubber (Latex)		36	Non-ferrous Metal
8	Other Crops		37	Fabricated Metal Products
9	Livestock		38	Industrial Machinery
10	Forestry		39	Electrical Machinery and Apparatus
11	Fishery		40	Motor Vehicles and Repairing
12	Crude Oil and Coal		41	Other Transportation Equipment
13	Metal Ore		42	Leather Products
14	Non-Metal Ore		43	Saw Mills and Wood Products
15	Slaughtering		44	Other Manufacturing Products
16	Processing and Preserving of Foods		45	Electricity and Gas
17	Rice and Other Grain Milling		46	Water Works and Supply
18	Sugar Refineries		47	Building Construction
19	Other Foods		48	Public Works and Other Construction
20	Animal Food		49	Trade
21	Beverages		50	Restaurants and Hotels
22	Tobacco Processing and Products		51	Transportation
23	Spinning, Weaving and Bleaching		52	Communication
24	Textile Products		53	Banking and Insurance
25	Paper and Paper Products		54	Real Estate
26	Printing and Publishing		55	Business Services
27	Basic Chemical Products		56	Public Services
28	Fertilizer and Pesticides		57	Other Services
29	Other Chemical Products		58	Unclassified

Source: National Economic and Social Development Board (NESDB)

Figure 7: Structure of Input-Output table

		Intermediate Demand			Final Demand (F_i)	Total Output (X_i)
		X_1	X_2	X_{58}		
Intermediate Transactions	X_1	X_{11}	X_{12}	$X_{1,58}$	F_1	X_1
	X_2	X_{21}	X_{22}	$X_{2,58}$	F_2	X_2
	…	…	…	…	…	…
	…	…	…	…	…	…
	X_{58}	X_{n58}	X_{n58}	$X_{58,58}$	F_{58}	X_{58}
Value Added		V_1	V_2	V_{58}		
Total Input		X_1	X_2	X_{58}		

4. Methodologies

There are two main methodologies used in this analysis. The first method is the computation of Backward Linkage and Forward Linkage Indices derived from the Leontief multipliers. This method shows the magnitude of economy-wide influences of each production sector. The second is the SPA which decomposes each Leontief multiplier and reveals both direct and indirect paths of influences embedded inside each multiplier.

4.1 Backward Linkage and Forward Linkage Indices

As illustrated on Figure 7, each sector *i* produces the output of X_i, which can be used as intermediate input for sector *n* (*i.e.* $X_{i,n}$) and the final consumption of F_i. This relationship can be mathematically expressed as follows.

$$X_1 = X_{11} + X_{12} + X_{13} + \ldots\ldots + X_{1n} + F_1$$

$$X_2 = X_{21} + X_{22} + X_{23} + \ldots\ldots + X_{2n} + F_2$$

$$. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad . \quad .$$

$$X_n = X_{n1} + X_{n2} + X_{n3} + \ldots\ldots + X_{nn} + F_n ,$$

The above set of equations can be succinctly represented in matrix format as eq (1).

$$X_i = \sum_{j=1}^{n} x_{ij} + F_i \qquad (1)$$

Based on the above set of equations, the value of Input-Output coefficient or the technical coefficient (a_{ij}) can be computed as eq (2).

$$a_{ij} = \frac{x_{ij}}{x_j} \qquad (2)$$

The value of a_{ij} can be written in the matrix format as A.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{12} & a_{22} & \cdots & a_{2n} \\ . & . & \cdots & . \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \qquad (3)$$

Therefore, all transitions list on the Input-Output matrix can be mathematically represented in matrix algebra.

$$AX + F = X \qquad (4)$$

With the re-arrangement, the above equation can have the new representation as shown in the following steps.

$$X - AX = F \qquad (5)$$

$$(I\text{-}A)\,X = F \qquad (6)$$

$$X = (I\text{-}A\,)^{-1} F \qquad (7)\ ,$$

where

$$X = \begin{bmatrix} X_1 \\ X_2 \\ . \\ X_n \end{bmatrix}$$

The term of inversed matrix , i.e. $(I\text{-}A\,)^{-1}$, is Leontief multiplier. This term can be represented as matrix *B*, where each element (B_{ij}) indicates the influence from sector *j* to sector *i*.

$$(I\text{-}A\,)^{-1} = B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{12} & b_{22} & \cdots & b_{2n} \\ . & . & \cdots & . \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix} \quad , \quad (8)$$

Therefore, the economy-wide influence from the expansion of sector *j* along the supply chain is the value of Backward multiplier, as indicated in eq(9).

$$BACKWARD_j = \sum_i \boldsymbol{b_{ij}} \qquad (9)$$

Alternatively the value of each Backward multiplier can be adjusted by comparing to the mean of all Backward ones (i.e normalization). This computation yields the Backward Linkage Index of *j* (BLI_j), mathematically expressed in eq(10).

$$BLI_{\boldsymbol{j}} = \frac{\sum_i \boldsymbol{b_{ij}}}{\frac{1}{n}\sum_j \sum_i \boldsymbol{b_{ij}}} \qquad (10)$$

Likewise the overall forward influence along the chain of sector *j* is denoted as Forward multiplier as indicated in eq (11).

$$FORWARD_i = \sum_j \boldsymbol{b_{ij}} \qquad (11)$$

The value of Forward multiplier can be normalized and denoted as the Forward Linkage Index *(FLI_i)*, which has the formula as follows.

$$FLI_i = \frac{\sum_j \boldsymbol{b_{ij}}}{\frac{1}{n}\sum_i \sum_j \boldsymbol{b_{ij}}} \qquad (12)$$

The value of Backward Linkage Index *(BLI_j)* identifies the normalized magnitude of impacts of sector *j* on its suppliers of raw materials and intermediates (i.e. the impacts on the upstream sectors). On the other hand, the Forward Linkage Index (FLI_j) indicates the normalized impact on the opposite direction of influences, which are the users of outputs of sector *j* (i.e. the impacts on the downstream sectors or users).

4.2 Structural Path Analysis (SPA)

Initially introduced to the economic analysis by Defourny and Thorbecke(1984), the Structural Path Analysis (SPA) is the computational technique that decomposes components of each Leontief multiplier. The SPA is based on the mathematical concept developed by Lantner (1974), which extends the conventional concept of multipliers and reveals embedded linkages of all direct and indirect influences propagating from the sector of origin to the end user or consumer. The comprehensive mathematical derivation of SPA is demonstrated by Lenzen(2007) and Hong(2016), showing the origin of decomposition as the Taylor expansion of Leontief multiplier as denoted by eq (12).

$$(I - A)^{-1} = I + A + A^2 + A^3 + \cdots \qquad (11)$$

Substitute eq (11) into eq (7) gives the expression of decomposed multipliers, following the Taylor expansion as follows.

$$X = (I - A)^{-1}F \qquad (12)$$

$$= \sum_{i,j=1}^{n} \left(\delta_{ij} + A_{ij} + A_{ij}^2 + A_{ij}^3 + \cdots\right) f_j \qquad (13)$$

$$= \sum_{i,j=1}^{n} \left(\delta_{ij} + A_{ij} + \sum_{k=1}^{n} A_{ik}A_{kj} + \sum_{l=1}^{n}\sum_{k=1}^{n} A_{il}A_{lk}A_{kj} + \cdots\right) f_j \quad (14),$$

where *i*, *j*, *k*, and *l* are compartment indices. Eq (14) shows that the direct impact from *i* to *j* is quantitatively represented by A_{ij} , considered as the first-order influence. The second-order influence is the term of $\sum_{k=1}^{n} A_{ik}A_{kj}$, which expresses the indirect paths starting from sector *i* and running via the intermediate sectors of *k* before reaching the destination of sector *j*. Similarly the third-order influences is the term of $\sum_{l=1}^{n}\sum_{k=1}^{n} A_{il}A_{lk}A_{kj}$, which indicates that the transmission mechanism of impacts originating from sector *i* , then running through sector *l* and *k*, and finally causes the effects on *j*. Based on Taylor expansion, the computation can be done infinitely, while the higher order shows the deeper detail of combinations of paths that have smaller magnitudes. Therefore, the computation of SPA has to specify the upper limit of order influences. Also in order to obtain the compact format of presentation of computational outcomes, the reported results are the selected paths which have the magnitude of influences higher than the threshold value. In this study, the calculation of SPA has conducted until the forth-order of influence, and the threshold value of reported paths is specified at 0.00001.

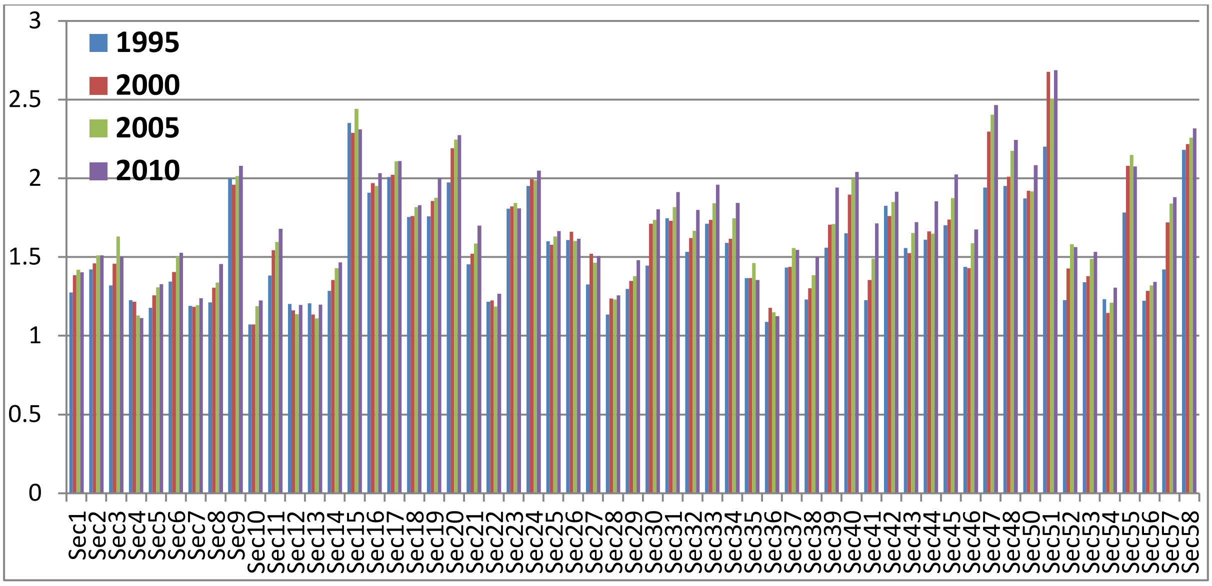
5. Computational results

5.1 Backward Linkage and Forward Linkage Indices

This section shows results obtained from calculation of Backward and Forward multipliers, previously stated their theoretical backgrounds in 4.1. In order to normalize the magnitude, the average values of either Backward or Forward multipliers were used as the denominator, yielding the Backward Linkage Indices and Forward Linkage Indices. Figure 8 and 9 illustrate charts comparing values of Backward multipliers and Backward Linkage Indices of 1995, 2000, 2005 and 2010. Also Figure 10 and 11 show the similar comparison in the case of Forward multipliers and Forward Linkage Indices and Forward Linkage Indices. To prioritize the impact of sectors on Thai economy, Table 2 and 3 show the ranking of five sectors that have highest Backward and Forward multipliers, and Table 4 and 5 indicate the similar ranking in the case of Backward Linkage Indices and Forward Linkage Indices. The ranking of Forward multipliers and Forward Linkage Indices identify that the fossil fuel, represented as sector 30 (Petroleum Refineries and Coal), has played a major role as the upstream sector supplying many downstream users in Thai economy since 1995. In addition, magnitudes of Forward multiplies and those Forward Linkage Indices have increased since 1995. These obtained results signify the gradually rising contribution of fossil fuel over time. Also both rankings indicate that Electricity generation (sector 45) and Transportation (sector 51), which are activities related to fossil fuel, are the major suppliers to the system of Thai economy. However, the multipliers do not identify details of connection among these sectors. The Structural Path Analysis (SPA) has been then applied and reveals details of inter-sector relationship as discussed in section 5.2.

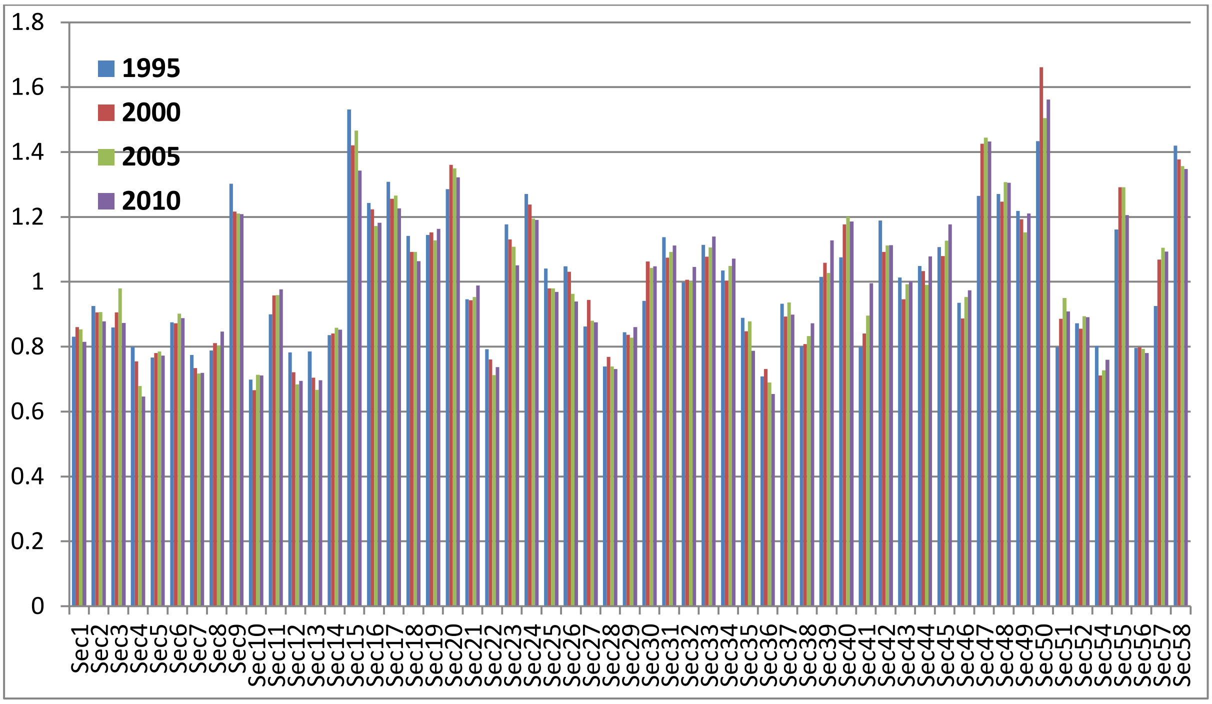
It is noted that both rankings of Backward multipliers and Backward Linkage Indices do not include the fossil fuel as the top-five backward influencer. Both rankings indeed show that other sectors utilize the larger proportion of domestic intermediates and raw materials than the sector 30 (Petroleum Refineries and Coal). The main cause yielding these computational outcomes is that most of crude oil is imported and the multiplier calculation recognizes all imported items as exogenous. Based on these reasons, rankings therefore do not indicate that sector 30 is the top backward influencers in the domestic supply chain.

Figure 8: Backward multipliers computed from IO tables of 1995 2000 2005 and 2010



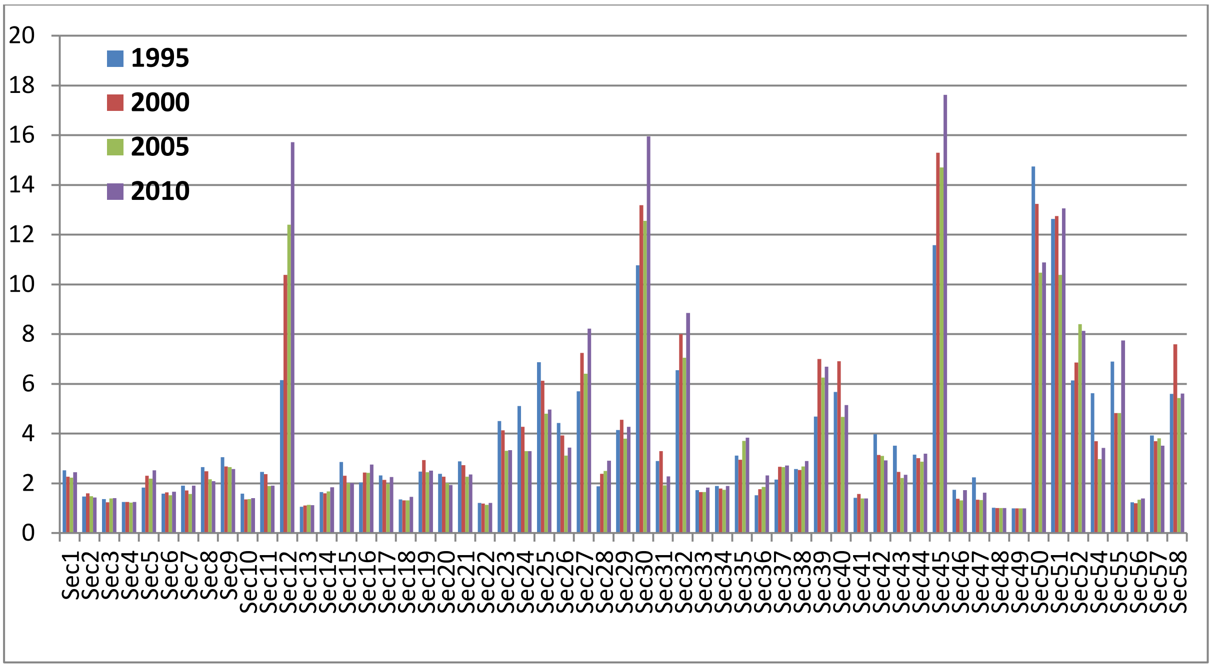
Source: Author's calculation

Figure 9: Backward Linkage Indices computed from IO tables of 1995 2000 2005 and 2010



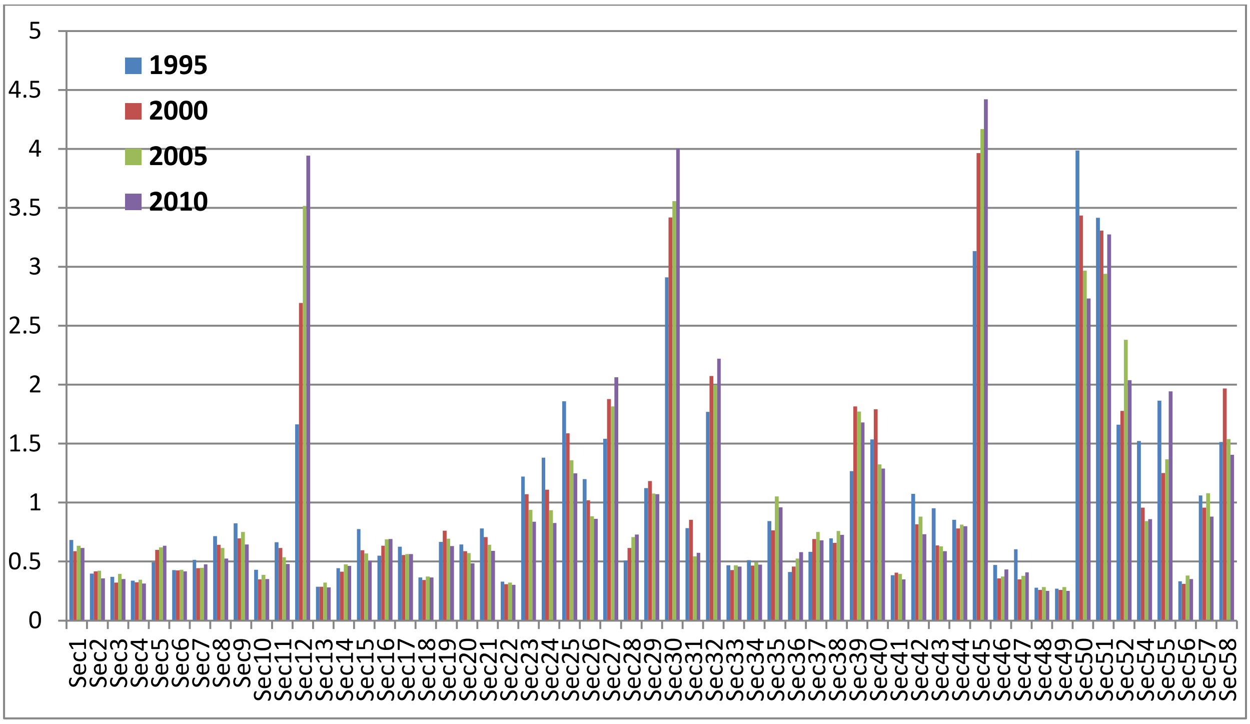
Source: Author's calculation

Figure 10: Forward multipliers computed from IO tables of 1995 2000 2005 and 2010



Source: Author's calculation

Figure 11: Forward Linkage Indices computed from IO tables of 1995 2000 2005 and 2010



Source: Author's calculation

Table 2: Rank of backward multiplier 1995, 2000, 200 and 2010

1995		
Sector		**Multiplier**
Sec15	Slaughtering	2.352
Sec51	Transportation	2.201
Sec58	Unclassified	2.181
Sec17	Rice and Other Grain Milling	2.009
Sec9	Unclassified	2.000
2000		
Sector		**Multiplier**
Sec51	Transportation	2.677
Sec47	Building Construction	2.297
Sec15	Slaughtering	2.288
Sec58	Unclassified	2.218
Sec20	Animal Food	2.192
2005		
Sector		**Multiplier**
Sec51	Transportation	2.505
Sec15	Slaughtering	2.440
Sec47	Building Construction	2.404
Sec58	Unclassified	2.259
Sec20	Animal Food	2.246
2010		
Sector		**Multiplier**
Sec51	Transportation	2.686
Sec47	Building Construction	2.465
Sec58	Unclassified	2.318
Sec15	Slaughtering	2.311
Sec20	Animal Food	2.274

Source: Author's calculation

Table 3: Rank of Backward Linkage Indices 1995, 2000, 200 and 2010

1995		
Sector		**Multiplier**
Sec15	Slaughtering	1.531
Sec51	Transportation	1.433
Sec58	Unclassified	1.420
Sec17	Rice and Other Grain Milling	1.308
Sec9	Unclassified	1.302
2000		
Sector		**Multiplier**
Sec51	Transportation	1.743
Sec47	Building Construction	1.496
Sec15	Slaughtering	1.490
Sec58	Unclassified	1.444
Sec20	Animal Food	1.427
2005		
Sector		**Multiplier**
Sec51	Transportation	1.631
Sec15	Slaughtering	1.589
Sec47	Building Construction	1.565
Sec58	Unclassified	1.471
Sec20	Animal Food	1.462
2010		
Sector		**Multiplier**
Sec51	Transportation	1.561
Sec47	Building Construction	1.433
Sec58	Unclassified	1.347
Sec15	Slaughtering	1.343
Sec20	Animal Food	1.322

Source: Author's calculation

Table 4: Rank of forward multiplier 1995, 2000, 200 and 2010

1995		
Sector		**Multiplier**
Sec50	Restaurants and Hotels	14.737
Sec51	Transportation	12.627
Sec45	Electricity and Gas	11.585
Sec30	Petroleum Refineries and Coal	10.765
Sec55	Business Services	6.894
2000		
Sector		**Multiplier**
Sec45	Electricity and Gas	15.289
Sec50	Restaurants and Hotels	13.241
Sec30	Petroleum Refineries and Coal	13.180
Sec51	Transportation	12.754
Sec12	Paddy	10.382
2005		
Sector		**Multiplier**
Sec45	Electricity and Gas	14.708
Sec30	Petroleum Refineries and Coal	12.556
Sec12	Paddy	12.406
Sec50	Restaurants and Hotels	10.476
Sec51	Transportation	10.381
2010		
Sector		**Multiplier**
Sec45	Electricity and Gas	17.618
Sec30	Petroleum Refineries and Coal	15.956
Sec12	Paddy	15.720
Sec51	Transportation	13.055
Sec50	Restaurants and Hotels	10.889

Source: Author's calculation

Table 5: Rank of Forward Linkage Indices 1995, 2000, 200 and 2010

1995		
Sector		**Multiplier**
Sec50	Restaurants and Hotels	3.053
Sec51	Transportation	2.616
Sec45	Electricity and Gas	2.400
Sec30	Petroleum Refineries and Coal	2.230
Sec55	Business Services	1.428
2000		
Sector		**Multiplier**
Sec53	Banking and Insurance	4.713
Sec45	Electricity and Gas	3.707
Sec50	Restaurants and Hotels	3.210
Sec30	Petroleum Refineries and Coal	3.195
Sec51	Transportation	3.092
2005		
Sector		**Multiplier**
Sec53	Banking and Insurance	5.673
Sec45	Electricity and Gas	3.826
Sec30	Petroleum Refineries and Coal	3.266
Sec12	Paddy	3.227
Sec50	Restaurants and Hotels	2.725
2010		
Sector		**Multiplier**
Sec45	Electricity and Gas	6.751
Sec30	Petroleum Refineries and Coal	3.974
Sec12	Paddy	3.599
Sec51	Transportation	3.546
Sec50	Restaurants and Hotels	2.945

Source: Author’s calculation

5.2 Results obtained from Structural Path Analysis (SPA)

Although results shown in the previous section illustrate the important role of sector 30 (Petroleum Refineries and Coal) as one of main suppliers to most production activities in Thailand, these obtained outcomes have the limitation of identifying paths of influencing. Hence the SPA has been conducted to decompose paths of impact propagation of each multiplier. Following the method suggested by Defourny and Thorbecke(1984), the output of decomposition shows paths of influences embedded in a particular multiplier. As listed on Table 6 – Table 9, the value of global multiplier is identical to the magnitude of each multiplier obtained from conventional computation as show on eq(5) - (8). In addition, the SPA's outcome shows all direct and indirect paths and their magnitudes of influences. Also all tables of SPA's outputs list the proportion of each path's influence to the value of global influence.

Table 6 through Table 9 show the selected results of paths that have the fossil fuel as the origin of supply chain and have highest global multipliers. Most of these top paths are similar for all outputs of conducting SPA on Thailand’s Input-Output tables of 1995, 2000, 2005 and 2010. Specifically these significant paths can be classified into three groups, and each has interesting characteristics as discussed below.

<u>Group (1) the direct paths showing the fossil fuel as the origin of supplier to sectors of transposition and electricity generation.</u>

As earlier stated in the section of 5.1, both electricity and transportation have a high value of Forward multiplier because they supply their outputs to most sectors in Thai economy. Also the sector 30(Petroleum Refineries and Coal) is the major supplier of fuel to electricity generation and transportation. These networks of supply chain are therefore the main mechanism leading to the high value of direct paths starting from sector 30 (Petroleum Refineries and Coal) to directly serve sector 45 (Electricity and Gas) and sector 51(Transportation).

<u>Group (2) the combination of direct and indirect paths starting from fossil fuel and supporting productions of main intermediate goods such as Cement, Non-Metal Ore.</u>

All paths classified in this group are indeed the consequent effect influenced by the result in group (1). With the underlying structure in which many intermediate goods have the transportation as their main cost of production together with the role of fossil fuel as the main input of transportation service, the content of fossil fuel running through both the direct use and indirect path via transportation service is among the main components.

Group (3) the government's public works and other constructions which are mostly a large combination of indirect paths

The decomposition results generated by SPA unveil the interesting feature of linkage between fossil fuel and public works and other constructions. The first unique characteristic is that this linkage is comprised of the widespread network of indirect paths having the fossil fuel as the origin and influencing through many sectors related to government's expenditure and investment. As shown by SPA outcome listed on Table 6 – Table 9, the economy-wide of supply chain between fossil fuel and government's expenditure is dominated by indirect paths. The second characteristic of this linkage is that its magnitude has increased over time. This trend indicates the rising role of government's spending on products and services with fossil-content embedded.

Table 6: Results from Structural Path Analysis showing major paths of fossil fuel (Thailand's IO table of 1995)

	Transmission Paths					Global Influence(GI)	Direct Influence	Path Multiplier	Total Influence(TI)	TI/GI	Cumulative
1	Petroleum Refineries -->	Transportation				0.229	0.208	1.081	0.224	98.107	98.107
2	Petroleum Refineries -->	Electricity and Gas				0.142	0.106	1.256	0.133	93.368	93.368
3	Petroleum Refineries -->	Fishery				0.125	0.103	1.091	0.113	90.347	90.347
	Petroleum Refineries -->	Transportation -->	Fishery				0.060	1.081	0.065	61.263	97.002
4	Petroleum Refineries -->	Other Crops				0.064	0.051	1.096	0.056	87.661	87.661
5	Petroleum Refineries -->	Cement				0.074	0.032	1.190	0.039	52.081	52.081
		Transportation -->	Cement				0.009	1.198	0.011	15.199	67.280
		Electricity and Gas -->	Cement				0.005	1.392	0.007	9.674	76.954
		Non-Metal Ore -->	Transportation -->	Cement			0.005	1.199	0.006	8.002	84.956
		Non-Metal Ore -->	Cement				0.003	1.191	0.003	4.341	89.297
6	Petroleum Refineries -->	Other Non-metallic Products				0.076	0.035	1.095	0.038	50.486	50.486
		Transportation -->	Other Non-metallic Products				0.010	1.101	0.011	14.549	65.035
		Non-Metal Ore -->	Transportation -->	Other Non-metallic Products			0.007	1.102	0.008	10.448	75.483
		Electricity and Gas -->	Other Non-metallic Products				0.004	1.280	0.005	6.054	81.537
		Non-Metal Ore -->	Other Non-metallic Products				0.004	1.095	0.004	5.669	87.206
7	Petroleum Refineries -->	Processing Foods				0.037	0.028	1.085	0.031	84.360	84.360
	Petroleum Refineries -->	Fishery -->	Processing Foods				0.024	1.229	0.029	53.159	74.539
8	Petroleum Refineries -->	Public Works and Other Construction				0.062	0.023	1.074	0.025	40.142	40.142
		Public Works and Other Construction -->	Transportation -->	Public Works and Other Construction			0.009	1.081	0.010	5.846	55.988
		Public Works and Other Construction -->	Non-Metal Ore -->	Transportation -->	Public Works and Other Construction		0.006	1.081	0.006	10.348	66.337
		Public Works and Other Construction -->	Cement -->	Public Works and Other Construction			0.004	1.190	0.005	7.555	73.892
		Public Works and Other Construction -->	Non-Metal Ore -->	Public Works and Other Construction			0.003	1.075	0.003	5.614	79.506

		Public Works and Other Construction -->	Iron and Steel -->	Public Works and Other Construction			0.001	1.349	0.002	2.743	82.249
		Public Works and Other Construction -->	Cement -->	Transportation -->	Public Works and Other Construction		0.001	1.198	0.001	2.205	84.454
		Public Works and Other Construction -->	Cement -->	Public Works and Other Construction			0.001	1.392	0.001	1.403	85.857
9	Petroleum Refineries -->	Metal Ore				0.034	0.023	1.074	0.024	72.353	72.353
	Petroleum Refineries -->	Transportation -->	Metal Ore				0.016	1.130	0.019	44.067	91.809

Source: Author's calculation

Table 7: Results from Structural Path Analysis showing major paths of fossil fuel (Thailand's IO table of 2000)

	Transmission Paths			**Global Influence(GI)**	**Direct Influence**	**Path Multiplier**	**Total Influence(TI)**	**TI/GI**	**Cumulative**
1	Petroleum Refineries -->	Transportation		0.321	0.284	1.110	0.315	98.038	98.038
2	Petroleum Refineries -->	Fishery		0.153	0.120	1.129	0.135	88.417	88.417
3	Petroleum Refineries -->	Electricity and Gas		0.104	0.069	1.352	0.093	89.833	89.833
4	Petroleum Refineries -->	Other Crops		0.100	0.076	1.131	0.086	86.339	86.339
	Petroleum Refineries -->	Transportation -->	Other Crops		0.076	1.110	0.084	58.678	96.695
5	Petroleum Refineries -->	Non-Metal Ore		0.143	0.047	1.101	0.052	36.088	36.088
	Petroleum Refineries -->	Transportation -->	Non-Metal Ore		0.076	1.110	0.084	58.678	94.767
6	Petroleum Refineries -->	Cement		0.099	0.042	1.212	0.051	51.607	51.607
	Petroleum Refineries -->	Transportation -->	Cement		0.013	1.222	0.016	16.515	68.122
	Petroleum Refineries -->	Non-Metal Ore -->	Cement		0.007	1.222	0.009	8.665	76.787
	Petroleum Refineries -->	Electricity and Gas -->	Cement		0.005	1.488	0.008	8.246	85.033
	Petroleum Refineries -->	Non-Metal Ore -->	Cement		0.004	1.212	0.005	5.329	90.362
7	Petroleum Refineries -->	Basic Chemical Products		0.060	0.028	1.420	0.040	66.641	66.641
	Petroleum Refineries -->	Transportation -->	Basic Chemical Products		0.007	1.431	0.010	16.265	82.906
	Petroleum Refineries -->	Electricity and Gas -->	Basic Chemical Products		0.002	1.743	0.004	6.290	89.196
	Petroleum Refineries -->	Trade-->	Basic Chemical Products		0.001	1.443	0.002	2.640	91.836
8	Petroleum Refineries -->	Other Non-metallic Products		0.083	0.035	1.130	0.039	47.352	47.352

					Global Influence(GI)	Direct Influence	Path Multiplier	Total Influence(TI)	TI/GI	Cumulative
9	Petroleum Refineries -->	Public Works and Other Construction			0.098	0.035	1.101	0.039	39.754	39.754
	Petroleum Refineries -->	Transportation -->	Public Works and Other Construction			0.018	1.110	0.020	20.627	60.380
	Petroleum Refineries -->	Non-Metal Ore -->	Transportation -->	Public Works and Other Construction		0.008	1.110	0.009	9.499	69.880
	Petroleum Refineries -->	Cement -->	Public Works and Other Construction			0.006	1.212	0.008	7.868	77.747
	Petroleum Refineries -->	Non-Metal Ore -->	Public Works and Other Construction			0.005	1.101	0.006	5.842	83.590
	Petroleum Refineries -->	Cement -->	Transportation -->	Public Works and Other Construction		0.002	1.222	0.002	2.518	86.107
	Petroleum Refineries -->	Iron and Steel -->	Public Works and Other Construction			0.001	1.347	0.001	1.348	87.455
	Petroleum Refineries -->	Cement -->	Electricity and Gas -->	Public Works and Other Construction		0.001	1.488	0.001	1.257	88.712
10	Petroleum Refineries -->	Processing Foods			0.035	0.028	1.111	0.031	88.699	88.699
	Petroleum Refineries -->	Fishery -->	Processing Foods			0.023	1.282	0.030	46.893	67.186

Source: Author's calculation

Table 8: Results from Structural Path Analysis showing major paths of fossil fuel (Thailand's IO table of 2005)

	Transmission Paths			Global Influence(GI)	Direct Influence	Path Multiplier	Total Influence(TI)	TI/GI	Cumulative
1	Petroleum Refineries -->	Transportation		0.346	0.313	1.084	0.340	98.027	98.027
2	Petroleum Refineries -->	Fishery		0.160	0.124	1.116	0.139	86.780	86.780
3	Petroleum Refineries -->	Electricity and Gas		0.110	0.075	1.275	0.096	86.643	86.643
4	Petroleum Refineries -->	Transportation -->	Electricity and Gas		0.081	1.085	0.087	52.865	96.593
5	Petroleum Refineries -->	Non-Metal Ore		0.165	0.064	1.078	0.069	41.640	41.640
	Petroleum Refineries -->	Transportation -->	Non-Metal Ore		0.081	1.085	0.087	52.865	94.505
6	Petroleum Refineries -->	Other Crops		0.086	0.060	1.110	0.066	77.299	77.299
7	Petroleum Refineries -->	Cement		0.110	0.047	1.174	0.056	50.377	50.377
	Petroleum Refineries -->	Transportation -->	Cement		0.011	1.181	0.012	11.295	61.672
	Petroleum Refineries -->	Non-Metal Ore -->	Cement		0.009	1.175	0.010	9.076	70.748
	Petroleum Refineries -->	Electricity and Gas -->	Cement		0.006	1.388	0.008	7.069	77.817

	Petroleum Refineries -->	Crude Oil and Coal -->	Cement		0.001	1.188	0.002	1.504	79.321
	Petroleum Refineries -->	Trade-->	Cement		0.001	1.193	0.001	0.883	80.204
	Petroleum Refineries -->	Iron and Steel -->	Cement		0.001	1.512	0.001	0.767	80.971
	Petroleum Refineries -->	Basic Chemical Products -->	Cement		0.000	1.463	0.000	0.209	81.180
8	Petroleum Refineries -->	Other Non-metallic Products		0.090	0.039	1.112	0.043	48.059	48.059
9	Petroleum Refineries -->	Public Works and Other Construction		0.115	0.039	1.078	0.042	36.164	36.164
	Petroleum Refineries -->	Transportation -->	Public Works and Other Construction		0.022	1.084	0.023	20.264	56.428
	Petroleum Refineries -->	Cement -->	Public Works and Other Construction		0.008	1.174	0.010	8.345	64.773
	Petroleum Refineries -->	Non-Metal Ore -->	Public Works and Other Construction		0.008	1.078	0.009	7.687	72.461
	Petroleum Refineries -->	Iron and Steel -->	Public Works and Other Construction		0.002	1.388	0.002	2.013	74.473
	Petroleum Refineries -->	Other Non-metallic Products-->	Public Works and Other Construction		0.001	1.112	0.001	0.526	75.000
	Petroleum Refineries -->	Fabricated Metal Products-->	Public Works and Other Construction		0.000	1.105	0.000	0.272	75.272
	Petroleum Refineries -->	Business Services -->	Public Works and Other Construction		0.000	1.107	0.000	0.256	75.528
	Petroleum Refineries -->	Industrial Machinery -->	Public Works and Other Construction		0.000	1.226	0.000	0.165	75.693
	Petroleum Refineries -->	Electrical Machinery -->	Public Works and Other Construction		0.000	1.597	0.000	0.124	75.817
10	Petroleum Refineries -->	Sugarcane		0.080	0.032	1.169	0.038	47.048	47.048

Source: Author's calculation

Table 9: Results from Structural Path Analysis showing major paths of fossil fuel (Thailand's IO table of 2010)

	Transmission Paths				Global Influence (GI)	Direct Influence	Path Multiplier	Total Influence(TI)	TI/GI	Cumulative
1	Petroleum Refineries-->	Transportation			0.527	0.414	1.243	0.514	97.598	97.598
2	Petroleum Refineries-->	Fishery			0.152	0.128	1.138	0.146	95.727	95.727
3	Petroleum Refineries-->	Public Works and Other Construction			0.108	0.043	1.074	0.046	42.141	42.141
	Petroleum Refineries-->	Transportation -->	Public Works and Other Construction			0.021	1.243	0.027	24.631	66.772
	Petroleum Refineries-->	Cement -->	Public Works and Other Construction			0.009	1.188	0.011	9.697	76.469
	Petroleum Refineries-->	Non-Metal Ore -->	Public Works and Other Construction			0.007	1.076	0.007	6.652	83.121
	Petroleum Refineries-->	Non-Metal Ore -->	Cement -->	Public Works and Other Construction		0.002	1.189	0.002	2.168	85.289

	Petroleum Refineries-->	Iron and Steel -->	Public Works and Other Construction			0.002	1.298	0.002	2.052	87.341
	Petroleum Refineries-->	Transportation -->	Non-Metal Ore -->	Public Works and Other Construction		0.001	1.245	0.001	1.272	88.613
	Petroleum Refineries-->	Electricity and Gas -->	Cement -->	Public Works and Other Construction		0.001	1.493	0.001	1.128	89.741
	Petroleum Refineries-->	Business Services -->	Public Works and Other Construction			0.001	1.131	0.001	0.763	90.504
4	Petroleum Refineries-->	Electricity and Gas			0.100	0.058	1.350	0.078	78.449	78.449
	Petroleum Refineries-->	Crude Oil and Coal -->	Electricity and Gas			0.012	1.365	0.016	15.775	94.225
5	Petroleum Refineries-->	Cement			0.091	0.047	1.188	0.056	61.805	61.805
	Petroleum Refineries-->	Non-Metal Ore -->	Cement			0.011	1.189	0.013	13.817	75.622
	Petroleum Refineries-->	Electricity and Gas -->	Cement			0.004	1.493	0.007	7.188	82.810
	Petroleum Refineries-->	Transportation -->	Cement			0.002	1.375	0.003	3.435	86.245
	Petroleum Refineries-->	Transportation -->	Non-Metal Ore -->	Cement		0.002	1.376	0.002	2.643	88.888
	Petroleum Refineries-->	Crude Oil and Coal -->	Cement			0.001	1.202	0.002	1.923	90.811
6	Petroleum Refineries-->	Non-Metal Ore			0.086	0.062	1.076	0.067	77.293	77.293
	Petroleum Refineries-->	Transportation -->	Non-Metal Ore			0.010	1.245	0.013	14.785	92.078
	Petroleum Refineries-->	Electricity and Gas -->	Non-Metal Ore			0.001	1.352	0.001	1.656	93.733
7	Petroleum Refineries-->	Other Crops			0.080	0.065	1.141	0.074	92.371	92.371
8	Petroleum Refineries-->	Basic Chemical Products			0.070	0.047	1.316	0.063	89.393	89.393
9	Petroleum Refineries-->	Business Services			0.068	0.038	1.132	0.043	62.917	62.916
	Petroleum Refineries-->	Transportation -->	Business Services			0.006	1.308	0.008	11.878	74.795
	Petroleum Refineries-->	Electricity and Gas -->	Business Services			0.0006	1.4212	0.0009	1.2573	82.6966
	Petroleum Refineries-->	Printing and Publishing-->	Business Services			0.0006	1.1317	0.0007	0.9796	83.6762
	Petroleum Refineries-->	Communication-->	Business Services			0.0004	1.3194	0.0005	0.6865	84.3626
	Petroleum Refineries-->	Restaurants and Hotels -->	Business Services			0.0003	1.1356	0.0003	0.4512	84.8139
	Petroleum Refineries-->	Banking and Insurance -->	Business Services			0.0002	1.2494	0.0003	0.4292	85.2430

Source: Author’s calculation

6. Conclusion and policy recommendation

This study applied two computational methods to Thailand's four latest versions of officials IO tables. The first computation delivered sets of Backward and Forward multipliers, and also it generated values of Backward Linkage Indices and Forward Linkage Indices. These results indicate that fossil fuel has been among the main upstream sectors functioning as the origin point of supply chains. To examine details of inter-sectoral connections among sectors, the second computation, which is the SPA, has been applied to those four IO tables of Thailand. The results of multiplier decomposition show that there are three main categories of paths. Particularly these computational outcomes indicate that it is possible to apply the sector-specific policy to each category of fossil-fuel forwarding paths in order to effectively mitigate the GHGs emission. This is because the conventional policy scheme such as imposing the carbon tax on fossil fuels would cause the economy-wide negative impacts due to petroleum and coal's widespread network of forwarding paths as previously shown in section 5.1 and 5.2, while the non-tax sector-specific policy would contain propagation of downside effects.

Specifically, the first category of top influential paths having the fossil fuel as the origin is comprised of transportation and electricity generation. Because both activities are also among the main costs of productions of many intermediate goods, the second groups of high influential paths having the fossil fuel as the origin are manufacturing of key intermediate products such as non-metal ore and cement. The implication of the carbon tax would inevitably incur the higher price of transportation and electricity, and would subsequently induce the higher costs to manufacturers of many intermediate goods. Therefore, the alternative schemes for medium and long run implication would be the government's support on changing the mode of transportation and the replacement toward renewable sources of electricity generation and/or transmission network optimization. The last category of high influencing group of paths is the public works and other constructions. This result interestingly identifies that government expenditures are related to the highly embedded fossil-content products and services. Hence the government's program of green procurement would be the most relevant mechanism for this category of paths, and it would initiate the expanding demand for the low fossil-content products. Based on these results, the further study should be conducted in order to investigate and compare all aspects of costs and benefits of implementing suggested policies. Particularly the full structural and price-endogenous model such as Computable General Equilibrium (CGE) model should be utilized.

References

Acquaye, A. A., Wiedmann, T., Feng, K., Crawford, R. H., Barrett, J., Kuylenstierna, J., . . . McQueen-Mason, S. (2011). Identification of 'carbon hot-spots' and quantification of GHG intensities in the biodiesel supply chain using hybrid LCA and structural path analysis. *Environmental science & technology, 45*(6), 2471-2478.

Benavides, C., Gonzales, L., Diaz, M., Fuentes, R., García, G., Palma-Behnke, R., & Ravizza, C. (2015). The impact of a carbon tax on the Chilean electricity generation sector. *Energies, 8*(4), 2674-2700.

Bin, S., & Dowlatabadi, H. (2005). Consumer lifestyle approach to US energy use and the related CO 2 emissions. *Energy Policy, 33*(2), 197-208.

Callan, T., Lyons, S., Scott, S., Tol, R. S., & Verde, S. (2009). The distributional implications of a carbon tax in Ireland. *Energy Policy, 37*(2), 407-412.

Chung, W.-S., Tohno, S., & Shim, S. Y. (2009). An estimation of energy and GHG emission intensity caused by energy consumption in Korea: an energy IO approach. *Applied Energy, 86*(10), 1902-1914.

Cohen, C., Lenzen, M., & Schaeffer, R. (2005). Energy requirements of households in Brazil. *Energy Policy, 33*(4), 555-562.

Defourny, J., & Thorbecke, E. (1984). Structural Path Analysis and Multiplier Decomposition within a Social Accounting Matrix Framework. *The Economic Journal, 94*(373), 111-136. doi: 10.2307/2232220

Eto, R., Uchiyama, Y., & Okajima, K. (2011). A scenario analysis of energy-economic in Ibaraki prefecture in 2030, Proceeding 17th International Input-Output Conference, San Paulo, Brazil.

Gonne, N. (2010). The impact of a carbon tax on sectors competitiveness, University of Namur, Department of Economics, Working Paper Series WP 1015.

Gonzalez, M. B. (2015). Implementing a Carbon Tax in Spain: How to Overcome the Fear of Inflation?, The Energy and Resources Institute (TERI) and the United Nations Environment Programme (UNEP).

Gough, I., Abdallah, S., Johnson, V., Ryan-Collins, J., & Smith, C. (2011). The distribution of total greenhouse gas emissions by households in the UK, and some implications for social policy. *LSE STICERD Research Paper No. CASE152*.

Goulder, L. H. (1992). Carbon tax design and US industry performance *Tax Policy and the Economy, Volume 6* (pp. 59-104): The MIT Press.

Hong, J., Shen, Q., & Xue, F. (2016). A multi-regional structural path analysis of the energy supply chain in China's construction industry. *Energy Policy, 92*, 56-68.

Jain, S. (2012). An input–output analysis to estimate embodied energy of goods. *International Journal of Scientific and Research Publications, 2*(11), 1-12.

Kofoworola, O. F., & Gheewala, S. H. (2008). An Input–output Analysis of Total Requirements of Energy and Greenhouse Gases for all Industrial Sectors in Thailand. *Asian J. Energy Environ, 9*(3), 177-196.

Lantner, R. (1974). *Théorie de la dominance économique*: Dunod.

Lenzen, M., Dey, C., & Foran, B. (2004). Energy requirements of Sydney households. *Ecological Economics, 49*(3), 375-399.

Leontief, W. W. (1936). Quantitative Input and Output Relations in the Economic Systems of the United States. *The Review of Economics and Statistics, 18*(3), 105-125. doi: 10.2307/1927837

Liang, S., & Zhang, T. (2011). Direct and indirect energy demands and CO2 emissions from production activities in Jiangsu Province in 2007. *Energy Procedia*(11), 2973-2979.

Liu, Z., Geng, Y., Lindner, S., Zhao, H., Fujita, T., & Guan, D. (2012). Embodied energy use in China's industrial sectors. *Energy Policy, 49*, 751-758.

Lu, X., & Lei, S. (2011). Household energy demand of China towards a well-off society by 2020. *Energy Procedia, 5*, 1676-1681. doi: http://dx.doi.org/10.1016/j.egypro.2011.03.286

Mathur, A., & Morris, A. C. (2014). Distributional effects of a carbon tax in broader US fiscal reform. *Energy Policy, 66*, 326-334.

Mongelli, I., Tassielli, G., & Notarnicola, B. (2009). Carbon tax and its short-term effects in Italy: an evaluation through the input-output model *Handbook of Input-Output Economics in Industrial Ecology* (pp. 357-377): Springer.

Mukhopadhyay, K., & Chakraborty, D. (2005). Energy intensity in India during pre-reform and reform period–An Input-Output Analysis. *Calcutta, India*.

Nápoles, P. R. (2012). Low carbon development strategy for Mexico: An Input-Output Analysis. *Final report published by United Nations Environment Programme*.

Yang, Z., Dong, W., Xiu, J., Dai, R., & Chou, J. (2015). Structural Path Analysis of Fossil Fuel Based CO 2 Emissions: A Case Study for China. *PloS one, 10*(9), e0135727.