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Accounting for External Costs in the Allocation of Carbon Emissions Quotas for Selected Industries in Thailand

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Abstract

This study aims to account for the external economic impact costs to allocate an optimal CO_2 emissions quota system in the Thailand ETS. The focus industries were the highly intensive energy sectors including electricity, petrochemicals, cement, iron and steel, and aviation. The economic impact is computed in terms of the combined strength of forward and backward linkages measured by Leontief's inverse produced by the input-output (I-O) model. The calculation of the difference of Economic Impact – Emission Ratio (EIER) for industries indicated the differences in the ratio of change in economic impact as a result of one additional unit of CO_2 emission reduction. The results show that economic efficiency and optimal allocation of CO_2 emissions quotas can be achieved using the equi-marginal method. The results suggest that total economic costs of approximately 10.78% can be saved by implementing this optimal emissions quota allocation method. Moreover, the electricity sector should be allocated a larger quota than the other four industries.

Keywords: Optimal allocation; Equi-marginal principle; Economic cost

1. Introduction

The Thailand Voluntary Emission Trading Scheme (Thailand V-ETS) was established on October 1, 2014 by the Thailand Greenhouse Gas Management Organization (Public Organization) [TGO]. The purpose of Thailand V-ETS is to prepare the stage for emissions trading. Emission trading is an economic incentive instrument based on the principle of cap and trade which is program in which "A government issues a limited number of annual permits that allow companies to emit a certain amount of carbon dioxide. The total amount permitted thus becomes the "cap" on emissions". It is widely considered to be the main mechanism for GHG emissions reduction used by the European Union (EU), the United States of America (USA), Canada, China, Korea, and other countries (ICAP, 2016). Emission Trading Schemes (ETS) are an effective mechanism to absolutely control the amount of GHG emissions, allowing flexibility on the part of the polluter to choose the option with the lowest cost, thus minimizing the total costs of reducing GHG (Field, 2006; Kunnoot, 2015; Zhao *et al*., 2018). Thailand V-ETS focuses on highly energy intensive industries including the electricity, cement, petrochemicals and iron and steel sectors.

In the preparation stage, participation in Thailand ETS is voluntary. At this stage, there is no legal obligation to meet the target of CO_2 emissions reduction. In the next stage however, industries will be obliged to meet targets for GHG emissions reduction which are set at 2 % based on the carbon intensity of the reference year (Usapein and Chavalparit, 2017). The GHG emission quota is administered by TGO. The quota is allocated in proportion to existing emissions in which all parties are allowed the right to pollute yet at lesser levels than business as usual (BAU). To comply with the regulation, enterprises need to purchase credits to eliminate their excess emissions.

The implementation of the ETS can be expected to lead to economic changes as reducing emissions involves extra investment and spending, thereby raising costs and prices of goods and services of various industries that are interdependent (Sutummakid, 2011). Some industries are connected as input sources while output is used downstream by other industries. However, the costs of emission reduction borne by the interdependence of industries are external to the initiating industry.

In this study, the concept of external costs is introduced as a supplement to market allocation of emissions quotas. The external cost is the economic impact quantified using the method known as backward and forward linkages measured with Leontief's inverse produced by the input-output (I-O) model. The objective of this study in computing an optimal emissions quota is to minimize total external costs. In general, external costs can be expected to differ across industries. Here, a special case is described where external costs are the same for all industries in order to achieve economic efficiency. The minimum total external cost is realized by the allocation of overall emissions quotas for enterprises in any percentage that equates the marginal external cost. This is known as the equi-marginal principle.

2. Materials and Methods

This study considered the comparison of two allocations based on the grandfathering (GF) and equi-marginal methods to calculate CO_2 emissions quotas in the Thailand ETS, for the sake of a reasonable emission quota allocation to ensure minimal economic costs of allocation. The conceptual framework of this study is shown in Figure 1.

2.1 Data

The latest input-output (I-O) table for Thailand for 2010 released by the Office of the National Economics and Social Development Board (NESDB), which represents the Thai economy with the total of 180 commodities, is used for the computation of backward and forward linkages. The I-O table has n rows and n columns as shown in Figure 2.

- The horizontal row (i^{th}) expressed as output distribution, consists of (1) intermediate input; and (2) final consumption, including investment expenditure, household consumption, government consumption, inventories, exports, and special exports.

- The vertical column (j^{th}) expressed as input requirements for production of goods and services activities (demand), consists of (1) primary input (value added), including wage income, capital, depreciation, and indirect taxes and (2) intermediate input, consisting of domestic, and imported inputs.

2.2 Methods

The industries targeted to participate in the Thailand ETS include the petrochemicals, cement, iron and steel, electricity, and aviation sectors. They are coded according to Thailand's system in the I-O table as 086, 102, 106, 135, and 156, respectively. The information required for the computation of the GHG emissions quota include, (1) the amount of CO_2 emissions of respective target industries, (2) the economic impact - emissions ratio (EIER) and (3) the total CO_2 emissions quota for the Thailand ETS.

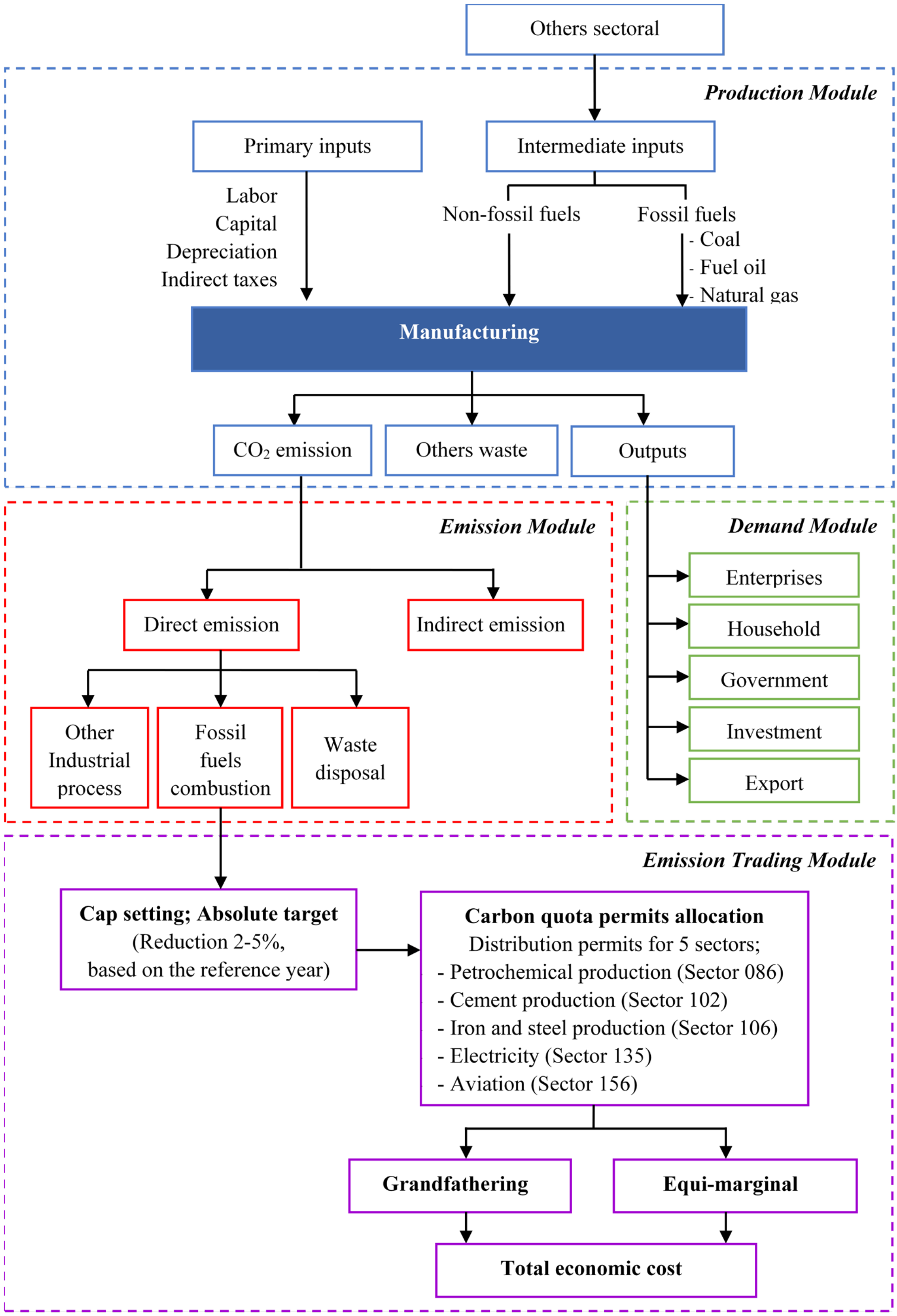


Figure 1. Conceptual framework of the study

Table 1. The Structure of Input-Output table

		Industrial sectors												
		Intermediate Input ($X0D_{i,j}$)						Final Demand (F)						
Commodities (Domestic)		Sec 1	Sec 2	Sec 3	Sec 4	…	Sec 180	Investment	Household	Government	Inventories	Export	Special Export	**Total Output (X_i)**
	Sec 1	$X0D_{1,1}$	$X0D_{1,2}$	$X0D_{1,3}$	$X0D_{1,4}$	…	$X0D_{1,180}$	$F1D_1$	$F2D_1$	$F3D_1$	$F4D_1$	$F5D_1$	$F6D_1$	$\mathbf{X_1}$
	Sec 2	$X0D_{2,1}$	$X0D_{2,2}$	$X0D_{2,3}$	$X0D_{2,4}$	…	$X0D_{2,180}$	$F1D_2$	$F2D_2$	$F3D_2$	$F4D_2$	$F5D_2$	$F6D_2$	$\mathbf{X_2}$
	…	…	…	…	…	…	…	…	…	…	…	…	…	**…**
	Sec 180	$X0D_{180,1}$	$X0D_{180,2}$	$X0D_{180,3}$	$X0D_{180,4}$	…	$X0D_{180,180}$	$F1D_{180}$	$F2D_{180}$	$F3D_{180}$	$F4D_{180}$	$F5D_{180}$	$F6D_{180}$	$\mathbf{X_{180}}$
Commodities (Import)		Intermediate Input($X0I_{i,j}$)												Total Import Demand
		Sec 1	Sec 2	Sec 3	Sec 4	…	Sec 180							
	Sec 1	$X0I_{1,1}$	$X0I_{1,2}$	$X0I_{1,3}$	$X0I_{1,4}$	…	$X0I_{1,180}$	$F1I_1$	$F2I_1$	$F3I_1$	$F4I_1$			
	Sec 2	$X0I_{2,1}$	$X0I_{2,2}$	$X0I_{2,3}$	$X0I_{2,4}$	…	$X0I_{2,180}$	$F1I_2$	$F2I_2$	$F3I_2$	$F4I_2$			
	…	…	…	…	…	…	…	…	…	…	…			
	Sec 180	$X0I_{180,1}$	$X0I_{180,2}$	$X0I_{180,3}$	$X0I_{180,4}$	…	$X0I_{180,180}$	$F1I_{180}$	$F2I_{180}$	$F3I_{180}$	$F4I_{180}$			
Value Added	Labor ($X1_j$)	$X1_1$	$X1_2$	$X1_3$	$X1_4$	…	$X1_{180}$							Sum of Labor (VA1)
	Capital ($X2_j$)	$X2_1$	$X2_2$	$X2_3$	$X2_4$	…	$X2_{180}$							Sum of Capital (VA2)
	Indirect taxes ($X3_j$)	$X3_1$	$X3_2$	$X3_3$	$X3_4$	…	$X3_{180}$							Sum of Indirect taxes (VA3)
Total Input (X_j)		$\mathbf{X_1}$	$\mathbf{X_2}$	$\mathbf{X_3}$	$\mathbf{X_4}$	**…**	$\mathbf{X_{180}}$							

2.2.1 Evaluation of economic impact

The backward and forward linkages of respective targeted industries are found through the computation of Leontief's inverse using Thailand's I-O table for 2010. With the representation of X as the column vector of output, F as the column vector of final demand, A as the square matrix of coefficients of intermediate inputs, and I as the identity matrix, the Leontief system equation (Leontief, 1986; Perese, 2010) is initially expressed as:

$$X = AX+F \tag{1}$$

which can be transformed into:

$$X = (I-A)^{-1} F \tag{2}$$

The square matrix of Leontief's inverse $(I – A)^{-1}$ represents the multipliers of economic impacts on output X initiated from final demand F. The sum row accounts for forward linkages of respective industries, whereas the sum column accounts for the backward linkages of respective industries. The equation is as follows.

Backward linkages

$$L_j^B = \sum_{i=1}^{N} (I - A)^{-1} \tag{3}$$

Forward linkages

$$L_i^F = \sum_{j=1}^{N} (I - A)^{-1} \tag{4}$$

The sum of forward and backward linkages is used to account for the economic impact of GHG emissions reductions.

2.2.2 The quantity of CO_2 emissions for respective industries

The amount of CO_2 emissions of the five target industries in Thailand ETS is computed from the value of fossil fuel consumption by converting the value of coal, petroleum and gas energy consumption into a physical quantity unit. The data for value of energy consumption are drawn from Thailand's I-O table from 2010. The conversion is based on the fuel prices reported in the Thai energy context in 2010 and the Energy balance of Thailand in 2010. The amount of fossil fuels consumed is computed using the equation:

$$FC_j = \sum_{k=1}^{12} \frac{FV_k}{P_k} \tag{5}$$

where index k denotes the types of fossil fuels consumed, the term FC_J denotes the quantity of fuel consumption of industry j, whereas FV_k denotes the value of fuel consumption, while Pk denotes the price of fuel in 2010 as shown in Table 2.

CO_2 emissions were computed by applying the emissions factor *(EF)* released in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), to the quantity of the respective fuel with the following equation:

$$E_j = \sum_{k=1}^{12} (FC_k x EF_k) \tag{6}$$

where the term E_j denotes the quantity of CO_2 emitted by industry j (in terms of CO_2 equivalent- CO_2e), while the term FC_k denotes the quantity of consumption of fossil fuel of type k in industry j, and the term EF_k denotes the CO_2 emission factor for fuel type k, as shown in Table 2.

2.2.3 Simulation of Economic Impact - Emissions Ratio (EIER)

The EIER is the ratio of the change in economic impact as a result of one additional unit of CO_2 emissions reduction. The inverse linear is simply assumed to represent the marginal cost of CO_2 emissions reduction. The EIER of targeted industries can be expressed in a general linear equation as follows:

$$EI_j = -a_j E_j + C_j \tag{7}$$

where the term EI_j denotes the economic impact of industry j, while the term E_j denotes the CO_2 emissions of industry j, with the parameter a_j describing the ratio between the economic impact and the CO_2 emissions, with constant C_j for the value of the EI_j when E_j takes the value of zero.

Table 2. The price of fossil fuels in 2010 and the GHG emission factor for fossil fuel combustion.

Type of Fossil Fuel	Unit	Price* (Baht/Unit)	GHG Emission (kg CO_2e/unit)
Stationary Combustion			
Coal and its products			
- Anthracite *(k_1)*	kg	4.187	3.1014[1]
- Bituminous *(k_2)*	kg	2.349	2.3440[1]
- Sub-bituminous *(k_3)*	kg	1.977	2.5466[1]
- Lignite *(k_4)*	kg	0.5697	1.0624[1]
- Coal coke *(k_5)*	kg	6.825	2.8377[2]
Petroleum oil products			
- Diesel *(k_6)*	litre	27.55	2.7080[1]
- Gasoline *(k_7)*	litre	36.10	2.2376[1]
- Fuel oil *(k_8)*	litre	23.59	3.0883[1]
- Kerosene *(k_9)*	litre	37.51	2.4777[1]
- Liquefied Petroleum Gas (LPG) *(k_{10})*	litre	9.79	1.6812[1]
Natural gas			
- Natural gas *(k_{11})*	kg	10.5	2.2472[1]
Mobile Combustion			
- Jet kerosene *(k_{12})*	litre	37.51	2.4910[2]

Note: * Price of fossil fuel for each fuel type (k) in 2010

Sources: [1] Intergovernmental Panel on Climate Change [IPCC] (2006)

[2] United States Environmental Protection Agency [EPA] (2014)

2.2.4 Estimation of Proportional Allocation

The cap of the total quantity of CO_2 emissions, denoted by the term E_{Target}, is determined by Thailand ETS to achieve a 2-5% reduction in emissions. The sum of CO_2 emissions of a respective industry, denoted by the term Q_j, is determined as follows:

$$E_{Target} = \sum_{j=1}^{N} Q_j \qquad (8)$$

2.2.4.1 The Quota Allocation with the Grandfathering Method

Accordingly, each industry is obliged to reduce CO_2 emissions by 2-5%. This allocation is known as the GF (Zhou and Wang, 2016). The GF is economically efficient only if the EI of each industry is exactly the same.

2.2.4.2 The Quota Allocation based on the Equi-marginal method

Alternatively, if the EI of each industry differs, minimum costs will be achieved by equating the EI on every industry. This method is known as the equi-marginal principle according to which the total CO_2 emissions reduction of 2-5% is unequally shared by industries. The allocation is thus any percentage that equates the EI of all industries. The CO_2 emissions quotas that equate the EI of all industries can be calculated with the equation in matrix form as follows:

$$AV = C \qquad (9)$$

$$V = A^{-1} C \qquad (10)$$

where the term V denotes column vector of endogenous variables, while C denotes the column vector of a constant, and A denotes the square matrix of coefficients.

2.2.5 Computation of total economic cost

The total economic cost of CO_2 quota permit allocations in the Thailand ETS can be calculated with the aggregate area of the EIER linear of all industries for the given quantity of reduction of CO_2 emissions. The total economic cost, denoted by TC_j for respective industries, can be found from the integral of EIER as follows:

$$TC_j = \int_{Q_j}^{E_j} \left(EI_j - a_j E_j\right) \partial E_j \qquad (11)$$

In this study, the EIER is the marginal function which is similar to marginal abatement cost (MAC) curves. Subsequently, to further reduce emissions, new investment in technology is required resulting in significant increases in EIER. The economic cost of individual polluters is shown in the area under the EIER curve between E and Q. The aggregate EIER curve is a summation of individual polluters computed by the integration of the EIER function.

3. Results and discussion

3.1 Economic impact on industries

As described earlier, the sum of the value of backward and forward linkages is used to measure the magnitude of the economic impacts on industry of emissions reductions. Accordingly, the economic impacts were calculated as 9.7334, 5.4200, 5.0269, 4.5735, and 4.1612 for electricity, iron and steel, petrochemical, aviation, and cement industries, respectively, as shown in Figure 3. The results indicate the differences in economic impact among the five industries targeted. Clearly, electricity generation suffers the highest economic impact, implying that further emissions reductions will have much greater economic effects on the Thai economy.

3.2 CO_2 emissions and emission intensity

The computed quantity of total CO_2 emissions of the five industries under Thailand ETS is 94.72 $MtCO_2e$. The CO_2 emissions for the electricity, cement, petrochemicals, aviation and iron and steel industries are 68.840, 10.841, 10.119, 4.236 and 0.687 $MtCO_2e$, respectively, as shown in Figure 4. These amounts account for 72.68%, 11.44%, 10.68%, 4.47% and 0.73% respectively of total CO_2 emissions of 5 targeted industries. The highest emission intensity from the electricity and cement industries were 97.543 and 95.286 $tCO_2e/10^6$ baht, respectively. Thus, the CO_2 emissions of the electricity generating industry are approximately 6 times the levels in the cement industry.

3.3 Simulation of EIERs for Targeted Industries

The EIER is conceived as the change in the economic impact per additional unit of reduction of CO_2 emissions. This is symbolically denoted by *-EC/E*. The EIERs for the five target industries are shown in Table 3.

Figure 5 shows that the EIERs for five industries under Thailand ETS vary considerably. Thus, for the sake of minimizing the economic costs of emissions allocations, it is necessary to investigate the allocations of CO_2 emissions quotas among the industries according to their EIERs.

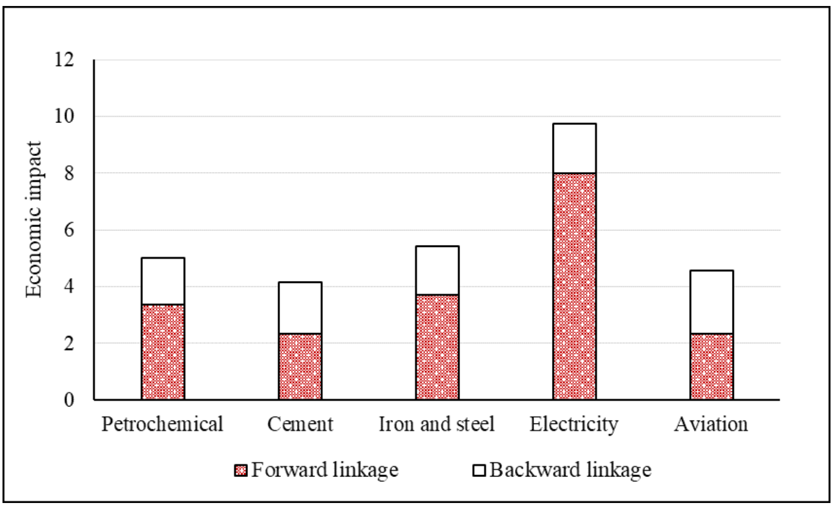


Figure 3. The economic impact of targeted industries under Thailand ETS in 2010.

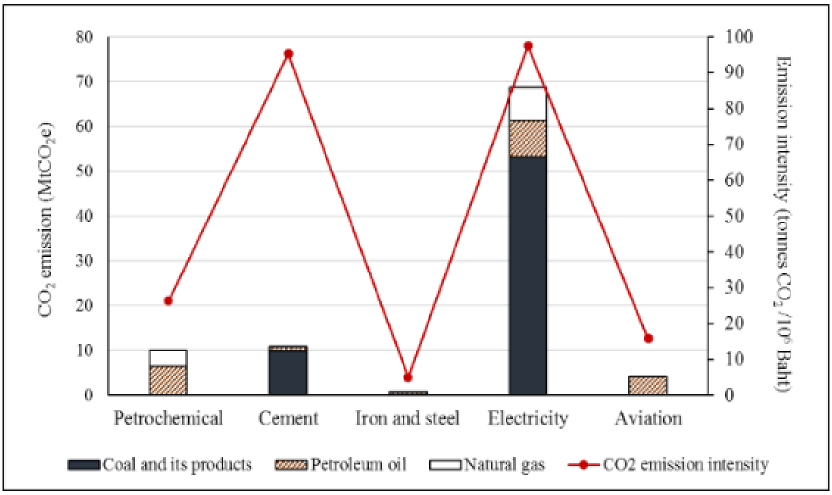


Figure 4. CO_2 emissions and emission intensity of target industries under Thailand ETS in 2010.

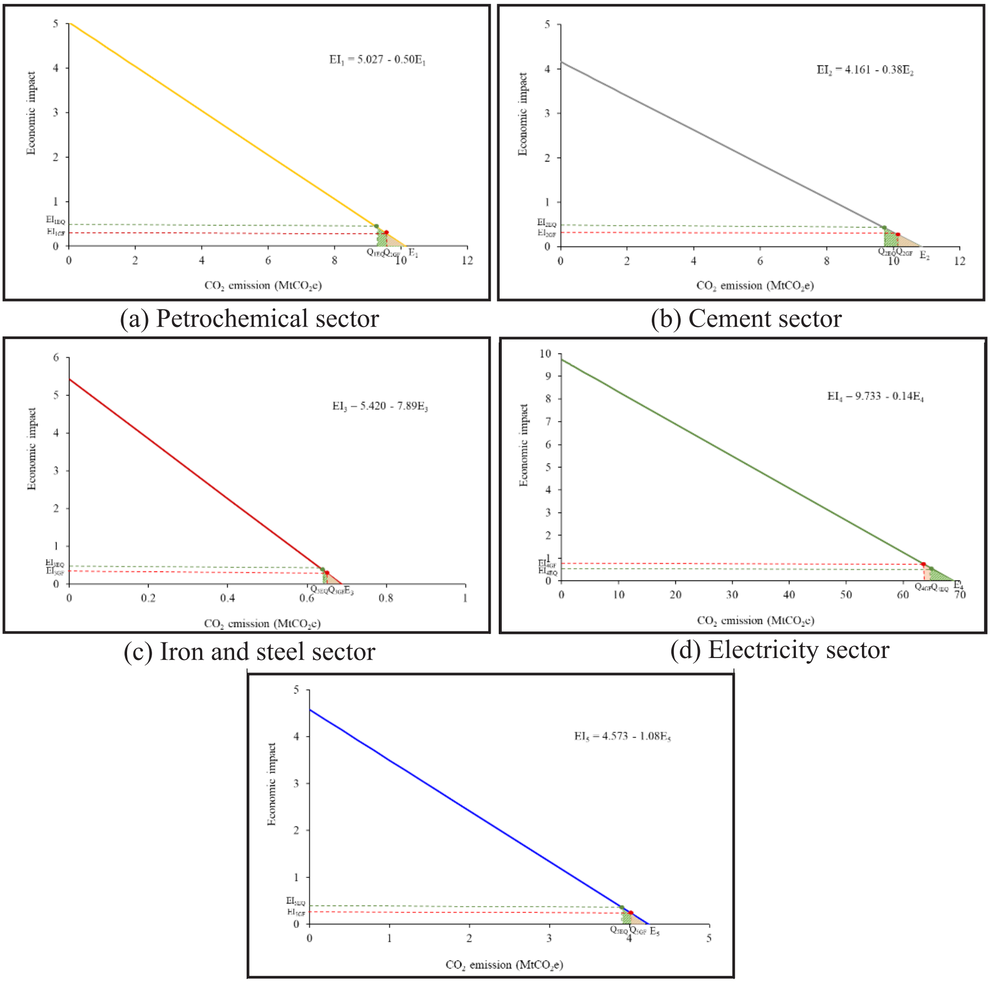
Table 3. The EIERs equation for five target industries.

Sector	EIERs equation
Petrochemical	$EI_1 = 5.027 - 0.50E_1$
Cement	$EI_2 = 4.161 - 0.38E_2$
Iron and steel	$EI_3 = 5.420 - 7.89E_3$
Electricity	$EI_4 = 9.733 - 0.14E_4$
Aviation	$EI_5 = 4.573 - 1.08E_5$

3.4 Unequal percentages for allocation of carbon quotas

The quantity of CO_2 emissions quotas for respective industries using the equi-marginal method, as described earlier, is presented in Table 4. In contrast with the grandfathering method, the computed quantity using the equi-marginal method differs in terms of percentage of allocation. Accordingly, the cap of 2-5% CO_2 emissions reduction under the Thailand ETS will be allocated to respective industries in whatever percentages to equate the EI. Table 4 shows the differences in economic impact under two allocation methods. With the GF method, the result shows that the EI in different industries varies considerably and the allocation is uneconomical. In contrast, with the equi-marginal method, all industries come out with an equal EI.

Clearly, the equi-marginal method allocates a higher quota for the electricity sector and fewer for the other 4 sectors. Likewise, with the equi-marginal method, CO_2 emission quotas for the electricity generation sector are much higher than in the grandfathering method. As mentioned earlier, we simplify the calculation of total CO_2 emissions quotas in the Thailand ETS while the sum of quotas for electricity is higher than the proportion based on historical CO_2 emissions percentages from a reference base year, whereas the emissions quotas for other industries, including petrochemicals, cement, iron and steel, and aviation, are allocated in lower quantities than their proportion of emissions. This result corroborates the conclusion of Li and Tang (2016) and Yang and Lin (2016), which suggest that the power industry is an important sector for allocating carbon emissions quotas.



(a) Petrochemical sector

(b) Cement sector

(c) Iron and steel sector

(d) Electricity sector

(e) Aviation sector

Figure 5. Carbon quota allocation and EIER of industries with 5% CO_2 reduction target.

3.5 Optimal allocation of carbon emissions quotas for industries in Thailand ETS

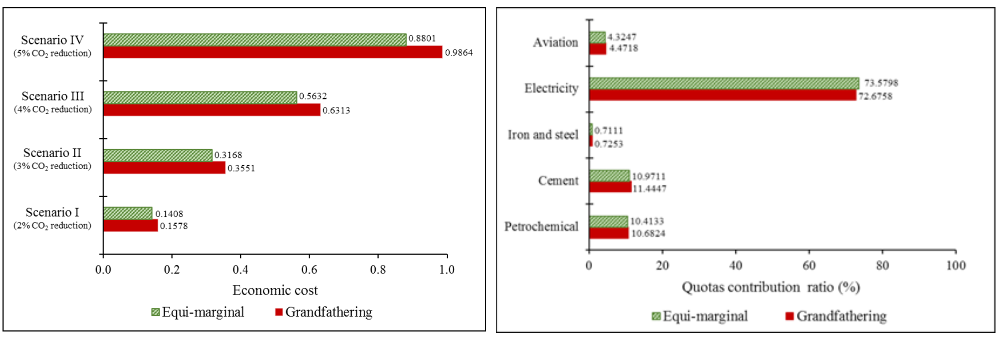
The total economic cost of the 2-5 % CO_2 reduction target in the given scenarios is shown in Figure 6 (a). Clearly the results indicate that the total economic cost calculated with the equi-marginal method is lower than the grandfathering allocation method by 0.017, 0.0383, 0.0681 and 0.1063, respectively. These results show that the total economic costs will increase when more stringent CO_2 reduction targets are applied.

It is clearly evident from Figure 6 (a) that the emissions quota allocation under the grandfathering method is inefficient because the total economic cost of all industries is not necessarily at minimum cost, which is in agreement with the findings of Mu *et al.* (2016).

Therefore, the optimal allocation of carbon emissions quotas can be managed using the equi-marginal principle to equate the EI_j of target industries to ensure minimum economic costs and achieve an economically efficient allocation of emissions quotas. The results of the optimal allocation for target industries are presented in Figure 6 (b). The proportions of the computed optimal initial carbon emission quotas for the petrochemicals, cement, iron and steel, electricity, and aviation industries are 10.4133%, 10.9711%, 0.7111%, 73.5798% and 4.3247%, respectively. Moreover, the differences between the emission quotas on the electricity industry under fixed allocation are approximately 0.904 % less than under the optimal carbon emissions quota allocation. Overall, approximately 10.78% can be saved by implementing the optimal quota allocation.

Table 4. Different Carbon quota allocations and economic costs to industries using the GF and equi-marginal allocation methods for 2-5 % CO2 target reduction.

Scenario	Characteristics	Allocation method	Industries					Total
			Petro-chemical	Cement	Iron and steel	Electricity	Aviation	
I 2% CO_2 reduction target	Emission quotas ($MtCO_2e$)	Grandfathering	9.9162	10.6238	0.673	67.4628	4.1511	92.8271
		Equi-marginal	9.8193	10.4533	0.668	67.7882	4.0981	92.8271
	Economic impact	Grandfathering	0.1005	0.0832	0.108	0.1947	0.0915	-
		Equi-marginal	0.1487	0.1487	0.148	0.1487	0.1487	-
	Total economic cost	Grandfathering	0.0102	0.0090	0.000	0.1340	0.0039	0.1578
		Equi-marginal	0.0222	0.0288	0.001	0.0781	0.0102	0.1408
II 3% CO_2 reduction target	Emission quotas ($MtCO_2e$)	Grandfathering	9.8150	10.5154	0.666	66.7744	4.1087	91.8799
		Equi-marginal	9.6697	10.2597	0.658	67.2625	4.0293	91.8799
	Economic impact	Grandfathering	0.1508	0.1248	0.162	0.2920	0.1372	-
		Equi-marginal	0.2230	0.2230	0.223	0.2230	0.2230	-
	Total economic cost	Grandfathering	0.0229	0.0203	0.001	0.3015	0.0087	0.3551
		Equi-marginal	0.0500	0.0648	0.003	0.1758	0.0230	0.3168
III 4% CO_2 reduction target	Emission quotas ($MtCO_2e$)	Grandfathering	9.7138	10.4070	0.659	66.0860	4.0664	90.9327
		Equi-marginal	9.5201	10.0660	0.649	66.7368	3.9604	90.9327
	Economic impact	Grandfathering	0.2011	0.1664	0.216	0.3893	0.1829	-
		Equi-marginal	0.2973	0.2973	0.297	0.2973	0.2973	-
	Total economic cost	Grandfathering	0.0407	0.0361	0.003	0.5360	0.0155	0.6313
		Equi-marginal	0.0890	0.1151	0.005	0.3126	0.0409	0.5632
IV 5% CO_2 reduction target	Emission quotas ($MtCO_2e$)	Grandfathering	9.6126	10.2986	0.652	65.3976	4.0240	89.9854
		Equi-marginal	9.3705	9.8724	0.639	66.2111	3.8916	89.9854
	Economic impact	Grandfathering	0.2513	0.2081	0.271	0.4867	0.2287	-
		Equi-marginal	0.3716	0.3716	0.371	0.3716	0.3716	-
	Total economic cost	Grandfathering	0.0636	0.0564	0.004	0.8376	0.0242	0.9864
		Equi-marginal	0.1390	0.1799	0.008	0.4884	0.0640	0.8801



(a) Total economic cost

(b) Carbon quota contribution ratio

Figure 6. Comparison of the total economic cost and carbon quota contribution ratio under grandfathering and equi-marginal methods.

4. Conclusion

The allocation of emissions quotas calculated with the equi-marginal method is based on principles of fairness and efficiency to achieve optimal CO_2 emissions quotas among industries in the Thailand ETS. Several main conclusions can thus be drawn as follows.

Firstly, the differences in EIERs for different industries are explained by the difference in magnitude of economic impact per additional unit of CO_2 reduction. The electricity sector was shown to experience the highest economic impact for allocation of emissions quotas, demonstrating this industry will directly influence prices of commodities and services in other industries.

Secondly, the equi-marginal quota calculation method equalizes economic impact among industries, thereby automatically achieving economic efficiency in contrast with the GF allocation method in which the EI on different industries varies considerably.

Finally, the optimal allocation of carbon emissions quotas in the Thailand ETS achieved with the equi-marginal method indicates that the electricity generating sector should have larger quotas while consequently, smaller quotas are allotted to the petrochemicals, cement, iron and steel, and aviation industries. The total economic cost of all industries in the Thailand ETS of approximately 10.78% can be saved by implementing this optimal emissions quota allocation.

Most studies on carbon emissions permit allocations are commonly based on the GF allocation method during the initial start-up phases of ETS. However, this study focuses on the different EIERs between industries. Thus, the main finding of this study shows that applying the equi-marginal method to calculate CO2 emissions quota allocations among industries according to their EIERs can minimize the economic costs of emissions allocations.

5. Limitations

This study focuses on the accounting of external costs for the allocation of carbon emissions quotas to achieve a more equitable emissions quota allowance among different industries in the Thailand ETS. Nonetheless, the study does have some limitations. One is that there are no official statistics on the internal costs of CO_2 emissions reductions for participating industries. Thus, for the Thailand ETS operation, the target industries need to aware of the internal costs for reduction of CO_2 emissions and the GHG abatement cost curve, which also has a significant impact on the ETS market.

Our findings imply that the Thailand ETS policies designed to allocate CO_2 emissions quotas should take into account not only historical GHG emissions but also the external costs of emissions reductions. It is recommended that the Thailand ETS authority should employ the equi-marginal method to arrange optimal emissions quota allocation to achieve economic efficiency by factoring in internal and external costs.

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