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Original research article

Price Determination of Electricity Supply in Thailand Based on Externalities, Wheeling Charges, and Losses

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ABSTRACT

In Thailand, the electricity rates imposed on end users do not adequately reflect generation technology, externalities suffered by localities, and the transmission of electricity across distances. Thus, this study proposes a new method to determine the price of electricity supply which differentiates among end users in Thailand by area or zone, thus offering choices in matching import with demand and establishing fairness for those affected by the undesirable effects of power generation. The cost of electricity incurred in each zone is calculated based on whether a given zone has the potential to be an exporter or importer of electric energy, which is evaluated on an annual average basis and is a combination of technology-specific, levelized cost of electricity (LCOE)-based generation cost and external cost. In addition, electricity importers must incur wheeling charges and losses when importing to match their deficits. Calculation results show significant reductions in electricity rate imposed on the exporter zones as a compensation of externalities suffered and delivering their excess to help those in deficit through the proposed price and export–import scheme. Policy recommendations from the study are intended to alleviate conflicts of interest of all stakeholders within the country's power sector, to encourage public participation and local authorities' involvement in the planning of power generation facilities, which will also comply with the latest Constitutions and provide suggestions for the Power Development Plan.

Keywords: Price determination; Electricity supply; Externalities; Wheeling charges; Losses

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1. Introduction

1.1 Rationale

The diversification of fuel sources for power generation in Thailand has long been the emphasis of efforts to strengthen national energy security, promote environmental protection and contribute to long- term economic competitiveness. However, as shown in Fig. 1, the country's power generation has largely relied on fossil fuels, particularly natural gas, since the 1970s, when domestic resources were discovered in the Gulf of Thailand as a substitute for high-price fuel oil [1,2]. This significant dependence on fossil fuels due to the least-cost approach towards electricity supply planning in Thailand has limited the contribution of renewable and alternative energy. The persistence of this trend will not only render the country unable to achieve its targets according to the proposed national energy and socio- economic development plan [3], but will also lead to the exploitation of limited fuel feedstock and intensify negative impacts on the environment and society.

Societies typically incur several costs of power generation through the significant damage power generation causes to human health and the environment. However, such damage costs tend to be neglected by power plant owners and remain unaccounted for in the electricity price paid by end users, which explains why it is referenced as an external cost [4]. Several studies have attempted to estimate external costs associated with power generation using ExternE's impact pathway approach (IPA). The methodology follows the pathway of pollutants from the root cause to the impacts on various receptors and addresses such impacts in monetary terms (Fig. 2) [5] and is also the most widely used when it comes to externality assessment [6]. Internalizing external costs is expected to increase the cost of dirty generation technologies and

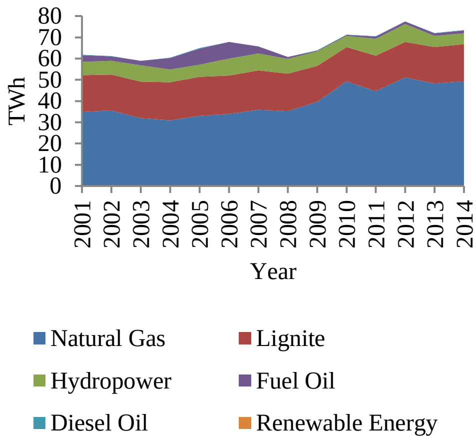


Fig. 1. History of Electricity Generating Authority of Thailand's (EGAT) gross electricity generation by fuel type. [2]

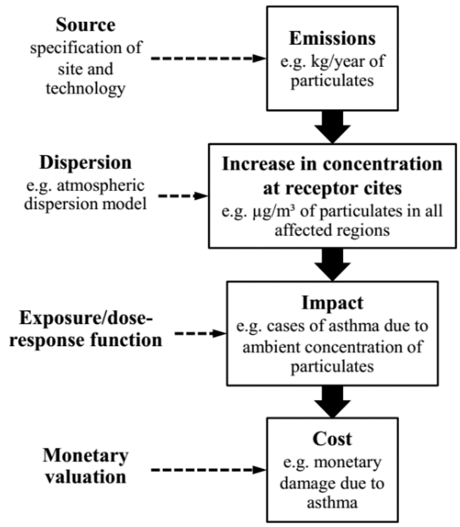


Fig. 2. Four principal steps of IPA using air pollutants as an example. [5]

discourage further investments in and capacity additions to such technologies, which will help mitigate environmental impacts and improve the quality of living [7]. Although, currently, power generation is more environmentally friendly, the changes are insufficient to regain its public acceptance, particularly in terms of compensating for the negative impacts suffered by affected localities.

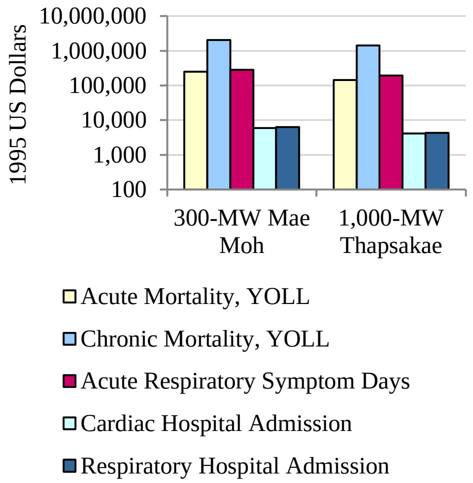


Fig. 3. Estimated external costs associated with two coal-fired power plants in Thailand by type of health damages. [8]

In Thailand, a study on the estimation of external costs associated with power generation was conducted on two coal-fired power plants: the existing 300-MW lignite-fired Mae Moh Plant and the proposed 1,000-MW Thap Sakae Plant, which is going to be fuelled using imported coal. Using the simplified version of IPA, the study revealed a significant reduction in damage costs in the 1,000- MW Thapsakae Plant despite the increased capacity (Fig. 3). This can be attributed to the use of imported coal, which has a much lower sulfur content and the installation of coal technologies [8,9]. However, resistance from localities persists [10]. This suggests the need for better compensation for the stakeholders of electricity supply chains.

The electricity rates imposed on end users in Thailand do not properly reflect how each unit of electricity is generated and the damages of power generation suffered by localities. At present, Thailand adopts two-part and time-of-day (ToD) tariff structures, which result in marginal variations in end-user prices per voltage level, peak and off-peak periods and the size of end users (Table 1) [11]. Pricing electricity at an average throughout the country fails to reflect fuel sources, the technologies used and damages caused by power generation. Even regarding the country's attempt to set up the Power Development Fund (PDF), which collects fees from power plant licensees by fuel type for the rehabilitation of those affected by power plant operations [12], the question remains as to whether it is an effective compensation measure.

Thailand's electricity supply industry (ESI) is presently under the state-owned, enhanced single buyer scheme, which receives gradually increasing contributions from independent, small, and very small power producers (IPP, SPP, and VSPP) [13]. This suggests that the country's electricity regulators should allow the transfer of electricity among utilities, which is technically termed as wheeling, to help enhance efficiency. To reflect the investment of transmission facility owners, for example, the Provincial and Metropolitan Electricity Authorities (PEA and MEA) in Thailand, wheeling charges are accessed and collected from utilities that perform transactions for electric energy for facilities [14].

Table 1. Bulk supply tariff structure of Thailand, excluding value-added tax (VAT) and automatic adjustment mechanism (F_t). [11]

Unit: Baht/kWh

Voltage Level (kV)	Generation		Transmission Service		Total	
	Peak	Off-peak	Peak	Off-peak	Peak	Off-peak
230	1.8758	1.1514	0.2810	-	2.1568	1.1514
Origin, 230 : 115/69	1.8803	1.1539	0.5042	-	2.3845	1.1539
Terminal, 115/69	1.9405	1.1753	0.8717	-	2.8122	1.1753
11-33	1.9450	1.1765	1.0439	-	2.9889	1.1765

Incorporating wheeling charges in end-user prices is expected to help decide between importing electricity from distant locations, constructing independent power generation facilities and contributing to deregulation and increased competition in the electricity market [15].

1.2 Objectives

This study aims to present a new approach towards the pricing of electricity supply such that rates among end users will differ by regions in Thailand. The new electricity rates will be a combination of technology-specific generation cost based on the levelized cost of electricity (LCOE), external cost associated with damages suffered by the localities and wheeling charges that reflect the transfer of electricity across a distance. To help compensate those who suffer from the adverse effects of emissions from power generation and encourage environmental awareness of future power plant construction, the findings of this study can serve as a decision-making tool for local authorities regarding the matching between electricity supply and consumers' interests. This study can also help resolve current disputes and conflicts among stakeholders of power plant projects and local communities in Thailand [10, 16] and comply with the Constitution of the Kingdom of Thailand, which encourages public participation in the planning of power plant projects and local ownership of power generation facilities [17-18].

1.3 Scopes

This study serves as a preliminary step towards an alternative approach to electricity supply pricing in Thailand. The study focuses on the existing grid-connected power generation facilities that supplied electric energy for consumption within the Kingdom of Thailand in the calendar year 2014, the period for which the necessary generation and monetary data are available and does not include future projections. This study adopts a simplification approach towards the pricing of electricity supply by considering the annual average cost of electricity, excluding the effects of unique price dynamics and pricing approaches under a much shorter time scale [19-20]. Instead of performing the assessment of the true cost of electricity, this study relies on the cost estimates arithmetically averaged in several studies, which is expected to adequately reflect different technologies in terms of generation cost and externalities suffered [7].

2. Materials and Methods

2.1 Supply and Demand of Electricity

This study considers annually generated and consumed electric energy within Thailand in 2014. Table 2 shows the broadly categorized supply and demand of electric energy in Thailand [21]. However, the table does not provide complete list or the type and location of grid- connected and commercially operating power plants. These data can be traced from the 2011 electric power report published by Department of Alternative Energy Development and Efficiency (DEDE) [22] and the SPP/VSPP database accessible on the web page of the Energy Regulatory Commission (ERC) [23], and we focus on the commercial operation date (CoD) up to 2014 and newly added capacity and plant shutdown during the three-year increment. The reason for relying on the 2011 report is that the latter versions do not provide the actual generation of electric energy (in GWh) for each of the grid-connected power plants in Thailand anymore. Relying on the generation data from as far as 2011 will no longer be relevant, so the best attempt is to reconcile the generation data by taking into account the national generation data (Table 2) and the SPP/VSPP database which provides a more up-to-date list of grid-connected power plants and the installed capacity (in MW) of each. For the demand side, particularly in terms of consumption by each province individually, data can be obtained from the National Statistical Office (NSO) of Thailand [24].

Table 2. Production and sale of electric energy in Thailand by broad categories as of 2014. [21]

Unit: GWh

Supply	**177,261**
Generation by EGAT	73,326
Generation by IPP	65,718
Generation by SPP	25,958
Imports from neighboring countries	12,260
Demand	**173,649 ***
PEA service areas	120,248
MEA service areas	50,044
EGAT's direct customers	1,592
Exports to neighboring countries	1,592
Others	173

* The difference between national annual supply and demand of electric energy is 2.04%.

2.2 Zoning

The supply and demand of electricity for the entire country are then allocated to each of the 13 zones comprising both PEA and MEA's service areas (Fig. 4) [25]. The allocations comply with the country's current transmission and distribution scheme and adequately realize the generation potential and consumption levels throughout the country.

2.3 Energy Balance

An energy balance accounting equation is established to describe the transfers of electric energy through the country during the given calendar year. The equation refers to the fact that the quantities of energy produced must equal those consumed and accounts for imports and exports [26]. Considering only electric energy, a simplified energy balance accounting equation can be written as follows:

$$\sum_{i=1}^{n} S_i - \sum_{i=1}^{n} D_i = 0 , \qquad (2.1)$$

where S_i = quantity of electric energy generated and imported or supply

D_i = quantity of electric energy consumed and exported or demand

n = total number of zones or service areas in the country

For each zone, the demand is subtracted from the supply to examine whether there is excess electric energy that is left unconsumed from the zone:

$$\Delta_i = S_i - D_i . \qquad (2.2)$$

where Δ_i = quantity of excess electric energy unconsumed or excess supply

This study suggests that a zone that produces more electric energy than it consumes, that is, $\Delta_i > 0$, exports excess supply to zones with insufficient supply, that is, $\Delta_i < 0$, which must import additional electric energy to match their deficit. A zone with $\Delta_i = 0$ is excluded from this export–import scheme. This can be expressed as Eq. (2.3) :

$$\Delta_i \begin{cases} > 0 \text{ ; export} \\ = 0 \text{ ; no export or import} . \\ < 0 \text{ ; import} \end{cases} \qquad (2.3)$$

Assuming the total quantity of electric energy produced by the country is consumed within the given year and since the difference between national annual electric energy supply and demand according to Table 2 is only 2.04%, D_i for each zone can be reconciled such that the summation of all Δ_i according to Eq. (2.2) becomes zero.

$$\sum_{i=1}^{n} \Delta_i = 0 . \qquad (2.4)$$

2.4 Energy Transfer

The transfer of electric energy across zones should be arranged such that the quantity of electric energy and distance wheeled are minimal and the wheeling charges incurred by the importer zones are also minimal:

$$\text{Min}\left[\Delta_{ij} \cdot d_{ij}\right], \qquad (2.5)$$

where Δ_{ij} = quantity of electric energy transferred between zones *i* and *j*

d_{ij} = distance or length of the existing transmission lines that connect zones *i* and *j*

The length of the existing transmission lines in Thailand can be obtained from the map of transmission systems and current status of transmission systems, which are both provided in the Thailand Power Development Plan 2015 to 2036 [27] . However, this study only considers the major lines that connect between zones and have a voltage level of 230 kV or above and excludes the lines that distribute electricity within each zone (Fig. 4).

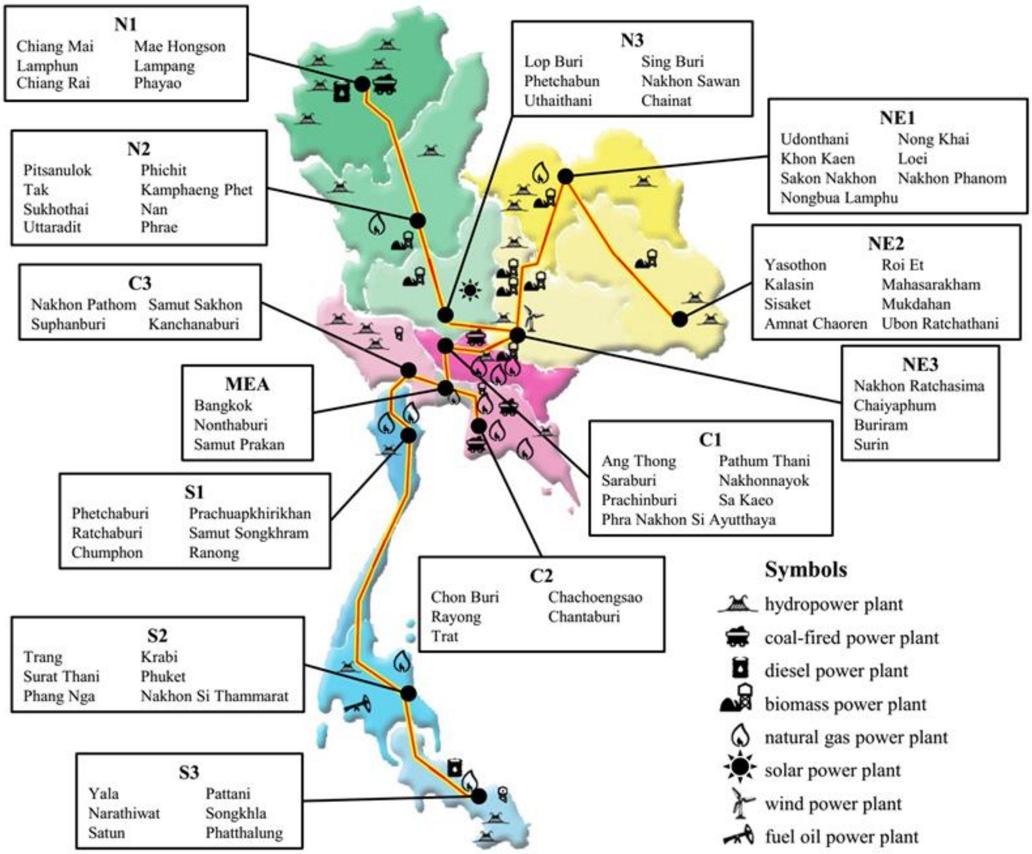


Fig. 4. Map of Thailand showing 13 PEA and MEA zones (indicated by different colors), major transmission lines (red-yellow lines) and a rough indication of power plants by fuel type.

2.5 Generation and External Costs of Electricity

This study is simplified by using cost estimates averaged from several studies to represent and compare each power plant technology [7]. In most cases, these electricity cost estimates only exist in non-Thai currencies and should be converted using the simplified methodology of a benefit transfer method, which involves scaling down the economic value from one economy to another using a proper conversion factor [28].

The generation cost estimates used in this study are based on LCOE, which reflects lifetime investment in power generation assets over lifetime electricity output. The official exchange rate is used as a conversion factor as shown in Equation 6. From the definition, LCOE is typically associated with, for example, construction and procurement, which require the owner to convert their money into local currency using the prescribed exchange rate. [29]

$$Gen._A = Gen._B \times \frac{Exch._A}{Exch._B}, \qquad (2.6)$$

where $Gen._A$ = generation cost estimate in local currency of country A
$Gen._B$ = generation cost estimate in local currency of country B
$Exch._A$ = official exchange rate of country A
$Exch._B$ = official exchange rate of country B

For external cost estimates, this study prefers those estimates associated with local environmental and human health impacts by power generation, which generally concern non-carbon air pollutants such as sulfur dioxide, oxides of nitrogen and particulate matter and are more significant in the case of national-level studies. Since external cost is largely associated with human health and environmental damage costs and willingness to pay (WTP) to avoid or reduce the risk of damages or illness, we use purchasing power parity (PPP) adjusted to gross domestic product (GDP) instead. As PPP reflects differences in the national prices of both traded and non-traded (e.g. services) goods, it is a more accurate indicator in terms of a standard-of-living comparison at an international level and allows for less deviation and misleading interpretations than the exchange rate. The conversion of external cost from foreign to Thai currency is shown in Eq. (2.7)and assumes that the elasticity of WTP is unity [8, 30-31]:

$$Ext._A = Ext._B \times \frac{PPP_A}{PPP_B}, \qquad (2.7)$$

where $Ext._A$ = external cost estimate in local currency of country A
$Ext._B$ = external cost estimate in local currency of country B
$PPP._A$ = purchasing power parity of country A
$PPP._B$ = purchasing power parity of country B

2.6 Wheeling Charges

The California Independent System Operator (ISO) provided a settlement guide and various scenarios on the determination of wheeling charges. To summarize, a wheeling charge is assessed for each scheduling coordinator as a product of price and quantity and is time dependent [14]. However, for Thailand whose transmission and distribution facilities are state owned but nationwide, wheeling charges should depend on quantity and the distance to which electricity is wheeled. Wheeling charges in this study are calculated on an annual average basis and, thus, transmission constraints and loop flows, which are characteristic to congestion management in real-time electricity market designs [19], will not be considered at this level.

Wheeling charges are the fees imposed by the participating transmission owners (PTOs) or, in case of the United States, the Federal Energy Regulatory Commission (FERC). As the regulator of transmissions and wholesale electricity in the country [32], the FERC's role is similar to that of Thailand's PEA. This study adopts California's ISO concept that wheeling charges are the fees collected to recover PEA's revenue requirements based on PEA's annual expenses. The financial statements of PEA, particularly the transmission and distribution facility expenses, can be obtained from its annual report for the corresponding year [25].

2.7 Monetary Flow

In addition to the balance and transfer of electric energy, the monetary flows of the collected electricity prices proposed in this study are estimated.

In monetary terms, each zone in which electricity flows in and out must bear total costs, which then determine the final cost incurred by end users. The method of calculating total cost incurred by each zone will differ according to whether the zone is an exporter or importer of electricity; this can be generalized as in Eq. (2.8):

$$TC = Gen. \pm Ext. \pm WChg., \qquad (2.8)$$

where TC = total cost incurred to a zone
Gen. = generation cost
Ext. = external cost
WChg. = wheeling charges

The price of electricity in each zone is determined by the total cost incurred by that zone divided by the amount of electric energy consumed by the zone:

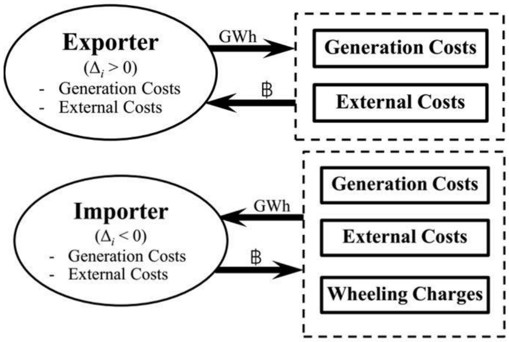
$$P = \frac{TC}{Q}, \qquad (2.9)$$

where P = price of electricity for the end user in a zone
Q = amount of electricity consumed by end users in that zone

The total cost incurred by a zone is determined based on whether the zone is an exporter or importer of electricity (Fig. 5). An exporter zone, that is, a zone with excess electric energy, must only pay for the generation cost of a portion of electric energy that it consumes while an importer zone must pay for the total generation. Since the exporter zone already suffers externalities from operating its local power plants, it does not need to pay for external costs. The electric energy left unconsumed by the importer zone is then exported to the importer zone, who shoulders both generation and external costs associated with the unconsumed electric energy. This results in the monetary compensation of exporter zones who already suffer externalities in the form of deductions in end- user prices. Moreover, the importer zone must pay for the importing of electric energy across the distance through wheeling charges.

The price of electricity paid by end users as a combination of generation costs, external costs and wheeling charges should then return to the stakeholders of Thailand's ESI as monetary compensations. First, electricity generators including state enterprise such as EGAT and private generators which are IPP, SPP, and VSPP should regain generation costs. Second, the owners of transmission and distribution facilities should regain wheeling charges to match their revenue requirement as well as make up for losses. Finally, end users or localities affected by power generation should be financially compensated for their loss of welfare through external costs.

Fig. 5. Total cost of electricity incurred by exporter (top) and importer (bottom) zone.



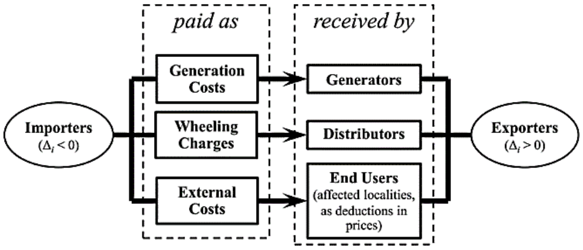


Fig. 6. Monetary flow diagram comprising costs to receiving end users (paid as) and returns to stakeholders (received by).

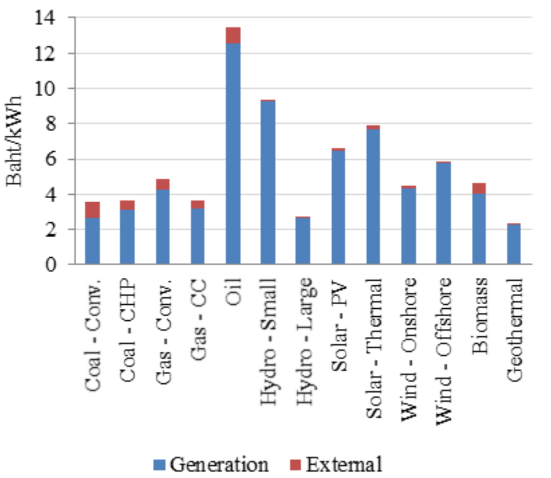


Fig. 7. Average unit cost of electricity based on major generation technologies, with LCOE-based generation and external costs.

3. Results

3.1 Generation and External Cost Estimates

Fig. 7 shows per-output unit costs of electricity gathered from several studies, which are averaged to represent each generation technology available in Thailand. Each of these unit costs comprises the LCOE-based generation cost [33-37] and external cost [38-40], both of which are technology-specific and are obtained from studies conducted by experts from other countries. These studies generally come up with the estimates for a variety of global regions, but the estimates allocated to developing countries are preferred for a more appropriate representation of Thailand [7]. Considering solar photovoltaics (PV), which is a popular renewable option in Thailand, even with annually averaged costs being relatively high, the trend for falling module prices can be anticipated (Fig. 8). With the LCOE being much lower than 6 Baht/kWh in 2015 and the projected falling trend in the next 10-35 years, solar PV systems are expected to be more embraced by the society due to its improved economic attractiveness in addition to being environmentally friendly [41]. Despite being carbon-neutral, the external cost estimate for biomass in this study is still high. This is because, throughout the lifecycle of energy production from biomass, surrounding communities still bear certain damages associated with land-use change, transportation of raw materials [42] and certain non-carbon aerosols which can still be harmful to human health and the environment [43].

3.2 Cost of Independent Generation

The results of allocating supply and demand of electric energy to each zone in Thailand and then subtracting each zone's demand from its supply reveals six zones, namely, N1, NE1, C1, C2, S1, and S3, denoted by the positive values of excess electric energy, as exporters of electricity, as shown in Table 3. With the power plants and

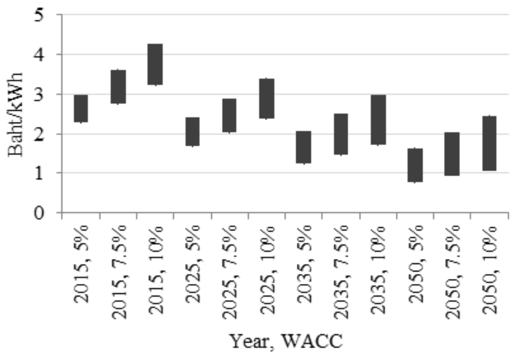


Fig. 8. Decreasing trend of LCOE of solar PV systems in Thailand, calculated at different weighted average cost of capital (WACC). [41]

generation technologies used in each zone listed, the cost of independent generation as a combination of generation and external costs can be calculated using a simple spreadsheet.

Overall, incorporating external costs associated with the local environmental impacts of power generation into the total cost of independent generation is far more meaningful compared to the current contribution rates to PDF. That is, a national total of 93,105 versus 2,279 million Baht for each power generation unit in the country. This suggests that the country's current PDF compensation scheme needs reconsideration and/or restructuring to better compensate for the damage costs of power generation absorbed by the society. In addition, note that using LCOE estimates, by definition [29], is sufficient to reflect several key elements of the automatic adjustment mechanism (F_t); that is, the power utilities' adjustment of electricity tariffs to compensate for the changes in fuel prices, revenue, investment capital due to inflation rates and exchange rates, among others [11].

The other zones in deficit, N2, N3, NE2, NE3, C3, S2, and MEA, will be required to import to cover their deficit at the amounts and through the paths shown in Fig. 9. The proposed transfer of electric energy is in line with EGAT's latest status of production and sales of electricity [44] and this study has already included imports from and exports to the neighboring countries as supply and demand.

Table 3. Electric energy and calculated cost of independent generation based on power generation technologies used in each zone.

Zone	Electric Energy (GWh)			Cost of Independent Generation (Million Baht)		
	Supply	**Demand**	**Excess**	**Gen. ****	**Ext. ****	**PDF ****
N1	16,867	6,686	10,181	44,727	16,045	337
N2	2,200	5,377	−3,177	6,410	278	40
N3	113	5,837	−5,724	732	13	1
NE1	16,865	6,865	10,000	46,980	2,831	291
NE2	361	4,968	−4,608	1,040	51	7
NE3	386	7,895	−7,509	3,274	10	8
C1	30,723	24,121	6,602	97,927	16,331	339
C2	49,268	27,692	21,576	155,487	26,514	618
C3	1,749	14,981	−13,231	4,592	58	35
S1	22,438	7,101	15,337	70,698	11,653	225
S2	7,853	9,283	−1,430	44,645	4,643	94
S3	11,415	5,444	5,971	36,302	5,794	114
MEA	17,021	51,011	−33,990	53,950	8,884	170
Total	177,261	177,261	0	566,763	93,105	2,279

** Gen. = generation, Ext. = external, PDF = contribution to the Power Development Fund, given for comparison

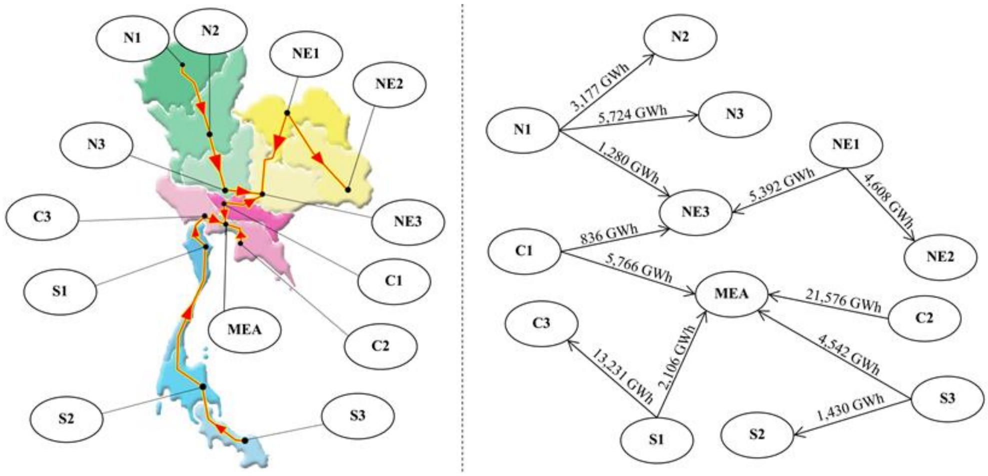


Fig. 9. Transfer of excess electric energy across zones: paths (left) and quantities (right).

Table 4. Calculation of unit cost of wheeling charges.

Total PEA's annual expenses, cost of sales and services excluded [25]		27,959	Million Baht
Total electric energy wheeled (Fig. 9)		69,668	GWh
Total length of transmission lines involved in export–import scheme [27]		3,117	km
Unit cost of wheeling charges	$(27{,}959 \times 10^6) \div (69{,}668 \times 3{,}117) =$	128.75	Baht/GWh · km

Table 5. Calculation of cost for receiving end users in an exporter zone using N1 as an example.

Supply (Table 3)		16,867	GWh
Demand (Table 3)		6,686	GWh
Excess, that is, exportable electric energy	16,867 – 6,686 =	10,181	GWh
Cost of independent generation, generation (Table 3)		44,727	Million Baht
Self-consumption, generation	(6,686 ÷ 16,867) × 44,727 =	17,729	Million Baht
Cost of independent generation, external (Table 3)		16,045	Million Baht
Self-consumption, external	(6,686 ÷ 16,867) × 16,045 =	6,360	Million Baht
Revenue gained from export, generation	(10,181 ÷ 16,867) × 44,727 =	26,997	Million Baht
Revenue gained from export, external	(10,181 ÷ 16,867) × 16,045 =	9,685	Million Baht
Cost to receiving end users	17,729 – 9,685 =	8,044	Million Baht
Price	8,044 ÷ 6,686 =	1.20	Baht/kWh

Table 6. Calculation of costs for receiving end users in an importer zone using N2 as an example.

Supply (Table 3)		2,200	GWh
Demand (Table 3)		5,377	GWh
Deficit, that is, amount of electric energy that needs to be imported	5,377 – 2,200 =	3,177	GWh
Cost of independent generation, generation (Table 3)		6,410	Million Baht
Self-consumption, generation		6,410	Million Baht
Cost of independent generation, external (Table 3)		278	Million Baht
Self-consumption, external		278	Million Baht
Unit cost of wheeling charges (Table 4)		128.75	Baht/GWh · km
Import from N1 (Fig. 9)		3,177	GWh
Cost of importing from N1, generation	(3,177 ÷ 16,867) × 44,727 =	8,425	Million Baht
Cost of importing from N1, external	(3,177 ÷ 16,867) × 16,045 =	3,022	Million Baht

Table 6. Calculation of costs for receiving end users in an importer zone using N2 as an example. (Continued)

Distance between N1 and N2 [27]		143	km
Wheeling charge incurred to N2	$(128.75 \times 3{,}177 \times 143) \div 10^6 =$	58.50	Million Baht
Cost to receiving end users	6,410 + 8,425 + 3,022 + 58.50 =	17,916	Million Baht
Price	17,916 ÷ 5,377 =	3.33	Baht/kWh

Table 7. Summarized calculation of electricity price for end users by zone.

Zone	Self-consumption (Million Baht)		Exports (Million Baht)		Imports (Million Baht)			Price (Baht/kWh)
	Gen.	Ext.	Gen.	Ext.	Gen.	Ext.	WChg.	
N1	17,729	6,360	26,997	9,685	-	-	-	1.20
N2	6,410	278	-	-	8,425	3,022	58	3.33
N3	732	13	-	-	15,179	5,445	210	3.69
NE1	19,124	1,152	27,856	1,678	-	-	-	2.54
NE2	1,040	51	-	-	12,835	773	85	2.97
NE3	3,274	10	-	-	21,081	2,567	254	3.44
C1	76,884	12,822	21,043	3,509	-	-	-	3.04
C2	87,394	14,903	68,092	11,611	-	-	-	2.74
C3	4,592	58	-	-	41,689	6,872	77	3.55
S1	22,373	3,688	48,325	7,965	-	-	-	2.03
S2	44,645	4,643	-	-	4,547	726	56	5.38
S3	17,312	2,763	18,990	3,031	-	-	-	2.62
MEA	53,950	8,884	-	-	107,550	18,075	710	3.53

3.3 Wheeling Charges

T The calculation of the unit cost of wheeling charges to be applied across the country is shown in Table 4. However, this is only a simplification approach to making wheeling charges both energy- and distance-dependent, so that the costs of electric energy transfer under the proposed export–import scheme are reflected in end-user prices. In real practices, the assessment of wheeling charges is more dynamic and involves certain congestion management techniques such as nodal and zonal pricing [19]. Though not applicable to Thailand yet, different calculation models have recently caught the interest of the Thai authority and have potential for further discussions. [45]

3.4 Costs to Receiving End Users

The costs incurred by receiving end users in exporter and importer zones as per Equation 8 are calculated differently and are shown in Tables 5 and 6.

A similar pattern of calculation (Tables 5 and 6) is repeated for the other zones resulting in a different price for end users in each zone (Table 7) and the breakdown of the price as a combination of generation cost, external cost, wheeling charges, and losses, as shown in Fig. 10.

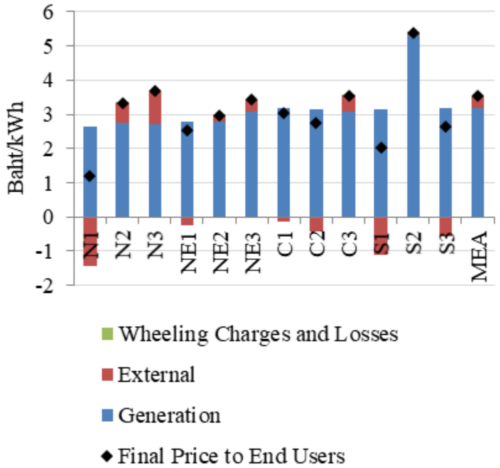


Fig. 10. Breakdown of price for end users by zone (negative cost indicates compensation of cost through the export–import scheme)

S2 is subject to the highest electricity rates because it is an importing zone but also because it is significantly reliant on excessively costly fuel oil, specifically, from EGAT's Krabi Power Plant; note that the proposed coal project is yet to begin operation [46]. This trend of high cost for independent generation is also observed in an exporting zone such as C2, whose exports remain insufficient to compensate for its excessive generation as it is the hub of Thailand's major industrial estates. In addition, with C2's choice of combined-heat-and-power (CHP) bituminous coal (specifically from IPP's BLCP Power Limited), combined with the most widely used natural gas combined cycle (NGCC) together with its only choice of exports (to MEA), the zone must still bear the relatively high cost of independent generation.

N1, on the other hand, imposes the least price on its end users because of its massive exports. Despite 99.53% of its domestic generation coming from conventional coal (specifically EGAT's Mae Moh Power Plant), the excessive external cost of its own generation is shouldered by importing zones. Pricing electricity at the lowest in N1 because of massive exports might give the impression that a zone should emphasize generation for export despite environmental and social awareness about power generation options. This new pricing of electricity supply must be implemented with care to ensure that the adverse effects of power generation are not neglected. Despite excess supply being observable in C1 also, its exports remain insufficient to compensate for the excessive cost of its independent generation, which explains the high unit price.

4. Conclusion

This study proposes various electricity prices across Thailand to better reflect fuel or technology options for power generation, externalities and the transfer of electric energy across distances. Different from the country's current tariff structure, the calculated electricity costs presented in this study vary by technology based on their LCOE. In addition to LCOE, external costs are aggregated so that the adverse effects of power generation borne by society are properly reflected. Cost estimates gathered from several studies are used which, at this stage, is enough to provide an overall picture of how a combination of technologies affects total cost and end-user price. The findings are useful for further policy considerations. The key findings of this study are as follows.

a) With generation and consumption levels varying by zone (based on the country's service areas), this study proposes an inter-zone transfer scheme that allows certain zones to deliver their excesses in electric energy supply to zones with deficits. Using the simplified approach, the supply, demand and transfer of electricity is estimated based on the annual average and energy bases rather than capacity, which could fail to cope with demand (e.g. as an effect of seasonality). The result reveals differences in end-user prices depending on whether a zone is a potential provider or receiver of electricity; that is, providers reduce their price as compensation for externalities. Such approach towards the pricing of electricity supply can be utilized for decision making, for example, matching consumers' interests and choosing between the construction of a new power generation facility and the importing of electricity from another zone(s). However, the proposed transfer scheme does not necessarily discourage exporters from relying on environmentally polluting technologies and thus, issues of environmental awareness must still be raised.

b) This study's results can support local participation in the planning of power plant projects, which is encouraged by the latest constitution of the Kingdom of Thailand. The increment or reduction in electricity prices should stimulate society's awareness of the current pricing scheme, which fails to account for costs absorbed by society to stimulate better compensation for those affected by power generation.

c) The proposed electricity supply pricing is expected to help minimize conflicts among the stakeholders of the country's power sector and encourage local authorities' participation in the planning process, for instance, when construction is more feasible than importing, local authorities should consider local ownership of power generation facilities and promote power generation from locally available energy sources, particularly renewables.

In addition, the concept of congestion management [19] should be studied so that it would be able to balance supply and demand of electric energy in each zone effectively and price them accordingly. This further suggests reconsideration of technical competence of the national grid in order to reach such goal [47]. More efforts on liberalizing and decentralizing its electricity market [48] should be considered so that local authorities can be more independent with their electricity affairs, while the central regulator ensures sufficient supply and fair price throughout the country.

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