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A challenge of incentive for small hydropower commercial investment in Thailand

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A B S T R A C T

Thailand implemented a premium-price Feed-in Tariff (FIT), or 'Adder' program, in 2006 as an incentive to generate renewable energy. However, the Adder rate for hydropower was very low, and failed to motivate investors. Later, the Thai government decided to change the Adder program to a fixed-price FIT instead. As of 2014, no studies had analysed hydroelectric power rates in Thailand. Therefore, the objective of this study is to determine the suitable rate for a fixed-price FIT for hydropower in Thailand, using the concept of the actual levelized cost of renewable energy generation. The results showed that the structure of the FIT rate was comprised of three elements: installed capacity, hydropower scheme, and grid connection. From experience with the Adder program, the rate will not be limited at only 200 kW. The proposed rate offers a steady annual return for over 25 years. The recommended rate provides an IRR of 12%, with water fee included. Moreover, we recommend an exclusive promotion rate to promote partnerships with, and to motivate, local communities to conserve and manage the water resource. Furthermore, we suggest using a guideline for calculating social cost-benefits as avoided costs, as well as allocating social benefits.

1. Introduction

Renewable energy (RE) is an important component to solving energy supply security for many countries, including Thailand. However, RE still has some disadvantages compared to fossil fuels, in particular, higher production costs and the uncertainty of energy sources subject to seasonal and climatic conditions. Consequently, government support – financial measures, rules and regulations, and technical support – are crucial for developing RE [1].

Thailand has implemented a technology-specific tariff 'Adder' program since 2006, as a financial incentive for generating RE [1]. Through this program, the power produces receive an additional payment on top of the normal prices, when selling electricity to the power utilities: the Electricity Generating Authority of Thailand (EGAT), the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA) using two types of regulations: (1) VSPPs, or Very Small Power Producers, regulations for generators sized less than or equal to 10MW and (2) SPPs, or Small Power Producers, regulations for generators sized greater than 10 MW and less than 90 MW.

For hydropower, the National Energy Policy Committee (NEPC) approved Adders of THB 0.80 (approximate currency exchange is THB 34 per USD 1) and THB 1.50 for capacities 50–200 kW and less than 50 kW, respectively [2]. Power producers with capacities of 200 kW and greater did not benefit from this Adder policy. The Adder policy for hydropower fails to motivate investors, because the price is not attractive compared to other types of renewable energy with lower carbon dioxide emissions [3,4].

Thailand's Adder program seemed systematic and transparent from 2007 to 2009; however, by end-2009, the Ministry of Energy

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(MOE) began to take notice of an unexpected amount of Power Purchase Agreements (PPAs), especially from solar power, and became concerned that many of these megawatts in the pipeline were not potentially realizable projects, and could result in a sharp increase in the pass-through cost to consumer power tariffs [1]. This led to sudden changes in the Adder program, which affected not just solar projects, but also the whole renewable energy sector. Therefore, in 2010, the National Energy Policy Commission (NEPC) passed a resolution to reduce the Adder rate for solar projects and establish a new committee that would oversee policy formulation and regulation of renewable energy policy. By 2011, fixed-price feed-in tariffs (fixed-price FIT) for all technologies were being considered. Nevertheless, as of 2014, no studies had analysed hydroelectric power rates in Thailand.

A fixed-price FIT rate is independent of market price and constant over a fixed period of time, while a premium-price feed-in tariff, or Adder, varies by the float-time tariff (Ft), plus base tariff, and increases over time. If the established FIT rate is too low and not consistent with the actual investment atmosphere, it will not be conducive for investment. However, if the rate is too high, it will burden consumers [5].

Therefore, the objective of this study is to determine a suitable rate for the fixed-price FIT for hydropower in Thailand. From experience with the Adder program, the rate will not be limited to less than 200 kW, since it would be difficult to attract the power producers. In addition to the installed capacity, this study will also consider the hydropower scheme and type of grid connections, as well as the feasibility of an exclusive promotion rate to promote partnership between public-private or private-private, especially local communities in the form of cooperatives. The operation costs of the joint agencies tend to be higher than of a single. Still, hydroelectricity requires cooperation between public and private companies, or within the private sector itself in the form of cooperatives, due to legal restrictions that, in some areas, prohibit solely private investments, but permit local government and community investment [6]. From a literature review of FITs in many countries, including Germany, Spain, Canada, Honduras, South Africa, China, Taiwan, and Philippines [7–13], most of the fixed-price FITs for hydropower in other countries are classified based on installed capacity only. The criteria for developing FITs in these countries is summarized in Table 1.

As hydroelectricity reduces fossil fuel imports and the social cost from environmental impacts, government should formulate a social benefits policy to reward hydroelectricity users. This study also suggests a guideline for calculating social cost-benefits, while also recommending social benefits allocation.

1.1. Renewable energy promotion using FIT

FIT programs have been widely implemented in many countries. According to REN21 (2014), FITs, either as fixed-price or premium payments, are in place in 66 countries [14]. The FIT rate are differed by technology type, project size, resource quality, and project location to better reflect actual project costs [15].

According to Couture et al. [15], in Mendonça (2007) [16], three main provisions for successful FIT policies consist of: (1) guaranteed access to the grid (2) stable, long-term purchase agreement, typically 15–20 years, and (3) payment levels based on the costs of RE generation. To determine the FIT rates, Cory et al. [17] has summarised approaches as follows:

" *1. Based on the actual levelized cost of renewable energy generation. This approach is the most commonly used in the EU, and has been the most successful at driving RE development around the world.*

2. Based on the 'value' of renewable energy generation either to society, or to the utility, generally expressed in terms of 'avoided costs'. This approach is used in California, as well as British Columbia.

3. Offered as a fixed-price incentive without regard to levelized RE generation costs or avoided costs. This approach is used by certain utilities in the U.S.

4. Based on the results of an auction or bidding process, which can help inform price discovery by appealing to the market directly. An auction-based mechanism can be applied by appealing to the market directly. An auction-based mechanism can be applied and differentiated based on different technologies, project sizes, etc. and is a variant on the cost-based approach and therefore different of establishing cost-based FIT payment levels.

Each of these approaches can be considered a different way of establishing FIT prices, due to the greater prominence of FIT policies structured to cover the cost of RE generation."

However, getting the prices right is not the only goal in determining FIT rates. Choosing FIT rates involves not only engineering-economics, but also balancing multiple policy goals, including more green energy, private sector participation and an increase in competition, economic growth, rural development, agricultural waste utilization, fuel diversification, local pollution reduction and reduced trade deficits from imported equipment [1].

1.2. Shift from adder to fixed-price feed-in tariff in Thailand

For the premium-price feed-in tariff, or Adder, program in Thailand, the total tariff rate varies with a float-time tariff (Ft) plus base tariff. The tariff reflects the expenditure by the country's electricity production agencies, including EGAT, MEA, and PEA. The investment by these agencies aims at accommodating future electricity needs for the next 15–20 years, according to the National Power Development Plan, which was developed based on the national power demand forecast. There are three types of expenditures: 1) financial costs for the expansion of future generation, transmission, distribution and sales systems; 2) operational costs, which include expenditures on the operations and maintenance of the distribution and sales systems, management, and investment returns; and 3) fuel and purchasing costs. The basic tariff covers the first two types of expenditures, while the float-time tariff depends on fuel and purchasing costs [18].

The key features of Thailand's Adder program are the cost of energy production and reasonable returns on investment, guaranteed payment period (10 years for solar and wind, 7 years for other RE), long-term must-take contracts and uniform interconnection standards [1]. The Adder rates are classified by technology type, installed capacity, contracted capacity, and project location. Thailand Adder rates are presented in Table 2.

In 2010, Thailand policymakers decided to change from an Adder program to a fixed-price FIT. Fig. 1 illustrates how the Adder and fixed-price FIT works, and how the Adder can affect electricity cost. Suppose the purchasing rate of the electricity from the producers are the same for using the Adder and fixed-price FIT measures in year 1. The purchasing rates of electricity using a fixed-price FIT are stable throughout the contract term, such as 30 years. The purchasing rate of electricity from the Adder measure is equal to the combination of basic tariff, float-time tariff and Adder. Even if the Adder is kept constant throughout the 30-year period, the purchasing rate might fluctuate as the basic tariff and float-time tariff change. Because of the likelihood of tariff increases, investors are

Table 1
Criteria for developing FIT.

Country	Project size	Investment cost and production cost	Rate of return (ROR)	Contract period (years)	Premium for peak hour supplies	Discount for off-peak supplies	Premium for aboriginal and community involvement	A minimum domestic content requirement for production equipment	Receive reduced payments to account for decreasing technology costs	Avoided costs	Duration of rate review (years)	Price degression	Note
Germany[a]	Tier rates depends on projects sizes: ranging from up to 500 kW to over 50 MW [b]	Yes	5-7%	15				No	Yes	No	4	Yes. 1–5% (depending on project size) under which projects that start uplater receive lower payments to account for decreasing technology costs.	
Spain[a]	Small hydropower: < 10MW, large scale: 10–50 MW[c]	Yes	Lower ROR for lower-risk projects.	Varies from 1 to 25 and more than 25 years depending on project size[h]						No	Annually or more frequently depending on technology		two pricing options—long term fixed pricing and variable pricing where the projects receives a premium relative to market price
Canada (Ontario)[a]	2 programs: microFIT for projects < 10 MW, FIT for projects between 10 and 50 MW	Yes with initial screen for transmission expansion of $500/kW threshold	11%	40	MicroFIT: No, FIT: 35% premium	microFIT: No, FIT: 10% discount	microFIT: No, FIT: Yes	microFIT: No, FIT: Yes		No	2	No	
Honduras[d]	No limit but there system size cap			20-30 depending on project size						Yes			
South Africa[e]	<10 MW	Yes		20							Annually for the first five years and every three years thereafter.		
China[f]	two-tier tariff (wet and dry seasons) for large scale projects	Yes	8%							No			Purchasing price is determined on a project-by-project basis.
Taiwan[g]	rate is not classified by plant size: fixed rate per kWh	Yes	5.25%	20						No	Annually		
Philippines[h]	rate is not classified by plant size			20						No	3	No	

Source:
[a] [7].
[b] [8].
[c] [15].
[d] [9].
[e] [10].
[f] [11].
[g] [12].
[h] [13].

Table 2
Adder rates classified by types of renewable energy and technologies (rate at April 2011).

Fuel type	Adders (Bath/kW-hr)	Supporting period since COD (yrs.)
1. Biomass		
(1) Capacity≤1 MW	0.50	7
(2) Capacity>1 MW	0.30	7
2. Biogas		
(1) Capacity≤ 1MW	0.50	7
(2) Capacity> 1MW	0.30	7
3. MSW[2/]		
(1) Composting and landfill	2.50	7
(2) Thermal Process	3.50	7
4. Wind		
(1) Capacity≤50 kW	4.50	10
(2) Capacity> 50 kW	3.50	10
5. Small hydropower		
(1) 50 kW ≤ Capacity< 200 kW	0.80	7
(2) Capacity< 50 kW	1.50	7
6. Solar	6.50	10

Note: COD is Commercial Operation Date.
Source: [2].

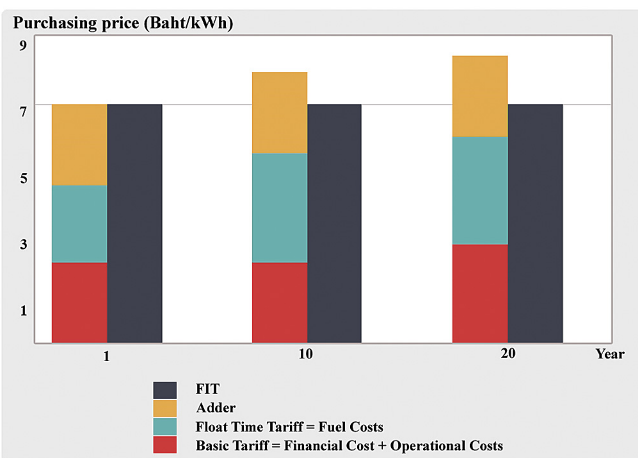

Fig. 1. Comparison of purchasing prices from adder measure and FIT measure.

more interested in projects under the Adder measure. However, a fixed-price FIT is more beneficial to users, because financial support for the investors does not increase according to future basic and float-time tariffs, and budgets to support renewable energy do not need to increase.

2. Methods

2.1. The calculation of appropriate fixed-price FIT rate

Upon assumption that the present and future costs of hydropower plant investment are similar, the fixed-price FIT rate in this study refers to the concept of marginal cost of electricity generation. The total marginal cost of electricity generation, MC_T, is comprised of marginal cost of capacity cost, MC_C, marginal energy cost, MC_E, and marginal operating and maintenance cost, MC_{OM} [19].

For capacity cost, the structure of the fixed-price FIT rate in this study is comprised of three elements: (1) the installed capacity, (2) the hydropower schemes, which are run-of-the-river and water storage, and (3) the grid connection.

For capacity range, information from 256 potential hydroelectric power plants from various studies of Supriyasilp et al. [20,21], Maneewan et al. [22], Taksa-Udom et al. [23], Chindaprasert et al. [24], and Teaumroong et al. [25] were collected and analyzed by plotting the hydroelectric power plants' production cost (excluding transmission line cost) per unit installed capacity versus installed capacity.

After calculating the capacity range, the included and excluded costs of transmission lines are categorized according to the hydropower scheme, whether run-of-the-river or water storage. Furthermore, the cost of transmission lines is included for the hydroelectric power plants with on-grid connection type. Therefore, the calculation of capacity cost in this study included not only the installed capacity, but also the hydropower scheme and connection type.

For energy cost, while the supply source for hydroelectricity is water, the costs vary by hydropower scheme type. The charge for hydropower produced under a water storage scheme is THB 0.0033 baht per cubic meter and for a run-of-the-river scheme is THB 0.01 per cubic meter. These regulatory charges are stated in the Ministerial Act on irrigation discount for users using irrigated water for the development of small-scale electricity plants [26]. The volume of water used varies by hydropower capacity size and type.

Therefore, in calculating MC_T, two separate cases exist – with and without water fees. For the no MC_E case, the charge for water use is zero ($MC_E = 0$), because the running water is used as fuel to turn the turbines that drive generators to produce electricity. No water is wasted or physically changed. In fact, by taking advantage of gravity and the water cycle, only fluid mechanics is used. For the MC_E case, the amount of water used is an opportunity cost for the use of water in other activities, and some water is lost in electricity production.

For operating and maintenance costs, this study assumed a ratio of 1.0 of total initial investment throughout the 25-year contract by the lifetime of machinery and equipment, according to the guidelines of the Electricity Generating Authority of Thailand.

This study proposes using exclusive promotion rates as an increased percentage of IRR. Consequently, the determined FIT rate is MC_T + exclusive promotion rate.

Fig. 2 summarises the proposed concept and design of the fixed-price FIT rate used in this study. The equations for marginal costs calculation are demonstrated below.

$$MC_T = MC_C + MC_E + MC_{OM} \quad (1)$$

as

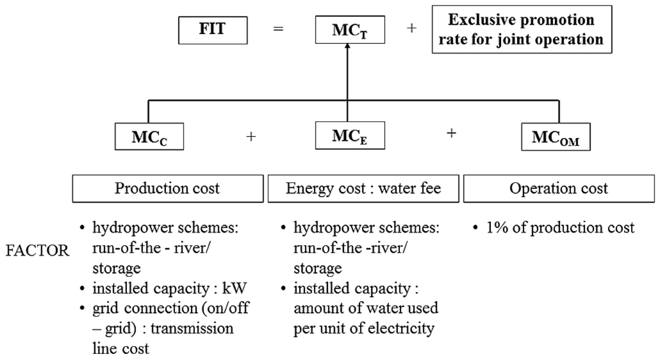

Fig. 2. Concept and design of fixed-price FIT rate.

$$MC_{C,t} = \left(\sum_{t=1}^{N} I_t \Big/ (1+r)^t\right) \Big/ \left(\sum_{t=1}^{N} \partial KW_t \Big/ (1+r)^t\right) \quad (2)$$

$$MC_{E,t} = \left(\sum_{t=1}^{N} E_t \Big/ (1+r)^t\right) \Big/ \left(\sum_{t=1}^{N} \partial KWh_t \Big/ (1+r)^t\right) \quad (3)$$

$$MC_{OM,t} = \left(\sum_{t=1}^{N} OM_t \Big/ (1+r)^t\right) \Big/ \left(\sum_{t=1}^{N} \partial KWh_t \Big/ (1+r)^t\right) \quad (4)$$

$$MC_{T,t} = MC_{C,t} + MC_{E,t} + MC_{OM,t} \quad (5)$$

Here, ∂KW_t is the increased quantity of electricity generation capacity, which is the increased kilowatt usage in year t. $MC_{C,t}$ is the marginal capacity cost as a fixed cost, which varies according to the quantity of installed kilowatts, $MC_{E,t}$ is the marginal energy cost, $MC_{OM,t}$ is marginal operation and maintenance cost, I_t is the plant construction investment cost (the total investment cost of installed capacity), and r is the discount rate. To achieve a stable FIT rate calculation, it is necessary to specify that $MC_{C,t}$, $MC_{E,t}$, and $MC_{OM,t}$ have a stable value throughout the project period (N years).

$MC_{C,t}$ is expressed in units of THB per kilowatt per year (calculated as THB rate per distribution hour), while $MC_{E,t}$ and $MC_{OM,t}$ have units of THB per kilowatt hour (kWh), which is the producible quantity of electricity generation based on the actual hydropower plant data.

As a result, to reflect the identical plant factor, this calculation defines the actual amount of hydroelectricity produced of $MC_{E,t}$ and $MC_{OM,t}$ equal to the number of distribution hours per year multiplied by the average production capacity of $MC_{C,t}$.

To determine the fixed-price FIT rate, the calculation is divided into two parts. First, the marginal capacity cost, the marginal energy cost, and the marginal operation and maintenance costs are calculated using the above equations by specifying the discount rate to determine the present values of the costs. This study used the average (8%) of the minimum loan rate (MLR) of major banks in Thailand as the discount rate (r) [27]. The project period (N) is 25 years according to the projected working age of the machinery. Second, the marginal cost of each type of hydropower scheme and capacity size is recalculated using the above marginal cost equations with fixed IRR. The feed-in tariff rate can then be determined from the total marginal cost.

2.2. The calculation of social cost-benefit

The social cost-benefit is calculated from avoided costs and the external costs of carbon and other gas emissions. The avoided cost is comprised of three costs: the electricity production cost of fossil fuel plants, the energy cost or direct variable cost, and the capacity cost or direct fixed cost. These production costs can be avoided when renewable energy replaces fossil fuels for electricity generation.

According to the Power Development Plan 2010 revision 3 [28], hydroelectricity is a substitute for future energy production of coal/lignite and natural gas. The weighted average method is used in calculating the cost per unit of coal/lignite and natural gas consistent with the amount of electricity produced in the current production structure. The same method is used in calculating the cost per unit of hydropower based on the production data of 256 potential plants, as stated in topic 2.1. Thus, the avoided cost of hydropower production is calculated by comparing the average production cost of the two energy sources with the hydropower production cost.

Because the electricity generation from fossil fuels with carbon content emits carbon dioxide (CO_2) into the air, the calculation of carbon emission cost in this study uses the 20-year forecast of CO_2 emissions in the future production capacity stated in the Power Development Plan Year 2012–2030, revision 3 [27]. As we assume a hydropower project life of 25 years term, we use the CO_2 emissions for year 20 to approximate years 21–25. Emissions of other greenhouse gases, such as CH_4, are calculated as CO_2 equivalents and included in the forecast of CO_2 emission in $kgCO_2$/kWh. Carbon prices have fluctuated hugely over the past years, affected by market conditions and other influential factors [29]. The carbon price used in this study is THB 0.6044 per $kgCO_2$ at a carbon reference price of 15 €/t CO_2 and an exchange rate of THB 40.2938 per EUR 1.

Moreover, during electricity production, other greenhouse gases, such as nitrogen oxide (NO_x) and sulphur oxide (SO_x), are released. However, the quantities and credit trading of these two gases in Thailand have not been studied. Consequently, this study uses American references for the emission allowance prices for these two gases [30]. The price of NO_x is USD 15.89 per ton or THB 0.477 per kg and the price of SO_x is USD 2.12 per ton or THB 0.064 per kg at an exchange rate of THB 30 per USD 1.

3. Research results

An analysis of the potential hydroelectric power plants from the various studies found that the plots were clustered below 8 megawatts (MW). When considering the distribution of these plots, the installed capacity to be supported by the fixed-price FIT can be classified into three ranges: less than 0.4 MW; greater than 0.4 MW, but not exceeding 2.0 MW; and greater than 2.0 MW, but not exceeding 8.0 MW.

Using a discount rate of 8%, the net present value of the total marginal cost was positive and the IRR ranged from 11% to 14%. Then, the marginal cost of each type of hydropower scheme and capacity size was recalculated using fixed IRR. An example of calculated marginal costs at IRR 11% with water fee is shown in Table 3, while Tables 4 and 5 show the results of fixed-price FIT rate at an IRR between 11% and 14% for two cases – without and with water fee, respectively.

The exclusive promotion rates are shown in Table 6. The rates vary depending on number of joint agencies, installed capacity size, hydropower scheme and grid connection type. For example, according to Table 3 the MC_T calculated for the run-of-the-river scheme at capacity not exceeding 400 kW with on-grid connection is THB 9.74 per kWh. If there is a joint investment between the private companies and community co-ops, the exclusive rate from the Table 6 would be THB 0.65 per kWh. Therefore, the total FIT is

Table 3
An example of total marginal cost of electricity generation (MC_T) (Baht/kWh) at IRR = 11.0%with water fee. Units: Baht/kWh.

Hydropower scheme	Capacity	Grid connection	Marginal capacity cost, MC_C	Marginal energy cost, MC_E	Marginal operating and maintenance cost, MC_{OM}	Total marginal cost, MC_T	Payback Period (yr)	Net present value (Baht)
Run-of-the-river	Not exceeding 400 kW	Off	8.13	0.248	0.68	9.07	8.20	22,943,359
		On	8.75	0.248	0.74	9.74	8.22	23,040,471
	More than 400 but not exceeding 2000 kW	Off	5.10	0.390	0.43	5.92	7.89	160,829,186
		On	5.34	0.390	0.45	6.18	7.92	161,003,534
	More than 2000 but not exceeding 8000 kW	Off	3.46	0.390	0.29	4.15	7.67	638,836,779
		On	3.51	0.390	0.30	4.20	7.68	638,975,746
Storage	Not exceeding 400 kW	Off	6.13	0.315	0.52	6.96	8.06	19,388,197
		On	6.52	0.315	0.55	7.39	8.28	19,430,253
	More than 400 but not exceeding 2000 kW	Off	2.44	0.271	0.21	2.92	7.68	116,898,509
		On	2.58	0.271	0.22	3.07	7.72	116,999,709
	More than 2000 but not exceeding 8000 kW	Off	1.60	0.490	0.13	2.22	6.68	960,614,357
		On	1.63	0.490	0.14	2.26	6.71	960,726,166

Table 4
Comparison of the feed-in tariffs (without water fee) for hydropower at different IRRs. Units: Baht/kWh.

Hydropower schemes	Capacity	Grid connection	Feed-in tariffs (without water fee)			
			11.0%	12.0%	13.0%	14.0%
Run-of-the-river	Not exceeding 400 kW	Off	8.82	9.42	10.03	10.65
		On	9.49	10.14	10.80	11.46
	More than 400 but not exceeding 2000 kW	Off	5.53	5.90	6.29	6.68
		On	5.79	6.19	6.59	6.99
	More than 2000 but not exceeding 8000 kW	Off	3.71	4.01	4.27	4.54
		On	3.81	4.07	4.33	4.60
Storage	Not exceeding 400 kW	Off	6.64	7.10	7.56	8.03
		On	7.07	7.56	8.05	8.54
	More than 400 but not exceeding 2000 kW	Off	2.65	2.83	3.01	3.20
		On	2.80	2.99	3.18	3.38
	More than 2000 but not exceeding 8000 kW	Off	1.73	1.85	1.97	2.09
		On	1.77	1.89	2.01	2.13

THB 10.39 per kWh.

For social cost-benefit calculation, the avoided cost is THB 0.9329 per kWh. Of the greenhouse gas emissions during the production process, carbon emissions are the highest, followed by NO_x and SO_x. Table 7 compares the quantities of NO_x, SO_x and CO_2 according to fuel types [31]. A comparison of the emissions of the three gases during the combustion of natural gas fuel, with the ratio of CO_2 emission per electrical power unit, reveals that the emission cost of NO_x is between THB 0.00000037284 and 0.00000042944 per kWh and the emission cost of SO_x is between THB 0.00000022385 and 0.00000025783 per kWh, which are far lower than the cost of CO_2 emissions. For this study, the cost of CO_2 emissions are THB 0.6044 per kWh. Since the emissions and costs of the other greenhouse gases are small, they are considered negligible.

The calculation of social cost-benefit and the associated costs are summarised in Fig. 3.

4. Discussion

Table 3 shows an example of calculating the total marginal cost of electricity generation at an IRR of 11% and the water fee included. For the hydropower plants with installed capacity exceeding 8.0 MW, the costs of production capacities are considered low, so the incentive from this fixed-price FIT should not be offered. Moreover, when considering the type of hydropower scheme, the FIT rates of

Table 5
Comparison of the feed-in tariffs (with water fee) for hydropower at different IRRs. Units: Baht/kWh.

Hydropower scheme	Capacity	Grid connection	Feed-in tariffs (with water fee)			
			11.0%	12.0%	13.0%	14.0%
Run-of-the-river	Not exceeding 400 kW	Off	9.07	9.67	10.28	10.90
		On	9.74	10.39	11.04	11.71
	More than 400 but not exceeding 2000 kW	Off	5.92	6.29	6.68	7.07
		On	6.18	6.58	6.98	7.38
	More than 2000 but not exceeding 8000 kW	Off	4.15	4.40	4.66	4.93
		On	4.20	4.46	4.72	4.99
Storage	Not exceeding 400 kW	Off	6.96	7.41	7.87	8.34
		On	7.39	7.87	8.36	8.86
	More than 400 but not exceeding 2000 kW	Off	2.92	3.10	3.29	3.47
		On	3.07	3.26	3.45	3.65
	More than 2000 but not exceeding 8000 kW	Off	2.22	2.34	2.46	2.58
		On	2.26	2.38	2.50	2.62

Table 6
Exclusive promotion rate for joint operations. Units: Baht/kWh.

Hydropower scheme	Capacity	Grid connection	% Increase of IRR	For 2 agencies	For more than 2 agencies
Run-of-the-river	Not exceeding 400 kW	Off	1.0%	0.60	1.20
		On	1.0%	0.65	1.30
	More than 400 but not exceeding 2000 kW	Off	1.0%	0.37	0.74
		On	1.0%	0.40	0.80
	More than 2000 but not exceeding 8000 kW	Off	0.5%	0.15	0.30
		On	0.5%	0.13	0.26
Storage	Not exceeding 400 kW	Off	1.0%	0.46	0.92
		On	1.0%	0.49	0.98
	More than400 but not exceeding 2000 kW	Off	1.0%	0.18	0.36
		On	1.0%	0.19	0.38
	More than 2000 but not exceeding 8000 kW	Off	0.5%	0.06	0.12
		On	0.5%	0.06	0.12

Note: 1.Two agencies indicates private sector with either a state agency or cooperative.
2. More than two agencies indicates private sector with other organisations such as state agencies and cooperatives.

Table 7
Comparison of emissions by fuel types. Units: kg/MMBTU.

Fuel type	Emissions		
	NO_x	SO_2	CO_2
Coal	1.5×10^{-3}	1.18×10^{0}	9.55×10^{1}
Oil	0.6×10^{-3}	0.51×10^{0}	7.88×10^{1}
Natural gas	0.1×10^{-3}	0.45×10^{-3}	5.31×10^{1}

Note: MMBTU = Million British Thermal Unit.
Source: [31].

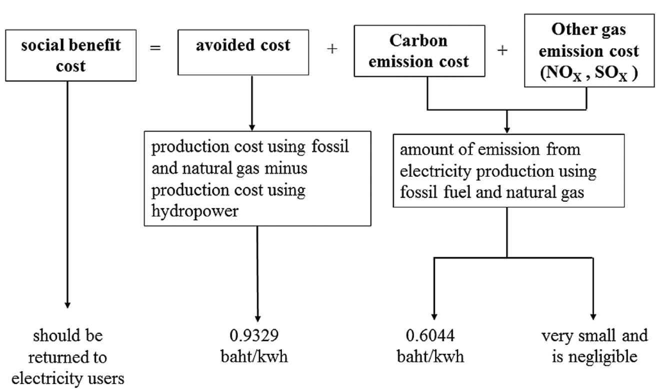

Fig. 3. Calculation of social cost-benefit.

hydroelectricity produced from run-of-the-river type are higher than that from storage type. This is because, in Thailand, water storage schemes, such as reservoirs and dams, most of which belong to the Royal Irrigation Department, are constructed for irrigation purposes, with the hydropower produced a by-product of water release. The project costs for this analysis do not include expenditures for constructing the dams and reservoirs and other irrigation elements. The cost per unit of these projects is thus lower than that of the run-of-the-river projects. Furthermore, within the same hydropower scheme, the total marginal cost reduces as the capacity of hydroelectricity increases.

Tables 4 and 5 show the FIT rates without and with water fees at different IRRs, respectively. The total marginal costs from Table 3 are the FIT rates in Table 5 at an IRR of 11% with water fee. The purchasing rates from the FIT measure with the water fee according to Table 5 is THB 9.07 per kWh for the run-of-the-river scheme and THB 6.96 per kWh for the storage scheme. Given the current electricity tariff of THB 3.94 per kWh (as of December 2012), and an adder of THB 0.8 per kWh for capacity range 50–200 kWh (from Table 2), the net purchasing rate from the adder measure would be THB 4.74 per kWh. If the total marginal cost of electricity generation at an IRR of 11% covered the hydroelectricity production costs only, without providing for any profit, then this implies that the electricity producer or investors could not survive, since the purchasing rate from the Adder measure is too low.

In principle, to calculate an appropriate fixed-price FIT rate for hydroelectricity investment in Thailand, the costs and benefits of the investors for their actual financial risk and return must be taken into account. The FIT rate must be neither too low nor too high, since it is fixed for 25 years – if too low, investors will not cover their costs; if too high, competition and future development of hydroelectric technology to lower investment cost will be discouraged.

Using an IRR of 11% to determine an appropriate FIT rate is not attractive enough to induce investment at an 8% loan interest rate (the average MLR of major Thai banks [27]) and a 3% expected inflation rate [32]. From this study, it is suggested that the appropriate FIT rate is the rate at IRR of 12% at a payback period within 8 years. In Thailand, an IRR of 12.5% and payback period of less than 8 years are recommended as investment guidelines for state enterprises. Private investors are expected to operate more efficiently than state enterprises.

Additionally, a fixed-price FIT rate with water fee included should be considered. Requiring consumers to pay for their water supply raises awareness of the need to conserve and efficiently use water resources.

The exclusive promotion rate is designed to support public-private or private-private partnerships, especially with the local community. An exclusive promotion rate is expected to build community participation in the form of cooperatives to produce hydropower. Once engaged, communities will take an active role in conserving and managing its water resources, as water brings investment and income into the local economy. Simultaneously, community participation can reduce the investors' risk of water scarcity.

Hydropower development projects in Thailand require approval from the local authority where sited. A key success factor to local approval is the community's attitude toward the project, including its impacts, especially environmental. As small hydropower projects usually have fewer negative environmental impacts than other types of renewable energy, they are more likely to meet with local approval, particularly if they involve a private-local partnership in the form of a cooperative or similar arrangement.

Hydropower has traditionally been considered environmentally friendly – a clean and nonpolluting source of electricity. This study then calculates the social cost-benefit out of avoided cost also carbon dioxide and other gases emission costs. In formulating policies to promote hydropower, government should allocate this social benefit back to electricity users, since the production and consumption of hydropower brings sustainability in every way. This study calculated a social benefit of THB 1.5373 per kWh (an avoided cost of THB 0.9329 per kWh and a carbon emission cost of THB 0.6044 per kWh). In all probability, social benefits will be paid at THB 0.7687 per kWh, or approximately 50% of estimated benefits as follows:

$$\text{Social benefits (THB per kWh)} = \text{return ratio} \times 1.5373 \times \text{amount of hydropower unit produced per year/amount of electricity consumption per year} \quad (6)$$

Social benefits per unit will be allocated back to consumers as a discount on their electricity bills in the following year by the Metropolitan Electricity Authority and Provincial Electricity Authority. This social cost-benefit approach is expected to promote hydroelectricity consumption, as well as environmental preservation and sustainable development.

Besides capacity size and technology type of hydropower schemes, this study determined a fixed-price FIT rate classified by a grid-connected system, as well. The off-grid system provides electricity to remote rural areas without the associated transmission line costs of accessing the grid. As off-grid distribution is often cheaper, the off-grid FIT rate should be lower than the corresponding on-grid rate. Although off-grid supply is important for rural electrification, there are, however, barriers to implementing off-grid hydroelectricity, especially the accuracy of measurement and verification of generation. Furthermore, off-grid production may cause possible forest invasion. Thus, promoting off-grid supply of hydropower needs to consider more than a financial approach alone, in order to avoid any possible negative impacts. Subsequently, on-grid should be promoted first, for it is rather barrier-free.

5. Conclusions

The fixed-price Feed-in Tariff is used in the promotion of hydroelectricity in small and very small scale. The financial model in this study is based upon the actual levelized cost of renewable energy generation, the most commonly used model in the EU, and the one that has most successfully driven RE development worldwide.

This study examined the calculation for a fixed-price Feed-in Tariff that offers a steady annual return for over 25 years. Based on investor costs and benefits with actual financial return, the FIT rate structure includes three cost components: installed capacity cost, hydropower scheme cost and grid connection cost. Moreover, the exclusive promotion rate is included in order to promote partnership between public-private or private-private, especially the local community in the form of cooperatives. Besides the advantage of local economy, the exclusive promotion rate also motivates communities to conserve and manage their water resource.

This study recommends FIT rate at IRR 12% with water fee included; this rate is neither too low to discourage investment nor so high as to burden the government and electricity users. Once substantial investments in hydroelectricity have been made, government should prioritize guaranteed access to the grid. The FIT rate should be reviewed every five years. The government should also commit to a purchase volume.

This FIT rate would offer an attractive return to investors. For government, promoting hydropower would help reduce fossil fuel imports and the accompanying social costs arising from the environmental impacts of its use. As a result, government should formulate a social benefits policy to reward hydroelectricity consumers.

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References

[1] S. Tongsopit, C. Greacen, An assessment of Thailand's feed-in tariff program, Renew. Energy 60 (2013) 439–445.
[2] Provincial Electricity Authority, The Adder from renewable energy for VSPPs, Resolut. Natl. Energy Policy Comm. 25 (November 2010). Available from, http://www.pea.co.th/vspp/ (Accessed July 2011).
[3] P. Wibulswas, Research of potential for small and very small hydropower dam in Thailand, Potential of water... to produce electricity, TRF Energy Policy Bull. 1 (March 2010) edition, 2010.
[4] A. Bangviwat, Determining adders from external costs for the production of electricity from small hydropower, Potential of water... to produce electricity, TRF Energy Policy Bull. 1 (March 2010) edition, 2010.
[5] Energy for Environment Foundation, E for E Newsletter, Highlight: Adder or Feed-in Tariff?, No.36:, April-June, 2012.
[6] T. Supriyasilp, K. Pongput, C. Robkob, Small hydropower development and legal limitations in Thailand, in: World Renewable Energy Congress 2011-Sweden, Linkoping, Sweden, May 2011, pp. 8–13.
[7] A. Yatchew, A. Baziliauskas, Ontario feed-in-tariff programs, Energy Policy 39 (2011) 3885–3893, http://dx.doi.org/10.1016/j.enpol.2011.01.033.
[8] M. Lang, A. Lang, German Feed-in Tariffs 2014 (01–07), German Energy Blog: Energy in Germany-legal Issues, Facts, and Opinions, 2014.
[9] D. Jacobs, N. Marzolf, J.R. Paredes, W. Rickerson, H. Flynn, C. Becker-Birck, M. Solano-Peralta, Analysis of renewable energy incentives in the Latin America and Caribbean region: the feed-in tariff case, Energy Policy 60 (2013) (2013) 601–610. Available from, http://www.germanenergyblog.de/?page_id=16376 (Accessed February 2015).
[10] A. Pegels, Renewable energy in South Africa: potentials, barriers and options for support, Energy Policy 38 (2010) 4945–4954.
[11] J. Ma, On-grid electricity tariffs in China: development, reform and prospects, Energy Policy 39 (2011) 2633–2645.
[12] Y.H. Huang, J.H. Wu, Assessment of the feed-in tariff mechanism for renewable energies in Taiwan, Energy Policy 39 (2011) 8106–8115.
[13] B. Bakhtyar, K. Sopian, A. Zaharim, E. Salleh, C.H. Lim, Potentials and challenges in implementing feed-in tariff policy in Indonesia and the Philippines, Energy Policy 60 (2013) 418–423.
[14] REN21, Renewables 2014 Global Status Report (Paris: REN21 Secretariat), 2014.
[15] T.D. Couture, K. Cory, C. Kreycik, E. Williams, A Policymaker's Guide to Feed-in Tariff Policy Design, Technical Report, NREL/TP-6A2–44849, July 2010, National Renewable Energy Laboratory, US Department of Energy, 2010.
[16] M. Mendonça, Feed-in Tariffs: Accelerating the Deployment of Renewable Energy, EarthScan, London, 2007.
[17] K. Cory, T. Couture, C. Kreycik, Feed-in Tariff Policy: Design, Implementation, and RPS Policy Interactions, Technical Report, NREL/TP-6A2–45549, March 2009, National Renewable Energy Laboratory, US Department of Energy, 2009.
[18] EGAT, Ft and the New Tariff Rate Structure, Available from, Electricity Generating Authority of Thailand, 2013, http://www.egat.co.th/index.php?option=com_content&view=article&id=544 (Accessed June 2013).
[19] V. Lorchirachoonkul, T. Vikitset, Costs of Power Generation in Thailand, NIDA Consulting Center, 2005.
[20] T. Supriyasilp, K. Pongput, T. Boonyasirikul, S. Boonyanupong, S. Karntanawanitchakul, P. Suntiparapop, Study of Hydropower Planning and Development for Ping River Basin, Institute for Science and Technology Research and Development, Chiang Mai University, 2007.
[21] T. Supriyasilp, K. Pongput, T. Boonyasirikul, S. Boonyanupong, C. Taksa-Udom, R. Yongprayun, The Study of Potential and Regulation Issues for Hydropower Development in Wang River Basin, Chiang Mai University, Kasetsart University and Lampang Rajabhat University, 2010.
[22] S. Maneewan, D. Tungtakanpoung, S. Tantanee, S. Chuenchooklin, M. Choawakul, S. Mitrsomwang, P. Palsaen, Investigation of Potential and Development for Mini-hydro Power Generation in Yom Basin, Naresuan University, 2006.

[23] C. Taksa-Udom, T. Supriyasilp, K. Pongput, T. Boonyasirikul, S. Boonyanupong, The Study of Potential and Acceptance for Hydropower Development in Yom River Basin, Chiang Mai University and Kasetsart University, 2011.
[24] P. Chindaprasert, K. Triratanasirichai, W. Kasaluk, S. Pathumnakul, W. Sri-amporn, W. Thanasate-angkool, A. Yimtae, C. Pawattana, C. Waiyasurasingh, W. Tiensuwan, N. Trikijwattanakul, The Potential Study and Development of Hydropower for Electricity Generation in Chi Basin, Sustainable Infrastructure Research and Development Center, 2009.
[25] N. Teaumroong, S. Horpibulsuk, S. Wongkaew, P. Jittamai, S. Sarapirom, Evaluation of Potential for Small Hydropower Development in Mun River Basin, Suranaree University of Technology, 2008.
[26] Ministerial Act on irrigation discount for users using irrigated water for the development of small-scaled electricity plants, Thai Gov. Gaz. 126 (39a) (2009) 10–11.
[27] Bank of Thailand, A. Daily Interest Rates of Commercial Banks, 2013. Available from, http://www.bot.or.th/thai/statistics/financialmarkets/interestrate/_layouts/application/interest_rate/IN_Rate.aspx (Accessed May 2013).
[28] EPPO, Power Development Plan 2012-2030 (PDP2010: Revision 3), Thailand: Energy Policy and Planning Office (EPPO), Ministry of Energy, 2012.
[29] Point Carbon, EU ETS – an Oversupply of Permits, 2012. Available from, http://econfix.wordpress.com/tag/eu-ets/ (Accessed October 2012).
[30] U.S. Energy Information Administration, Emissions Allowance Prices for SO2 and NOX Remained Low in 2011, 2012. Available from, http://www.eia.gov/todayinenergydetail.cfm?id=4830 (Accessed March 2013).
[31] Chesapeake Energy Corporation, Emission by Fuel Types, 2013. Available from, http://www.chk.com/corporate-responsibility/ehs/environment/air/Pages/Information.aspx (Accessed March 2013).
[32] Bank of Thailand, B. Inflation, 2013. Available from, http://www.bot.or.th/Thai/Pages/BOTDefault.aspx (Accessed May 2013).