Chapter 5

Renewable Energy and Policy Options in an Integrated ASEAN Electricity Market: Quantitative Assessment and Policy Implications

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CHAPTER 5

Renewable Energy and Policy Options in an Integrated ASEAN Electricity Market: Quantitative Assessment and Policy Implications

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Energy market integration (EMI) in the ASEAN region is a promising solution to relieve the current immobilization of these resources and would serve the fast increasing demand for electricity in the region. EMI could be further extended with coordinated policies in carbon pricing, renewable energy portfolio standards (RPS), and feed-in-tariffs (FIT) in the ASEAN countries. Using a linear dynamic programming model, this study quantitatively assesses the impacts of EMI and the above-mentioned policies on the development of renewable energy in the power generation sector of the region, and the carbon emissions reduction achievable with these policies. EMI is expected to 'harvest the low-hanging fruit' and could significantly promote the adoption of renewable energy. Along with EMI, FIT appears to be more cost-effective than RPS and is recommended, albeit the administration costs for implementation might be a practical concern. In addition, an RPS of 30% electricity from renewable sources by 2030 is in reality considered a reasonable option by many policy makers and it would achieve moderate improvements in carbon emissions reductions and renewable energy development, while incurring negligible increases in the total cost of electricity.

Keywords: Energy Market Integration (EMI); Renewable Energy Portfolio Standards (RPS); Feed-in-Tariff (FIT); Carbon pricing; Renewable energy resources

1. Introduction

Strong economic growth of the ASEAN countries in the recent decade has been coupled with far stronger growth in electricity consumption (see Table 1). The growth rate of electricity consumption in ASEAN countries is more than double the world average, which could reflect the fact that the region is undergoing rapid urbanisation and industrialisation.

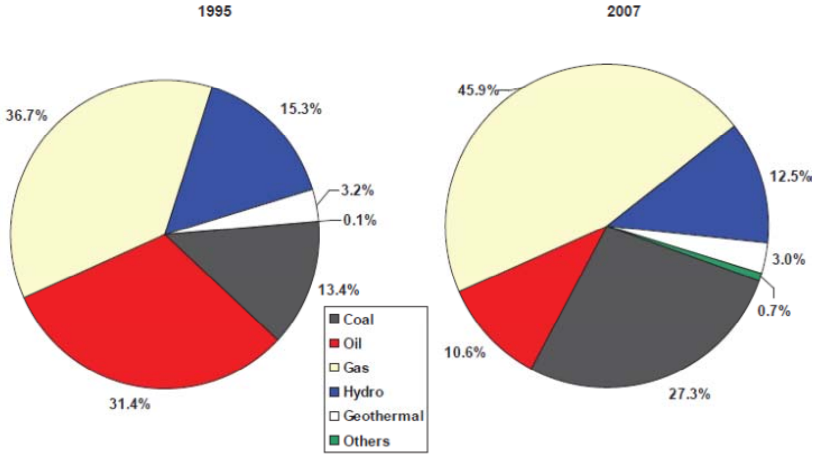
Table 1: Growth in GDP, Energy Consumption and Electricity Consumption - ASEAN and World Average 2000-2009

	GDP	Energy Consumption	Electricity Consumption
ASEAN	5.2%	4.8%	6.6%
World Average	3.5%	2.2%	3.1%

Source: Authors' estimation based on World Bank and Energy Information Administration (EIA) data

Like the rest of the world, fossil fuels dominate in the electricity generation of the ASEAN countries. The share of oil is decreasing while the shares of natural gas and coal are increasing. The share of renewable energy such as hydro and geothermal has been going down but the total rate of utilisation has increased. It was 18.6% in 1995 but 16.2% in 2007. These observations indicate that electricity generation from renewable energy sources has been developing slower than that from fossil fuels and that most of the increase in electricity demand has been met by electricity generated from fossil fuels (see Figure 1).

Figure 1: ASEAN Electricity Generation by Source, 1995 and 2007



Source: The Third ASEAN Energy Outlook, Institute of Energy Economics Japan, ASEAN Centre for Energy, National ESSPA Project Team, Feb 2011

According to various energy statistics, ASEAN countries have abundant renewable resources in the form of hydro, geothermal, biomass, solar, and wind. However, these resources are unevenly distributed among the member countries. It is estimated that ASEAN has 254 GW of hydro resources, excluding Vietnam. Hydro resources are concentrated in Myanmar, Indonesia, Lao PDR, and Malaysia. About 20,000 MWe or 40% of the world's geothermal energy resources are found in Indonesia, and the country is the second largest geothermal energy producer in the world. The Philippines also has abundant geothermal resources and is ranked fourth in the world. Indonesia, Malaysia, and Thailand have 50 GW, 29 GW, and 7 GW of biomass potential respectively. Malaysia has 41% of world palm oil production and it has the potential to be one of the major contributors of renewable energy in the world via palm oil biomass. Vietnam, the Philippines, and Lao PDR have the greatest theoretical wind power potential in the region (Abdullah, 2005; Do and Sharma, 2011, Lidula, *et al*., 2007; Thavasi and Ramakrishna, 2009; Ong, *et al*., 2011)

Despite its strong potential in renewable energy, the utilization of renewable energy for power generation is very low in the region. In the rural areas of many ASEAN countries, most of the biomass energy is still being used in traditional burning. The share of biomass used in this way has been as high as 73.8% in Cambodia, followed by Myanmar (64%), Vietnam (60%), and Lao PDR (54.2%) in their total energy mix (Thavasi and Ramakrishna, 2009).

There are a few major barriers for ASEAN countries to overcome in adopting modern technologies to harvest renewable energy and turn it into the cleaner form, which is electricity, for consumption. While the high upfront investment costs of the advanced renewable energy technologies are the key barrier to adoption, the lack of financial means and technology / knowledge transfer are the other critical barriers (Das and Ahlgren, 2010).

There are some solutions available to tackle such barriers of finance, technology and knowledge transfer. The Clean Development Mechanism (CDM) is one of the potential solutions. However, the methodology used by the CDM in determining the amount of emissions-reduction prevents the least-developed countries from certifying their renewable energy projects (Lim and Lee, 2011). Countries like Myanmar, Cambodia, Vietnam, and Lao PDR already have a high share of renewable energy in terms of traditional biomass such as wood in their energy mix, and using modern renewable energy technologies to replace traditional renewable energy cannot qualify for CDM credits unless there is a significant improvement in efficiency.

Energy market integration (EMI) in ASEAN is a promising means of relieving the immobilization of potential renewable energy development caused to a large extent by the above barriers. First, EMI brings an integrated regional power market, which would enable poorer countries that have abundant renewable energy to export their clean energy to richer countries by means of cross-border power trade. Second, EMI allows financial resources to move from richer countries to poorer countries. It thus relieves the financial constraint on renewable energy investment. Third, an integrated regional energy market also makes technology and knowledge transfer easier between the two groups of countries in the region (Lim and Lee, 2011). This study quantitatively assesses how the market integration brought by EMI could promote the development of renewable energy for power generation.

Importantly, EMI could go further towards implementing three sets of coordinated policy regimes to promote renewable energy development in the power sector of the region. First, ASEAN countries could coordinate and impose renewable energy standards (RPS) to a certain extent in the power sector of each member country, as Thailand and the Philippines have already been attempting. (Lidula, *et* *al.*, 2007). Second, it could seek the establishment of a common carbon emissions rights market in this region, and the common prices of carbon emissions rights could serve as an additional incentive to investments in power generation using renewable energy. Third, ASEAN countries could also seek to coordinate provision of feed-in-tariffs (FIT) to renewable energy development in the power sector. This study thus further delves into how these three policy regimes can help the development of renewable energy in the power sector of the region.

The remainder of this paper is organised as follows; section 2 presents the methodology of the study, which is linear dynamic programming modelling for quantitative simulation of the impacts of the above-mentioned policy scenarios. Section 3 describes key data inputs for the scenarios. Section 4 presents scenario simulation results and analysis of the results. Section 5 concludes.

2. Methodology and Model

This study adopts a linear dynamic programming model developed by Chang and Li (2012). In this model, taking a long time-horizon, a planner's objective is to choose power plant capacities and output levels across the countries covered in the research scope, so as to minimize the present value of total costs while meeting the growing demand for power over the modelling period. The model assumes that the ASEAN Power Grid (APG) is in place so that countries in the region are allowed to trade power. Levelized costs of generating electricity are embedded in this model. Depending on the modelled policies on cross-border power trade, the amounts of power to be traded between countries in each year of the period are also optimized. The model is solved using GAMS. Technical details of the original model can be found in Appendix A.

In addition, for the purpose of this study, two major modifications are applied to the original model. One modification models the implementation of uniform RPS policy in all countries of the region. The other models the implementation of uniform FIT policy in all countries of the region.

To model the RPS policy, an RPS constraint is imposed to the original model. The constraint says that the share of electricity generated from renewable sources should not be lower than a specified level in the total electricity generated in a certain year. The equation below represents this constraint.

$$\sum_{i=1}^{I}\sum_{j}^{J}\sum_{v=-V}^{t}\sum_{p=1}^{P}\sum_{RES=1}^{RES} u_{RES,ijtvp}\cdot\theta_{jp} \geq \sum_{i=1}^{I}\sum_{j}^{J}\sum_{v=-V}^{t}\sum_{p=1}^{P}\sum_{m=1}^{M} u_{mijtvp}\cdot\theta_{jp} \qquad (1)$$

Here, u_{mijtvp} is power output of plant type *m* (power generation technology), vintage *v*, in year *t*, country *i*, block p on the load, and exported to country *j*. θ_{jp} be the time interval of load block p within each year in the destination country. *RES* represents the subset technologies which are categorized as renewable energy technologies.

Importantly, to create realistic RPS scenarios, it is assumed that the policy is effective from 2020 onwards.

FIT is a policy to provide a certain favourable price to purchase the power generated from specified types of renewable energy sources. The implicit implication of FIT is that it provides per unit subsidy on renewable energy. Since our model deals with minimization of costs of power generation instead of maximization of revenue from power generation, only the implicit implication of FIT could be modelled. However, this interpretation of FIT in our model does not skew its impact on decision-making related to power generation capacity development and utilization. Therefore, in the FIT policy scenarios, an FIT subsidy for each unit of electricity generated from renewable sources is added into the objective function.

The following equation represents total FIT subsidy on renewable energy in each year and the value is subsequently inserted into the objective function of the model.

$$subsidy(t) = \left(\sum_{i=1}^{I}\sum_{j}^{J}\sum_{v=-V}^{t}\sum_{p=1}^{P}\sum_{RES=1}^{RES} u_{RES,ijtvp}\cdot\theta_{jp}\right)\cdot fit(t) \qquad (2)$$

Here, $subsidy(t)$ is the total subsidy for all renewable energy in year t. $fit(t)$ is the per unit implicit subsidy from FIT policy on renewable energy.

In addition, to reflect the potential of small hydro and Carbon Capture and Storage (CCS) technologies in the region, these technologies are now added into the model. To reflect the concern that the prices of carbon emission rights in future may still go through cyclical developments, our assumptions about the prices of carbon emissions follows a similar pattern to publically available U.S. carbon trading data.

3. Data Inputs and Scenarios

This study covers the ten member countries of ASEAN, which are Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. Technologies for power generation covered in this study include coal, coal CCS, diesel, natural gas, natural gas CCS, hydro, small hydro, geothermal, wind, solar PV, and biomass. The period covered by this study is 2012 to 2035.

The main items of data required for this study include existing capacities of the types of power generation mentioned above, the CAPEX and OPEX of these types of power generation, the load factor and life expectancy of each vintage of each type of power generation, the energy resources available for power generation in each country, the peak and non-peak power demand and duration of power demand of each country, projected growth rate of power demand, and transmission cost and transmission losses of cross-border power trade. Detailed data and sources of data are presented in Appendix B.

The purpose of this study has two layers. One is to assess how policies such as EMI, carbon prices, RPS and FIT impact the pattern of power generation capacity development and utilization, as well as that of cross-border power trade in the region, with special focus on renewable energy applications in the region. The other is to assess what level of policy intervention is most effective for each policy regime, in terms of the additional costs incurred and the additional capacity development in renewable energy achieved.

Specially, we focus on testing various RPS and FIT policies. For RPS, we test what percentage of renewable energy in the total electricity supply is most effective in promoting renewable energy capacity development. For FIT, we test how much subsidy is most effective in promoting renewable energy capacity development. The following table lists the key assumptions or parameters of the scenarios.

Table 2: Key Assumptions/Parameters of the Scenarios

Scenario	Description
BAU (No Carbon Costs or EMI)	Business-As-Usual (BAU) with no carbon costs[1] or EMI imposed on the power sector
BAUCC (Carbon Costs with No EMI	This scenario assumes that carbon costs are) imposed to the power sector but the region has no effective EMI to allow free cross-border power trade
BAUCCEMI (Carbon Costs with EMI)	Both carbon costs and EMI are implemented in the power sector of the region
FIT10	USD 10 / MWh of subsidy provided to electricity generated from renewable energy
FIT20	USD 20 / MWh of subsidy provided to electricity generated from renewable energy
FIT30	USD 30 / MWh of subsidy provided to electricity generated from renewable energy
FIT40	USD 40 / MWh of subsidy provided to electricity generated from renewable energy
FIT50	USD 50 / MWh of subsidy provided to electricity generated from renewable energy
RPS10	The share of renewable energy in total electricity is required to be above 10%
RPS20	The share of renewable energy in total

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[1] Carbon costs usually come from Cap-and-Trade schemes for carbon emissions from specified sectors. Although ASEAN has no such scheme at the moment, carbon costs from other markets such as the Europe and U.S. could be applied to reflect the environmental cost of carbon emissions from power generation activities. Importantly, as our model is a sector model, it is not possible to endogenise carbon costs which are derived from multi-sector markets.

	electricity is required to be above 20%
RPS30	The share of renewable energy in total electricity is required to be above 30%
RPS40	The share of renewable energy in total electricity is required to be above 40%
RPS50	The share of renewable energy in total electricity is required to be above 50%
RPS60	The share of renewable energy in total electricity is required to be above 60%
RPS70	The share of renewable energy in total electricity is required to be above 70%
RPS30 by 2030	The share of renewable energy in total electricity is required to be above 30% from 2030 onwards
FIT10 RPS10	A Combination of FIT10 and RPS10

The BAU scenario assumes that in the studied period no coordinated policies such as carbon costs, EMI, RPS or FIT are adopted to promote renewable energy in the power sector of the region.

The BAUCC scenario assumes that carbon costs are imposed on power generation in all countries in the region, but no EMI is implemented. This scenario, when compared with the previous BAU scenario, reflects the impact of carbon costs.

The BAUCCEMI scenario assumes that both carbon costs and EMI are introduced. This scenario, when compared with the previous carbon costs only scenario, reflects the impact of EMI.

FIT10 to FIT50 is a series of scenarios which test the impacts of various levels of FIT subsidies. RPS10 to RPS70 is another series of scenarios which test the impacts of various levels of RPS requirements on the share of renewable energy in total power generation to be met from 2020 onwards. Our model is solvable at up to RPS of 70% level, meaning that the region has ample renewable resources, especially hydro, to enable the scenario. Both FIT and RPS scenarios assume the implementation of both carbon costs and EMI.

RPS30 by 2030 is an additional scenario that says 30% of the power generated is supplied from renewable sources from 2030 onwards. This scenario is currently perceived by policy practitioners in the region as reasonable. The model thus helps assess the effectiveness of such a policy. FIT10 RPS10 is another additional scenario that says that FIT10 and RPS10 will be combined and implemented simultaneously. The scenario represents popular thinking from the U.S. policy makers. This model will also help assess if this policy would be favourable in ASEAN context.

4. Results and Analysis

Key results from the simulation of the scenarios in Table 2 are listed in the following table. The second column of Table 3 reports the objective value that is the variable portion of the total cost of electricity generated – CAPEX of newly added capacities and OPEX of both vintage and newly added capacities. Subsidies to OPEX incurred under the FIT scenarios of power generation are reported in the third column. These subsidies are also part of the social costs in producing the electricity. In addition, the historical vintage capacities incur a fixed amount of amortised CAPEX and this is reported in the fourth column. The adjusted actual total costs are therefore a summation of the objective value of the model, the total subsidies, and the amortised CAPEX of vintage capacities. They are reported in the fifth column. The sixth column reports total CO_2 emissions in the corresponding scenario. The penultimate column reports total newly added renewable energy power generation capacities achieved in the period in the corresponding scenario. The last column is a subset of penultimate column showing the newly added renewable energy capacities excluding hydro.

Table 3. Key Results of All Scenarios

Scenarios	Objective (Million USD)	Total Subsidy (Million USD)	CAPEX of Existing Capacity (Million USD)	Actual Total Cost (Million USD)	Total CO_2 Emissions (Million Tonnes)	Renewable Energy Capacity Added (MW)	Renewable Energy Capacity Added w/o hydro (MW)
BAU	470,982	0	2,525,266	2,996,247	17,158	61,419	13,125
BAUCC	489,908	0	2,525,266	3,015,174	16,580	79,355	24,155
BAUCCEMI	473,896	0	2,525,266	2,999,162	15,177	117,041	20,819
FIT10	436,244	43,984	2,525,266	3,005,494	12,475	160,399	38,445
FIT20	387,555	109,749	2,525,266	3,022,570	10,293	181,922	51,253
FIT30	322,592	233,162	2,525,266	3,081,020	7,408	197,425	74,970
FIT40	236,146	387,996	2,525,266	3,149,407	5,634	213,709	83,004
FIT50	130,619	583,638	2,525,266	3,239,522	4,257	250,859	93,702
RPS10	474,084	0	2,525,266	2,999,349	15,067	117,871	21,648
RPS20	476,963	0	2,525,266	3,002,229	14,460	123,725	27,487
RPS30	482,347	0	2,525,266	3,007,613	13,578	128,127	30,512
RPS40	496,085	0	2,525,266	3,021,351	12,351	139,903	40,325
RPS50	515,496	0	2,525,266	3,040,762	11,109	149,598	48,210
RPS60	544,266	0	2,525,266	3,069,532	9,646	178,033	57,849
RPS70	598,918	0	2,525,266	3,124,184	8,324	249,456	86,335
RPS30 by 2030	474,670	0	2,525,266	2,999,936	14,681	125,407	28,753
FIT10 RPS10	436,257	44,006	2,525,266	3,005,529	12,471	160,399	38,445

Source: Simulation results.

Some general observations may be drawn from results reported in Table 3.

- First, without any policy intervention and following the current track as in the BAU scenario, renewable energy will make moderate progress in the region, mostly driven by hydro. Renewable energy other than hydro sees minimum progress.
- Second, imposing carbon costs without EMI would greatly help the development of non-hydro renewables but only give moderate help to hydro.
- Third, EMI which enables cross-border power trade in the region would significantly boost the development of hydro, but cannot help non-hydro as compared to the carbon costs only scenario.
- Fourth, in terms of additional costs to achieve more renewable energy development, the BAUCCEMI scenario incurs less cost but adds much more renewable energy capacity than the carbon costs only scenario (BAUCC). The beneficial impact of EMI is evident.

- Fifth, for the FIT and RPS scenarios that are in addition to the implementation of carbon costs and EMI, the stronger the policy is, the more progress in renewable energy development would be made.[2]
- Sixth, the RPS30 by 2030 scenario does not seem to be better than the original RPS30 scenario that assumes the implementation of RPS requirement from 2020 onwards. It incurs less additional costs but achieves less carbon emissions reduction as well as newly added renewable energy capacities. The scenario is a marginal improvement compared to BAUCCEMI scenario.
- Seventh, the combined policy scenario, FIT10 RPS10, looks not much different than FIT10. RPS10 seems not to have much impact on the results but adds administrative complexity to the policy.

The comparison of effectiveness of FIT and RPS presents noticeable implications. Since FIT and RPS are two policies of very different nature – one is a subsidy and the other is a regulation standard, it is difficult to draw such implications from Table 3 directly. However, the resulting impacts of the two types of policies could be compared. It is especially interesting and useful to look at the incurred additional costs and the additional capacity development for renewable energy. The following table and figures are developed to facilitate the comparison.

Table 4 estimates percentage change of each FIT and RPS scenario in total costs and newly added renewable energy capacities, as compared to the baseline scenario with carbon costs and EMI only (BAUCCEMI). According to this table, for similar increases in total costs, FIT policies are more effective in reducing carbon emissions and promoting the development of renewable energy. Such is more obvious in Figure 2 to Figure 4.

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[2] RPS policy imposes restrictions on the share of electricity generated from renewable sources (in MWh terms) rather than the share of renewable power generation capacities (in MW terms). A stricter RPS not only encourages the development of more renewable power generation capacities, but also encourages higher utilization of the renewable power generation capacities built.

Table 4: Percentage Changes in Costs and Newly Added Renewable Energy Capacities under FIT and RPS

Scenarios	% Decrease in Carbon Emissions	% Increase in RE Capacity Added	% Increase in RE Capacity Added w/o hydro (MW)	% Increase in Cost
FIT10	18%	37%	85%	0.21%
FIT20	32%	55%	146%	0.78%
FIT30	51%	69%	260%	2.73%
FIT40	63%	83%	299%	5.01%
FIT50	72%	114%	350%	8.01%
RPS10	1%	1%	4%	0.01%
RPS20	5%	6%	32%	0.10%
RPS30	11%	9%	47%	0.28%
RPS40	19%	20%	94%	0.74%
RPS50	27%	28%	132%	1.39%
RPS60	36%	52%	178%	2.35%
RPS70	45%	113%	315%	4.17%
RPS30 by 2030	3%	7%	38%	0.03%
FIT10 RPS10	18%	37%	85%	0.21%

Source: Estimations based on Table 3.

Figure 2: FIT vs. RPS in Carbon Emissions Reduction

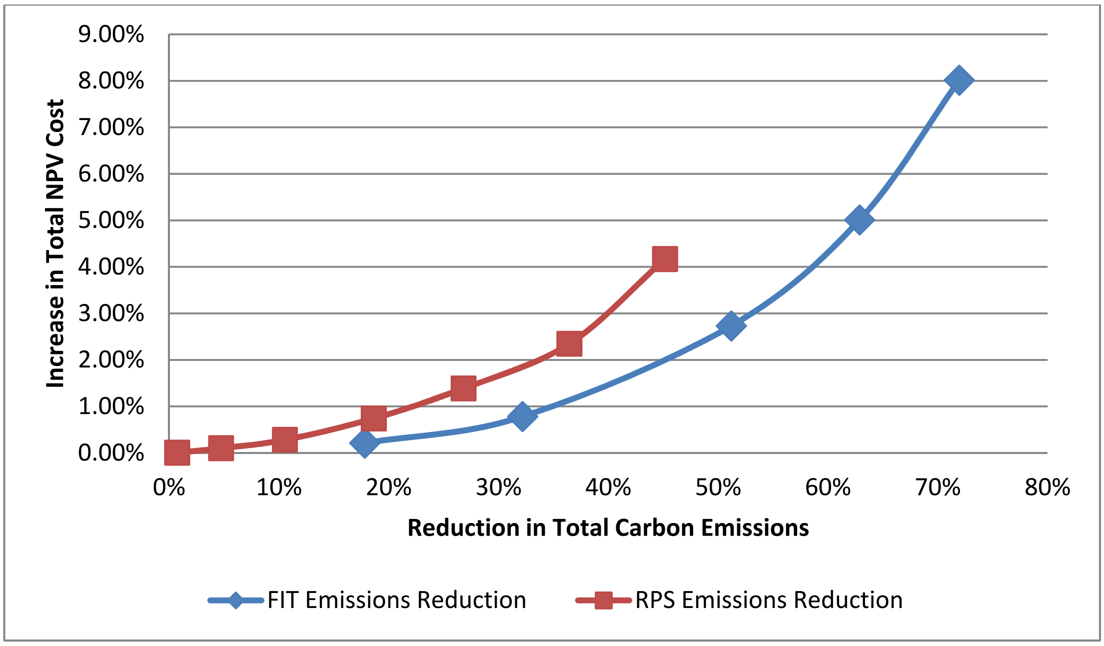


Figure 3: FIT vs. RPS in Increasing Renewable Energy (RE) Capacities

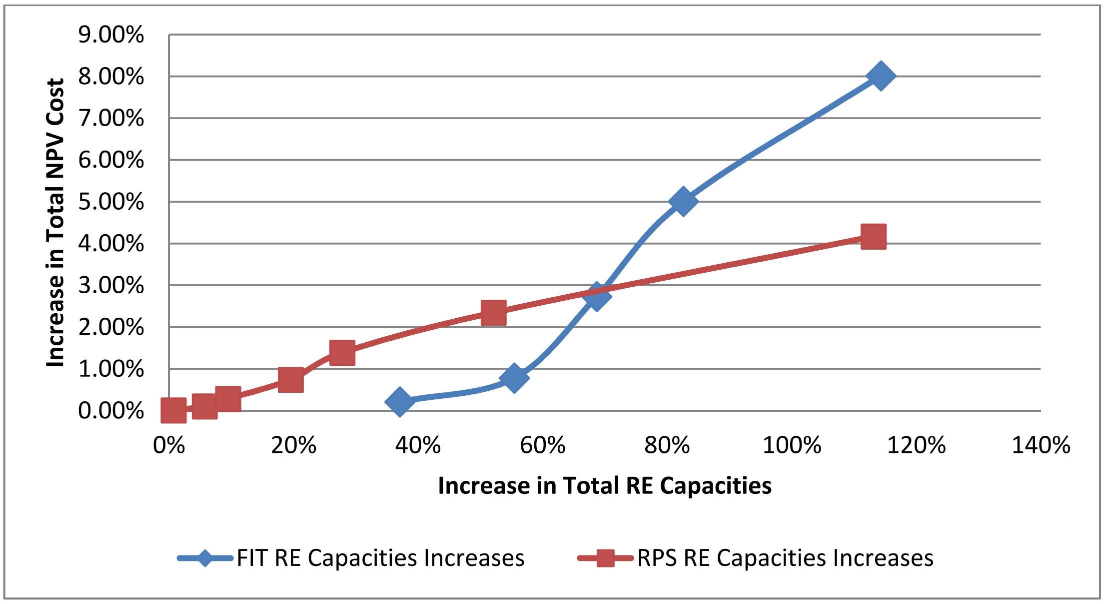


Figure 4: FIT vs. RPS in Increasing Renewable Energy (RE) Capacities (Excluding Large Hydro)

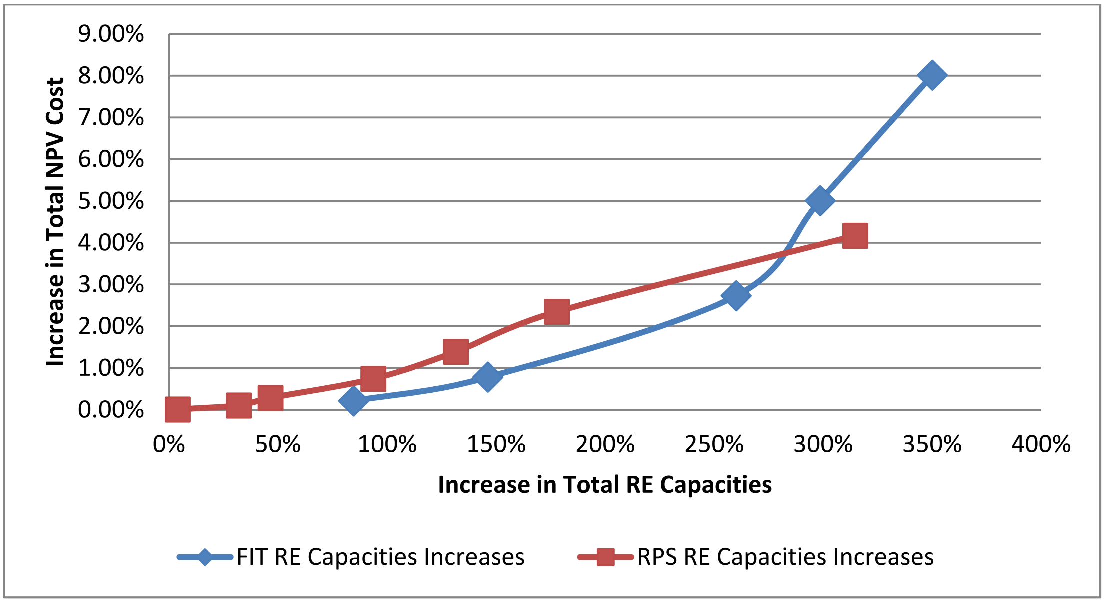


Table 4 and Figures 2 to 4 lead to the following important observations.

- First, in all simulated scenarios FIT performs better than RPS, as the curves of FIT in Figure 2 to Figure 4 constantly stay above those of RPS, except when RPS is raised to an unrealistic level of 70%. This means that for the same percentage of additional costs incurred, FIT achieves both more carbon emissions reduction and more additional capacity of renewable energy.

- Second, with up to 20% of increase in total costs in FIT scenarios, which is most likely acceptable in reality to policy makers and to the public, all curves appear to present diminishing marginal return to additional costs. (Diminishing marginal return means the rate of change in the target measurement is lower than the rate of change in costs.) Namely, as additional costs increase, the speed of increase in carbon emissions reduction and the capacity for renewable energy decrease.
- Third, within the above mentioned range, there exists a point at which the curve is tangent to a 45 degree straight line. Before this point, 1 percent increase in total costs incurs more than 1 percent increase in carbon emissions reduction or capacity of renewable energy. After this point, it incurs less than 1 percent increase in carbon emissions reduction or capacity of renewable energy. Theoretically, this point represents the optimal (or efficient) amount of additional cost for the society to invest and subsequently achieve carbon emissions reduction or renewable energy development.
- Perceived as practical and favourable policies under the current situation, RPS30 by 2030 seems to be a low-hanging fruit to achieve certain carbon emissions reduction and the development of renewable energy capacities. More stringent policies are needed subsequently to achieve meaningful impacts.
- The combined policy of FIT10 RPS10 appears to have the same impact as FIT10.

Unit Cost of Carbon Emissions Reduction and Additional Renewable Energy Capacity

It is also interesting to look at the unit cost of additional reduction in carbon emissions and additional renewable energy capacity for each of the FIT and RPS scenarios. Table 5 presents the calculations derived from Table 3 for this purpose.

Table 5: Unit Cost of Carbon Emissions Reduction and Additional Renewable Energy Capacity for FIT and RPS Scenarios

Scenarios	Unit Cost of Carbon Emissions Reduction (USD/Ton)	Unit Cost of Increases in RE Capacity (Million USD/MW)	Unit Cost of Increases in RE Capacity w/o Hydro (Million USD/MW)
FIT10	2.34	0.15	0.36
FIT20	4.79	0.36	0.77
FIT30	10.54	1.02	1.51
FIT40	15.74	1.55	2.42
FIT50	22.01	1.80	3.30
RPS10	1.71	0.23	0.23
RPS20	4.28	0.46	0.46
RPS30	5.29	0.76	0.87
RPS40	7.85	0.97	1.14
RPS50	10.23	1.28	1.52
RPS60	12.72	1.15	1.90
RPS70	18.24	0.94	1.91

Figure 5 to Figure 7 compare the results for FIT and RPS in Table 5 in pairs.

Figure 5: Unit Cost of Carbon Emissions Reduction

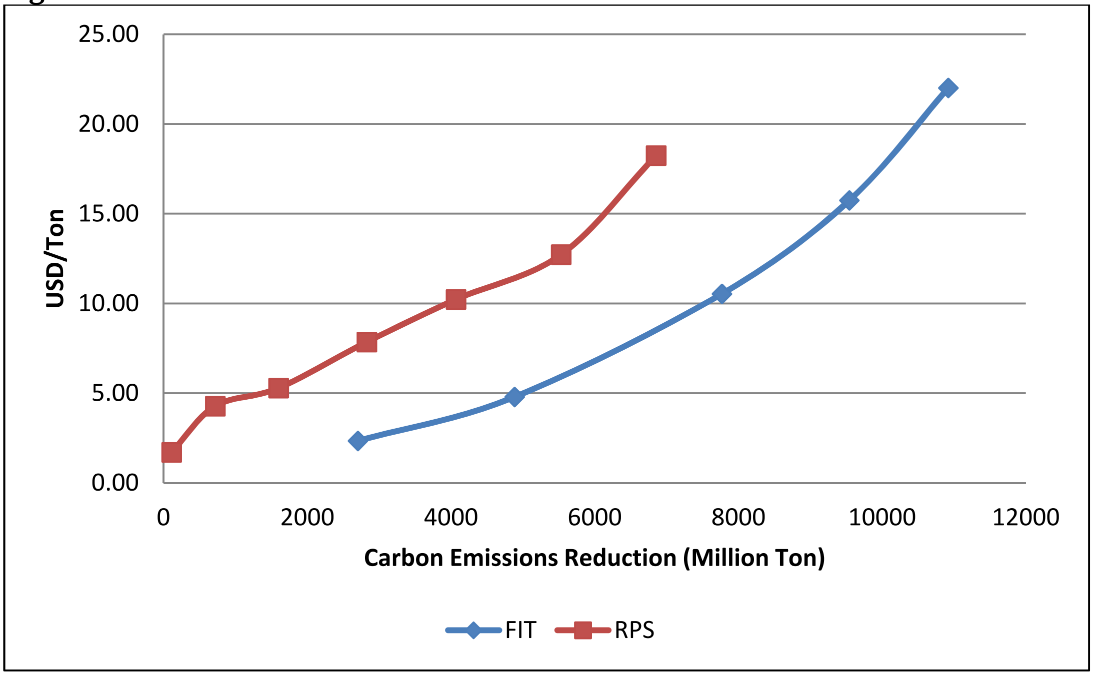


Figure 6: Unit Cost of Additional Renewable Energy Capacity

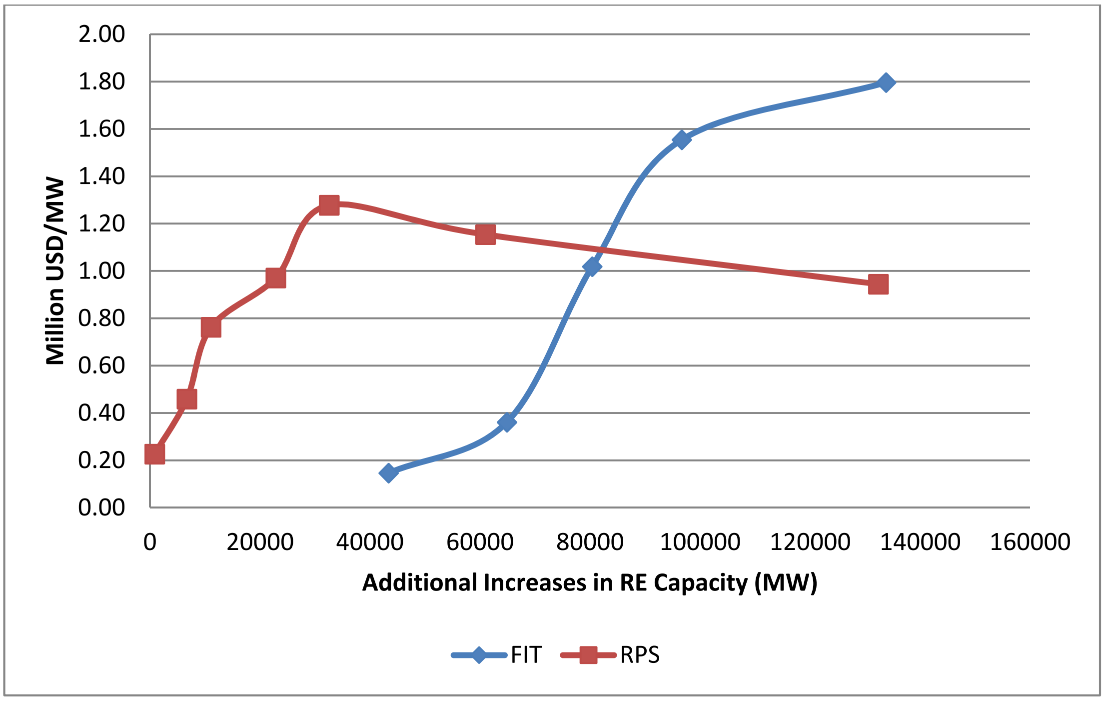
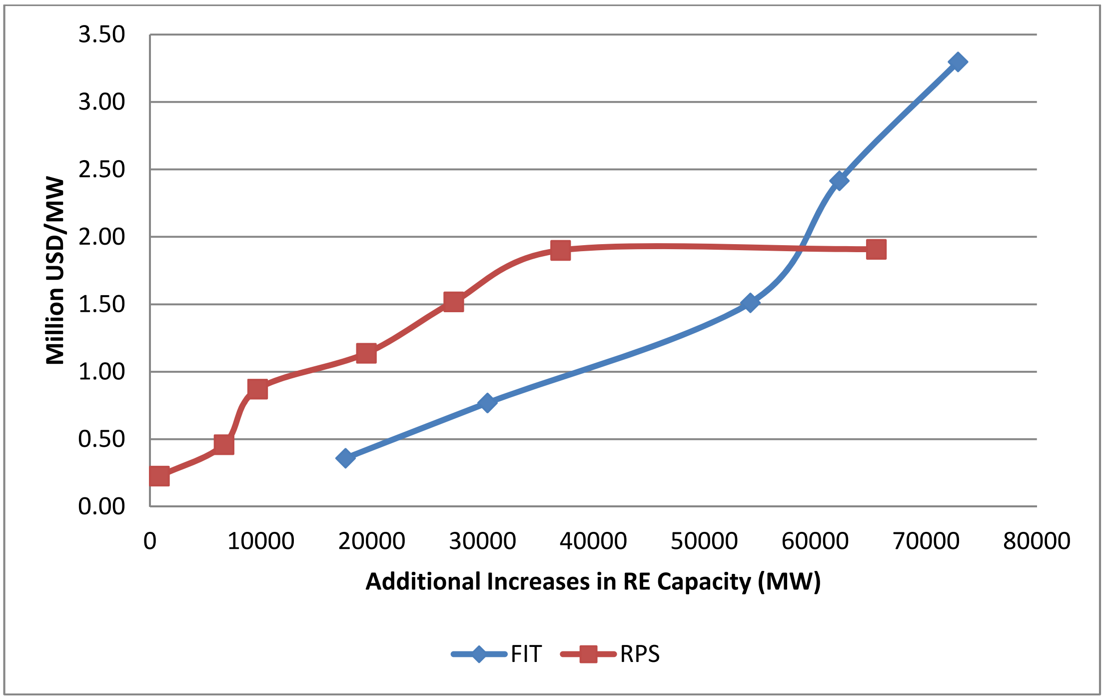


Figure 7: Unit Cost of Additional Renewable Energy Capacity (Excluding Large Hydro)



Two important implications can be derived. First, figure 5 shows that FIT is more cost effective in reducing carbon emissions at any level of total reduction. Second, in terms of cost effectiveness in promoting renewable energy capacities, FIT does better than RPS for most of the time, except when the targeted increase in percentage is exceptionally high.

In general, the above observations echo the empirical findings about the effectiveness of FIT and RPS in the literature. Dong (2012) shows that FIT is more effective in increasing renewable energy capacity than RPS, using multi-country panel data, and that such is consistent with many previous studies. The U.S. National Renewable Energy Laboratory (NREL) reported that properly designed FITs could also be more cost effective than RPS according to European evidence (NREL, 2009).

5. Sensitivity Analysis

Before concluding discussion of the observations drawn in Section 4, we are curious if the exclusion of large hydro would deliver significantly different patterns and observations when the above simulations are repeated. This is an important issue as many parts of the world do exclude large-scale hydro when devising renewable energy policies.

In exploring this possibility as a sensitivity analysis, it is noted that as the region has a limited total amount of renewable resources when large hydro is excluded, and the highest share renewable energy could contribute to total electricity supply from 2020 onwards could only be 14.5%. Therefore, in our sensitivity analysis, RPS scenarios run with requirements from 10% to 14.5%. FIT scenarios remain the same. In all simulations for sensitivity analysis, large hydro is not considered as renewable energy targeted by FIT or RPS. Figure 8 to 10 presents the findings in sensitivity analysis form.

Figure 8: Unit Cost of Carbon Emissions Reduction in Sensitivity Analysis

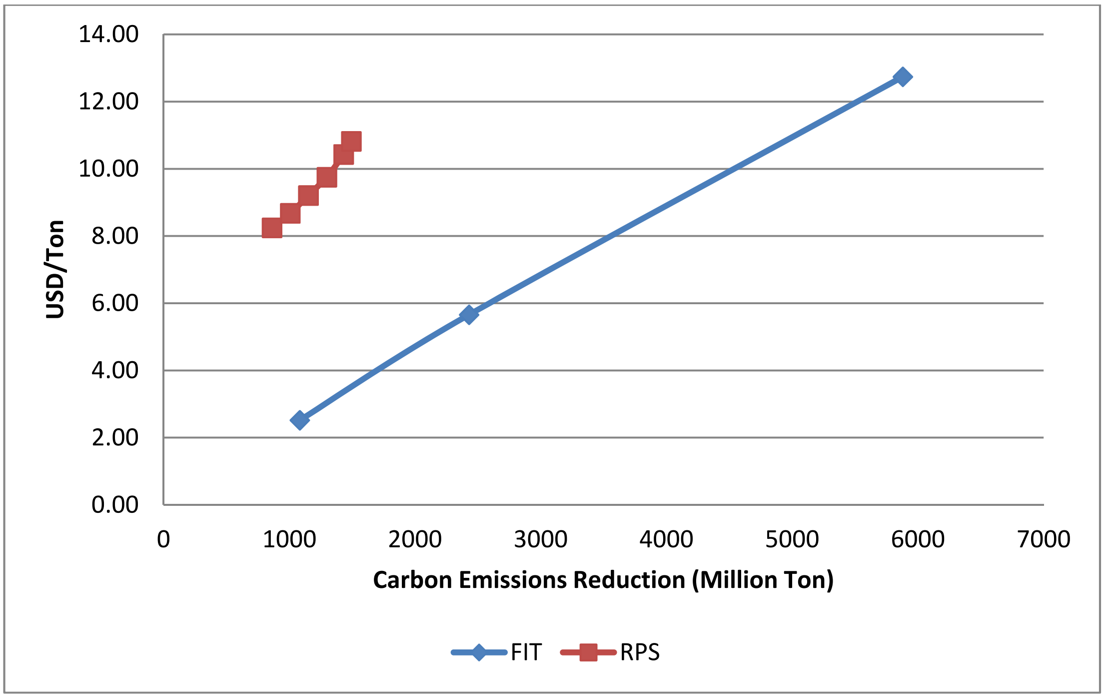


Figure 9: Unit Cost of Additional Renewable Energy Capacity in Sensitivity Analysis

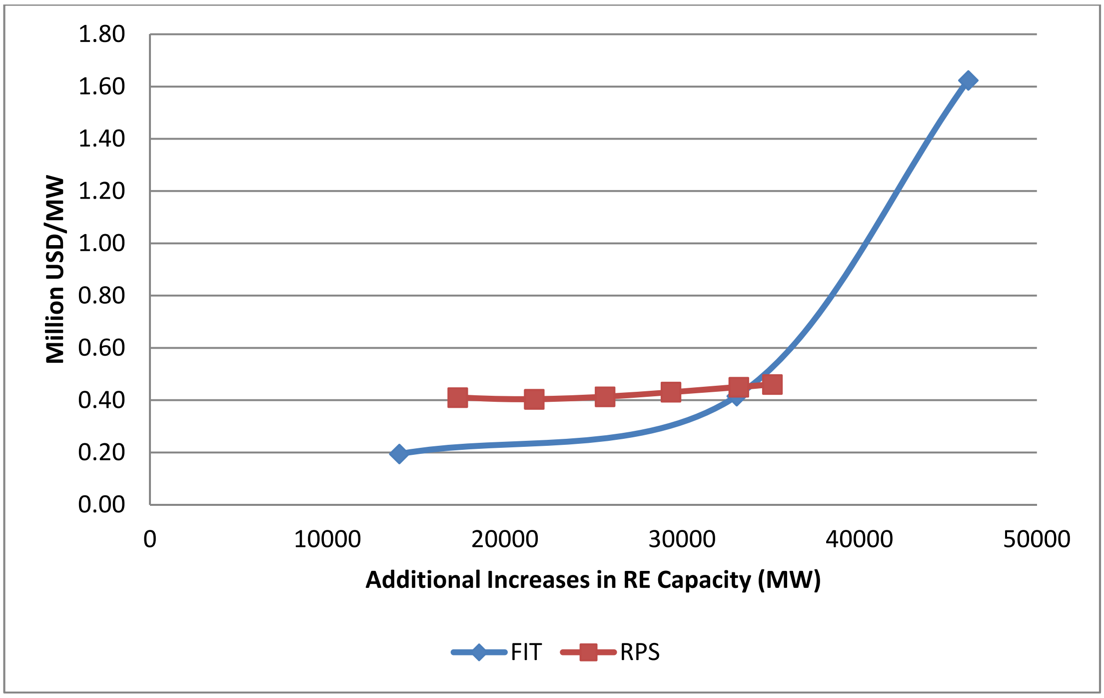
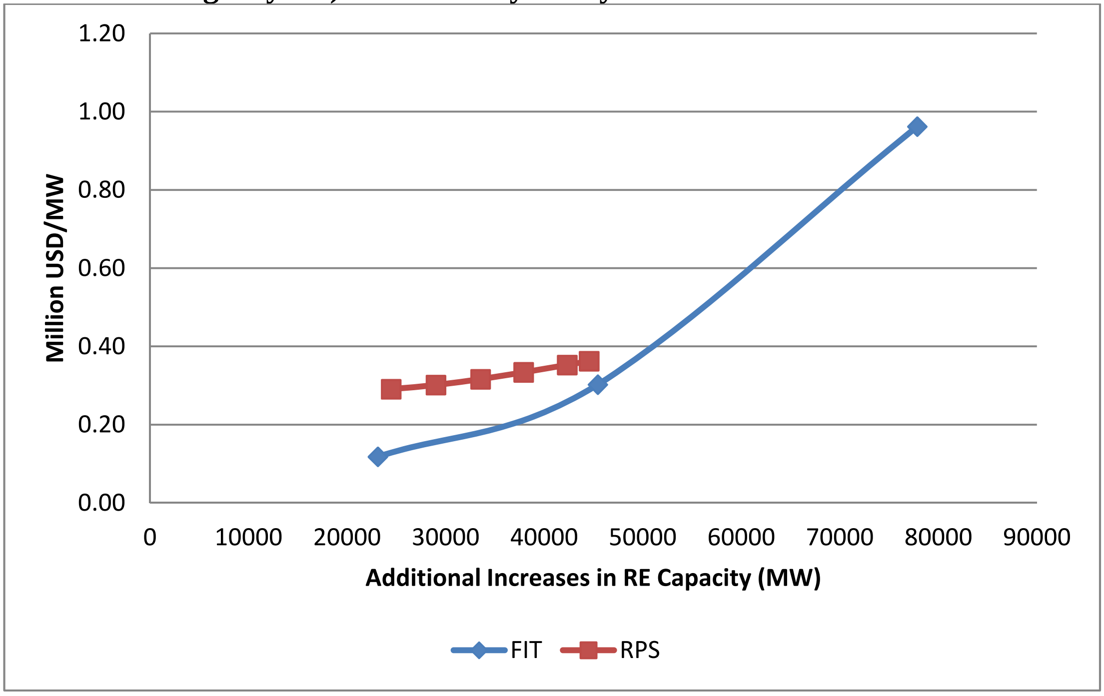


Figure 10: Unit Cost of Additional Renewable Energy Capacity (Excluding Large Hydro) in Sensitivity Analysis



Comparing the three figures (8, 9 and 10) with Figure 5 to 7, no significant pattern shift is observed. Therefore, the effectiveness of FIT and RPS does not seem to be affected by the scope of targeted renewable energy, namely the inclusion or exclusion of large hydro.

6. Conclusions and Policy Implications

This study investigates the impacts of various policy regimes on the development of renewable energy in the power sector of the region. These policy regimes include carbon pricing, EMI, FIT and RPS. A linear dynamic programming model is applied to quantitatively simulate and assess these policy scenarios.

Results from simulations deliver several important implications on these policy options, which are summarized as follows.

- With no changes in the current policies of countries in the region, in the business-as-usual (BAU) scenario, renewable energy will make moderate progress in the region, mostly driven by hydro.

- Imposing carbon costs without EMI would greatly help the development of renewable energy but only give a moderate help to that of hydro. This is because many countries in the region that need more electricity in the future do not have enough potential of hydro as a low-carbon energy source so that they will be forced to choose non-hydro renewable energy.
- EMI is the low-hanging fruit by implementing which the region not only achieves lower total costs in meeting the growing demand for electricity in the next two decades, but also significantly promotes the adoption of renewable energy.
- EMI enabled cross-border power trade in the region will significantly boost the development of hydro, but will not provide so powerful a boost for non-hydro renewable energy. This is because hydro is the cheapest energy for power generation.
- Moving ahead, FIT is theoretically a better choice than RPS according to our model. In reality, the administration costs for implementing FIT may be a concern. As FIT or RPS scales up to higher subsidy or proportion levels, additional effects on the promotion of renewable energy and reduction of carbon emissions decline. Our results suggest that a policy that increases total costs up to 10% is more efficient for the purposes discussed above, as within this range a 1% increase in total cost incurs more than 1% additional achievement in the targeted effects.
- Implementing RPS30 by 2030 is a reasonable choice as the low-hanging fruit if policy makers perceive it as more practically implementable. It achieves moderate improvements in carbon emissions reduction and renewable energy development while incurring negligible increases in total cost of electricity.
- Sensitivity analysis shows that the above conclusions are not affected by the inclusion or exclusion of large hydro as targeted renewable energy by FIT or RPS.

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Appendix A. The Original Model

CAPEX

The following models the capital expenditure (CAPEX) of a certain type of power generation capacity at a certain point of time. Let x_{miv} be the capacity of plant type *m*, vintage *v*,[3] in country *i*.[4] And c_{miv} is the corresponding capital cost per unit of capacity of the power plant. So the total capital cost during the period of this study would be $\sum_{i=1}^{I}\sum_{v=1}^{T}\sum_{m=1}^{M} c_{miv} * x_{miv}$. (In GAMS code, for consistency in presentation with the other cost terms, we add a time dimension to the equation besides the vintage dimension. By doing that, we amortize capital cost using a capital recovery factor).

OPEX

The following models the operational expenditure (OPEX) of a certain type of power generation capacity at a certain point of time. Let u_{mijtvp} be power output of plant *m*, vintage *v*, in year *t*, country *i*, block *p* on the load, and exported to country *j*. Let F_{mitv} be the corresponding operating cost which varies with *v*, and θ_{jp} be the time interval of load block *p* within each year in the destination country. *Opex*(*t*) in year t is expressed as $\sum_{i=1}^{I}\sum_{j}^{J}\sum_{v=-V}^{t}\sum_{p=1}^{P}\sum_{m=1}^{M} F_{mitv} * u_{mijtvp} * \theta_{jp}$.

Carbon Emissions

The model considers carbon emissions of different types/technologies of power generation capacity and takes the cost of carbon emissions into consideration. Let ce_m be the carbon emissions per unit of power plant capacity of type *j* plant, and cp_t be the carbon price per unit of carbon emissions in year *t*. The amount of carbon emissions produced are expressed as $\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{v=-V}^{T} u_{mijtvp} * \theta_{jp} * ce_m$, and carbon cost in year *t* is $CC(t) = cp_t * (\sum_{m=1}^{M}\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{v=-V}^{T} u_{mijtvp} * \theta_{jp} * ce_m)$.

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[3] Vintage indicates the time a certain type of capacity is built and put into use.

[4] This variable represents investment in new power generation capacity. Investment is considered done once the power generation facility has been constructed and not at the moment when investment decision is made and construction commences

Cross-border Transmission Cost

The costs of cross-border transmission come in two forms. One is the tariff paid to recover the capital investment and operational cost of the grid line. The other is the transmission loss, which could be significant if the distance of transmission is long. To model the tariff of transmission, let $tp_{i,j}$ be the unit MWh transmission cost of power output from country *i* to country *j*. Let *TC*(*t*) be the total cost of cross-border power transmission in year *t*, we have $TC(t) = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{v=-V}^{T} \sum_{p=1}^{P} u_{mijtvp} * \theta_{jp} * tp_{i,j}$.

Objective Function

As discussed earlier in the methodology section, our objective is to minimize the total cost of electricity during the period of this study. The objective function is written as:

$$obj = \sum_{i=1}^{I} \sum_{v=1}^{T} \sum_{m=1}^{M} c_{miv} * x_{miv} + \sum_{t=1}^{T} \{Opex(t) + CC(t) + TC(t)\} \qquad (1)$$

Constraint Conditions

Optimizing the above objective function is subject to the following constraints. Equation (2) shows a first set of constraints, which require total power capacity to meet total power demand in the region. Let Q_{itp} be the power demand of country *i* in year t for load block *p*.

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{m=1}^{M} \sum_{v=-V}^{t} u_{mijtvp} \geq \sum_{i=1}^{I} Q_{itp} \qquad (2)$$

The second one, shown in equation (3), states the constraint of load factor lf_{mi} of each installed capacity of power generation. Let kit_{mi} be the initial vintage capacity of type *m* power plant in country *i*.

$$u_{mijtvp} \leq lf_{mi} * (kit_{mi} + x_{miv}) \qquad (3)$$

The third constraint, shown in equation (4), says that power supply of all countries to a certain country must be greater than the country’s power demand. Let $tl_{i,j}$ be the ratio of transmission loss in cross-border electricity trade between country *i* and country *j*.

$$\sum_{j=1}^{J}\sum_{m=1}^{M}\sum_{v=-V}^{t} u_{mijtvp} \cdot tl_{ij} \ge Q_{itp} \tag{4}$$

Equation (5) states that total supply of power of one country to all countries (including itself) must be smaller than the summation of the country’s available power capacity at the time.

$$\sum_{j=1}^{J} u_{mijtvp} \le \sum_{m=1}^{M}\sum_{v=-V}^{t} lf_{mi} * (kit_{mi} + x_{miv}) \tag{5}$$

The fifth constraint, shown in equation (6), is capacity reserve constraint. Let pr be the rate of reserve capacity as required by regulation. And let $p = 1$ represent the peak load block.

$$\sum_{i}^{I}\sum_{m=1}^{M}\sum_{v=-V}^{t} lf_{mi} * (kit_{mi} + x_{miv}) \ge (1 + pr) * \sum_{i}^{I} Q_{it,p=1} \tag{6}$$

Specially, hydro-facilities have the so-called energy factor constraint as shown in equation (7). Let ef_{mi} be the energy factor of plant type *m* in country *i*. Other facilities will have *ef*=1.

$$\sum_{p=1}^{P}\sum_{j=1}^{J} u_{mijtvp} \le ef_{mi} * (kit_{mi} + x_{miv}) \tag{7}$$

Lastly, development of power generation capacity faces resource availability constraint, which is shown in equation (8). Let $XMAX_{mi}$ be the type of resource constraint of plant type *m* in country *i*.

$$\sum_{v=1}^{T} x_{miv} \le XMAX_{mi} \tag{8}$$

Appendix B. The Data Inputs

Table B1: Existing Power Generation Capacity of ASEAN Countries (Base year 2009, Unit: MW)

	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Coal	0	0	12203	0	9068.4	0	5584.4	0	10719.2	3301.7
Coal CCS	0	0	0	0	0	0	0	0	0	0
Diesel	5.8	372	3328	50	685.4	279.08	1330.4	2511.2	269.3	580.5
Natural Gas	753	0	10929	0	13380.2	980.92	3387.2	7934.8	32088.6	5795.9
Natural Gas CCS	0	0	0	0	0	0	0	0	0	0
Hydro	0	13	4872	1805	2107	1460	3291	0	3488	5500
Small Hydro	0	1.87	21	7.8	0.1	39.7	151.3	0	128	75
Geothermal	0	0	1189	0	0	0	1953	0	0.3	0
Wind	0	0	1	0	0	0	33	0	0.4	8
Solar PV	0	0	0	0	0	0	1	0	10	0
Biomass	0	5.78	0	0	0	0	0	20	800	0

Sources: EIA website, IEA website, and Energy Studies Institute (2012)

Table B2: CAPEX, OPEX, Life, and Availability of Power Generation Assets

	Coal*	Coal CCS	Diesel	Natural Gas	Natural Gas CCS	Hydro**	Small Hydro	Geothermal	Wind	Solar PV	Biomass
CAPEX (Million USD/MW)	2.079	4.925	1.139	1.054	2.27	4.933	2.3	6.18	2.187	5.013	4.027
OPEX (USD/MWh)	31.86	37.6	229.75	43	46.87	4.32	4.68	14.23	20.58	19.52	28.87
Life (Years)	40	40	30	30	30	80	50	30	25	25	25
Load Factor (Percentage of A Year)	0.85	0.85	0.85	0.85	0.85	0.9	0.9	0.95	0.3	0.11	0.85

Sources: IEA (2010) and EU SEC (2008)

* Due to the consideration of abundance in coal resources, countries including Indonesia, Malaysia, Thailand, and Vietnam are assumed to have 30% lower CAPEX and OPEX in coal-fired power generation.

** Due to the consideration of abundance in hydropower resources, countries including Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, and Philippines are assumed to have 30% lower CAPEX and OPEX in hydropower generation.

Table B3: Energy Resources for Power Generation in ASEAN Countries (Unit: MW)

	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Coal	15000	15000	50000	15000	50000	30000	30000	15000	50000	50000
Diesel	15000	15000	15000	15000	15000	15000	15000	15000	15000	15000
Natural Gas	15000	15000	50000	15000	50000	30000	30000	30000	50000	50000
Hydro	0	10300	75459	18000	29000	0	13097	0	700	2170
Small Hydro	0	300	493	48.8	20.4	231	1287	0	556	1800
Geothermal	0	0	27000	0	67	930	2379	0	5.3	270
Wind	0	452	7404	1600	452	1600	7404	0	1600	452
Solar PV	115	3771	37800	4538	6192	12967	6336	130.7	300	10321
Biomass	0	700	49810	0	29000	4098	200	50	7000	400

Sources: Lidula, *et al*. (2007) and WEC Survey of Energy Resources 2010.

Table B4: Power Demand and Duration of the Demand in ASEAN Countries

	Brunei	Cambodia	Indonesia	Lao PDR	Malaysia	Myanmar	Philippines	Singapore	Thailand	Vietnam
Peak Demand (MW)	454.7	291	23438	350	12990	1140	8766	5711	22586	11605
Peak Duration (Hours)	4681.7	4925.2	4681.7	4745	4681.7	2428	4015	5840	4015	2428
Non-peak Demand (MW)	257	85	5338	60	8388	162	3394	1324	8692	6862
Non-Peak Duration (Hours)	4078.3	3834.8	4078.3	4015	4078.3	6332	4745	2920	4745	6332

Sources: HAPUA website; Center for Data and Information on Energy and Mineral Resources, Handbook of Energy & Economic Statistics of Indonesia 2011; Electricite du Laos, Annual Report 2010; and Zhai (2008, 2009).

Table B5: Transmission Loss and Cost among ASEAN Countries

		Transmission Loss (%)	Transmission Cost ($/MWh)
Distance*	0-1600 km	0.01	3
	>1600 km	0.087	5
	>3200 km	0.174	7.5

Sources: Claverton Energy Research Group http://www.claverton-energy.com/

* Distance is estimated as the distance between Capital cities of countries.

Table B6: Carbon Emissions Coefficient for Different Power Generation Technologies

	Coal	Coal CCS	Diesel	Natural Gas	Natural Gas CCS	Hydro	Small Hydro	Geothermal	Wind	Solar PV	Biomass
Carbon Emissions (Ton per MWh)	1.0	0.1	0.8	0.5	0.038	0.001	0.001	0.05	0.01	0.05	0.05

Source: Authors’s estimation based on Varun, *et al*. (2009) and EU SEC (2008)

Table B7: Projected Cost of Carbon Emissions Right in ASEAN

Year	Cost of Carbon Emissions Right (USD/Ton)	Year	Cost of Carbon Emissions Right (USD/Ton)
2012	0.97	2025	3.51
2013	1.07	2026	4.12
2014	1.82	2027	1.03
2015	3.56	2028	0.10
2016	3.19	2029	0.06
2017	3.74	2030	1.18
2018	0.93	2031	1.29
2019	0.09	2032	2.20
2020	0.05	2033	4.31
2021	1.07	2034	3.86
2022	1.18	2035	4.53
2023	2.00		
2024	3.92		

Source: Authors' assumptions by referring to the patterns of the U.S. Chicago Climate Exchange historical prices of carbon emissions right, which is available at https://www.theice.com/ccx.jhtml.

Appendix C. List of Key Findings of This Study

- Without any policy intervention and following the current track as in the BAU scenario, renewable energy will make moderate progress in the region mostly driven by hydro. Renewable energy other than hydro sees minimum progress.
- EMI that enables cross-border power trade in the region significantly boosts the development of hydro. The BAUCCEMI scenario incurs less cost but adds much more renewable energy capacity than the carbon costs only scenario (BAUCC). The beneficial impact of EMI is evident.
- For the FIT and RPS scenarios that are built in addition to the implementation of carbon costs and EMI, the stronger the policy is, the more progress in renewable energy development would be made.
- In all simulated scenarios, FIT performs better than RPS. This means that for the same percentage of additional costs incurred, FIT achieves both more carbon emissions reduction and more additional capacity of renewable energy.
- With up to 20% of increase in total costs in FIT scenarios, which is most likely acceptable in reality to policy makers and to the public, both carbon emissions reduction and increases in additional renewable energy capacities present diminishing marginal returns to additional costs. Namely, as additional costs increase, the speed of increases in carbon emissions reduction and capacity of renewable energy decreases. Therefore, there exists a point that represents the optimal amount of additional costs for the society to invest and subsequently achieve carbon emissions reduction or renewable energy development.