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Large-Scale Renewable Energy Deployment in Developing Countries: Opportunities to address the energy trilemma of the Philippines' electricity industry

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Abstract

There is growing interest in how large-scale RE deployment can assist developed countries address climate change impacts. For developing countries, however, the focus is naturally more on security and equity goals rather than environmental sustainability. What does renewable energy (RE) offer developing countries that are still struggling with energysecurity and the challenges of providing access to modern energy services?

Large-scale renewables including wind and solar are falling in cost, but do raise some challenges for ensuring the continued high levels of reliability now enjoyed in developed countries, whilst effectively competing against existing conventional plants in wholesale electricity markets. In developing countries, electricity industries face significant challenges in providing access and security given growing demand, insufficient capacity, and funding constraints. The study presented in this paper seeks to understand how the greater integration of renewables into the Philippines grid might assist in achieving these goals, as well as environmental objectives.

The study uses the National Electricity Market Optimiser (NEMO) model to quantify the potential contribution of renewables towards reducing costs, improving reliability and reducing the present fossil fuel dependence of the Philippines electricity industry up to 2030, given the country's renewable energy resources, access to fossil fuels, possible future climate goals and existing generation and network assets. Conventional approaches prioritising energy security and access would likely continue to rely primarily on fossil fuels and risk locking the country into a highly carbon-based development path. This research, however, shows that renewables can potentially reduce generation costs and improve the currently low levels of reliability and security delivered by the Philippines grid whilst also reducing climate change emissions.

Keywords: flexibility, high renewables penetration, trade-offs, developing countries

1. Introduction

The Philippines, similarly to many other low-income countries, emerged from the colonial era with a formal economy focused primarily in capital cities (MacAndrews & Sien, 1979). Imbalance in access to energy services between growth centres and rural areas remains in many developing countries today (Urban, 2014). Metro Manila in Luzon Island consumes around 80% of the country's total electricity (with ~9 GW peak load), while only around 10% (~1.5 GW peak) is consumed by the other island groups of Visayas and Mindanao (DOE & WESM, 2016). Although per capita carbon emissions are very low (~0.80 tCO_2 per person) compared to the OECD average (~10 tCO_2), the Philippines has historically had a carbon-intensive electricity sector with around 70% of the generation capacity mix being fossil fuel generators (~44.5% coal-fired generators, ~22.9% CCGT, and ~14.2% diesel (or bunker fuel)-fired generators) (DOE & IEA, 2016). However, there is also large-scale hydro-electric (~21% of total installed capacity) and geothermal plants (~11.5%) renewable energy (RE) capacity in the mix. This actually makes the Philippines a top ranking country in the area of environmental sustainability according to the sustainability benchmarking of national energy systems by the World Energy Council (2016). Overall, however, the country is ranked 61, excelling in the environmental aspect but lagging in the areas of security and equity (WEC, 2016). It suffers from power supply shortages, causing on average 2-3 hours daily power interruption in urban centres and around 8-12 hours in many rural areas. In terms of energy access, the Philippines has a 94% electrification rate in urban areas and 67% in rural areas (IEA 2016). The country does not directly subsidise electricity consumption, making its electricity price twice the average price in the ASEAN region (Mundo, 2016).

The Philippines must address security of supply and improve access to electricity in rural areas, yet at the same time, manage growing demand for electricity due to increased industrialization, population growth, and use of electricity for a broader range of applications such as cooking, heating and transport. If coal power plants were used to meet the projected 2030 demand, carbon emissions would rise sharply to 65 Million $TCO_{2\text{-eq}}$. This scenario would lock the country into a highly carbon-intensive development path, which has created the present climate mitigation challenges of many developed industrialised countries. TheNational Renewable Energy Board (NREB) of the country's Department of Energy (DOE)(2012) instead aims to triple the contribution of renewable energy (~15.3 GW) in the generation mix by 2030 from a 2010 base (5,369 MW). While not explaining the basis for the projections, NREB projects additional capacity of 3.5 GW geothermal, 8.7 GW hydro-electric, 0.31 GW biomass, 2.4 GW wind, 0.285 GW solar, 70 MW ocean power as interim targets (Rowland, 2016).

This paper explores the potential implications of high RE scenarios for developing countries to meet the seemingly conflicting trilemma energy policy goals of energy equity, security and environmental sustainability, through a case study of the Philippines electricity industry to 2030. It also quantifies the level of system flexibility that is likely to be required to integrate high shares of variable renewables, notably wind and solar, in such a future electricity industry. The paper is structured as follows: Section 2 describes how the trilemma goals and the flexibility requirement of a high RE penetration will be quantified in this paper. Section 3 provides an overview of the optimization model used. Section 4 presents the results and discusses some of the characteristics of the power system that can best support a high penetration of variable renewable energy. Section 5 provides the conclusion, further work and policy recommendations for the Philippine electric power industry.

2. Quantifying energy sustainability: energy equity, energy security and environmental sustainability

The Sustainable Development Goals (SDGs) of the United Nations Development Programme set a post-2015 development agenda that includes a target for achieving an affordable, reliable and clean energy for all. This paper will use the three dimensions used by the World Energy Council to define energy sustainability: energy equity, energy security and environmental sustainability. In this paper, ‘energy equity’ is considered to mean access to affordable energy of appropriate quality, while ‘energy security’ is a function of reliability and resiliency of power supply and ‘environmental sustainability’ is focused on global warming impacts. The following metrics are used to quantify these different aspects of the energy trilemma: cost ($/MWh) is an indicator of energy affordability, unserved energy (% TWh) is an indicator of energy security and CO_2 emissions (tonnes) is an indicator for environmental sustainability.

3. Methodology

3.1. *NEMO Model overview*

The National Electricity Market Optimiser (NEMO), developed by Ben Elliston at the Centre for Energy and Environmental Markets in the University of New South Wales, (Elliston, et al 2014) was used to determine possible least-cost generation mixes for the Philippine Electricity System to 2030 (as per Equation 1).

$$\text{Generation cost} = \sum \text{Capital cost } (t, r) + \sum \text{Operational cost } (t, r)$$
$$\text{, where } t \text{ is the plant life and } r \text{ is the discount rate} \quad (1)$$

NEMO uses a genetic algorithm to find a least cost solution, and outputs a range of measures of cost, reliability and efficiency of the electricity system, including: installed capacity, energy supplied, capacity factor, annualized capital cost, operational cost and Levelised Cost of Energy (LCOE) for each of the simulated generating plant; and system level information on renewable energy spilled annual total hours with surplus energy, emissions, reserves available, unserved energy (USE), unserved total hours and total number of unserved energy events per year for the overall power system.

The tool can consider both existing as well as a range of potential new generation options – renewable as well as fossil fuel and nuclear. Both operating and investment costs can be included. Operating costs include variable O&M, fuel cost and potentially a carbon price. Capital costs in $/MW/year are estimated using the capital recovery factor CRF as shown in equation 2. Note that a 5% discount rate is assumed for capital expenditure. Fixed O&M costs are also expressed in $/MW/year. LCOE estimates can include these capital costs by allocating all capital and fixed O&M costs across actual annual generation. For existing generators, it is commonly assumed that the capital costs are ‘sunk’ and hence not relevant to estimating lowest cost future generation mixes. The LCOE estimates for existing plant, therefore, do not incorporate capital costs.

$$CRF = r(1+r)^t/[(1+r)^t-1]$$
$$\text{, where } t \text{ and } r \text{ are the same in equation 1} \quad (2)$$

3.2. Model inputs

For modeling of the Philippine electricity system, the 2030 hourly demand that is used in this paper is based on the 2015 load demand profile provided by WESM linearly grown to a conservative 40% projection of demand (TWh) in 2030. Reliability (USE), demand growth, non-synchronous generation penetration limits, fossil-fuel generation limits, regional generation limits, and limits for bioenergy, geothermal and hydro-electric resource are all constraints in the optimization. Renewable energy generation technology costs are derived from IRENA (2015) estimates. Technology costs for fossil fuel generators are derived from estimated costs in China and/or Indonesia. The prices for fossil fuels are derived from local (Semirara company) and international (Indexmundi) sources and average price over 20 years were used projected at 2.3% fuel inflation rate for 2030 (World Bank, 2014).

3.3. Scenario selection

For this paper, the identification of scenarios to explore the implications of high penetrations of renewable energy on the trilemma goals was based on the generation technology mix in 2030 with high penetration of renewables added on the existing generations (specifically using the coal, hydro and geothermal capacities of each of the grid) in 2015 at a reliability level approximated at a 1% USE – an estimate that falls within the much higher reliability standards of electricity industries in the developed world (the Australian NEM is 0.002% as an example) and the experienced grid reliability of the Philippines which sees many customers enduring more than an hour of power interruption a day on average. Within the constraints, NEMO will determine a least cost generation mix. To consider the viability of the scenario from the perspective of markets and investment, the scenario that has the highest average capacity factor for the variable generation (solar and wind) and the least spilled energy among the least cost options would be chosen. Although this paper pursues a scenario that is based on end-consumers agenda (i.e. affordability, reliability and emissions), supply-side market and financing questions in a developing country context are equally important (e.g. capacity factor, spilled energy) to be considered in the scenario selection. Superfluous spilled energy for a developing country context would be impractical as the market for power to heat, synthetic fuels and mobility are not yet developed. Those mix with large capacity factors for variable generators (e.g.~20-30% for wind and ~10-20% for solar) are selected to emulate the present trend of investments in developed economies, which would potentially become the trend in developing countries.

4. **Results and analyses**

4.1. Characterisation of the selected scenario ($70.41/MWh, 19.50 Mt CO2 @ 0.998% unserved energy)

Generation cost can significantly decrease to $70.41/MWh from the present average generation charge of ~$150/MWh at an estimated reliability level to 0.998% unserved energy (but noting that this reliability calculation does not incorporate plant or network failure, which is the key driver of USE in developed country electricity industries). This scenario also has lower emission as compared to the present grid emission. A wind capacity of 10.59 GW and a solar PV capacity of 9.08 GW can be integrated into the Philippine electricity grid by increasing the baseload capacity of geothermal generation, augmenting the capacity of pumped hydro storage and increasing the ramping capacity of coal, hydro and CCGT (Table 1). To reduce generation costs while keeping emissions low, reliability levels can be reduced and unserved demand taken off-grid. Increasing the ramping capacity of coal also decreases the cost and allows more variable renewables to be integrated.

To realise this scenario, Table 1 indicates that geothermal power capacity need to be approximately doubled on the Luzon and Visayas grids, while Mindanao needs geothermal capacity five times to the present capacity. Impound hydro capacity should be reduced to 2 GW total capacity: halved for Luzon and Mindanao and reduced by 20% for Visayas. In this scenario Luzon provides most of the wind capacity while both Luzon and Mindanao supply energy from solar PV. CCGT and pumped hydro storage are only located in the Luzon grid, where 80% of the consumption is served. Table 1 shows that there is no need for both diesel and gas turbine fueled by bioenergy. Furthermore, there is no need for a coal power plant in Mindanao and also the scenario does not require new hydro capacity in both Luzon and Mindanao grids. This scenario shows that a mix with high RE penetration (~80%) can lead to a significantly lower generation cost at a reliability level comparatively the same to the present situation of the Philippine electricity grid.

Table 1. Specifications of the selected scenario

			$70.41/MWh, 0.998% USE, 19.50 Mtonne $CO_{2\text{-eq}}$				
			Luzon	Visayas	Mindanao	Total	%
Baseload	Geothermal	Capacity (GW)	1.21	1.34	0.5	3.05	25.73
		Energy (TWh)	10.591	11.765	4.4063	26.7623	
Flexible generation	Hydro	Capacity (GW)	1	0.01	1.04	2.05	11.43
		Energy (TWh)	5.539	0.0696	6.28	11.89	
	Coal	Capacity (GW)	3.6	0.8	-	4.4	16.63
		Energy (TWh)	13.26	4.047	-	17.3	
	CCGT	Capacity (GW)	2.16	-	-	2.16	3.2
		Energy (TWh)	3.336	-	-	3.336	
	Pumped Hydro (η=0.80)	Capacity (GW)	0.80	-	-	0.80	0.65
		Energy-in (TWh)	1.209	-	-	1.209	
		Energy-out (TWh)	0.6715	-	-	0.6715	
Variable RE	Wind	Capacity (GW)	10.59	-	-	10.59	31.32
		Energy (TWh)	32.57	-	-	32.57	
	Solar PV	Capacity (GW)	9.08	-	0.41	9.494	10.62
		Energy (TWh)	10.51	-	0.526	11.04	
Total energy supplied (TWh)			76.48	15.88	11.21	**104**	100%
Regional generation %			73.54	15.27	10.78	100%	

Table 2 shows that: at a comparatively similar expected unserved energy of around 1% of the annual demand, a 79.75% renewables penetration scenario could provide a significantly lower generation cost in comparison to the present (2015) generation mix. This scenario only has ~20% of fossil fuels contribution as compared to the historical of ~70%.

Table 2: System parameters

Unserved energy (TWh)	0.998%
Demand energy (TWh)	104

Unused surplus energy (TWh)	7.4
Total hours per year with unused surplus energy	2267
LOLE (days/year)	2.35
System generation cost ($/MWh)	70.41
System emission (Million Tonne)	19.50
Total hours of outage events per year	847
Number of outage events per year	170
Min-Max shortfall (MW)	(1, 3499)

Figure 1 shows the LCOE of each generator, ordered by capacity factor in the selected scenario, and Figure 2 shows the supply-demand situation during a highly constrained period.

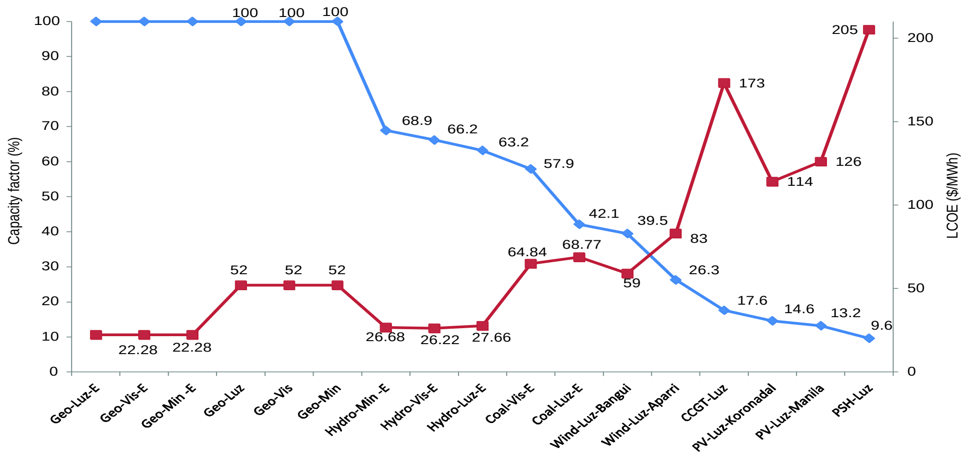

Figure 1: LCOE and capacity factors of generators

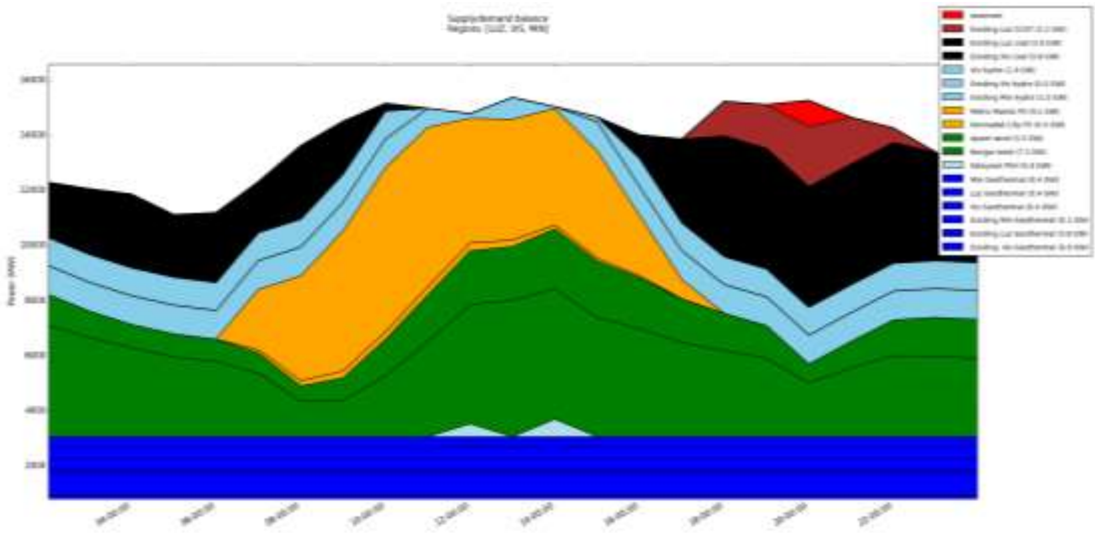

Figure 2. Supply and demand balance during a constrained period on 5 April 2030 (Friday)

4.1. *Required capacities to be built by 2030*

Table 3 compares the installed generation capacity at present and what is needed by 2030 in the optimal scenario. Diesel capacity will be phased out by 2030, coal capacity is reduced (that is, no new coal power plants should be put in the pipeline), impound hydro is also reduced (no need also to construct new impound hydro) but geothermal capacities are approximately doubled.

Table 3. Capacities to be built by 2030 for optimal scenario ($70.41/MWh, 19.50 Mtonne at 0.998% unserved energy)

Generation technologies	Generation capacity (GW)	
	2015	2030
Geothermal	1.9	3
Hydro	3.6	2
Coal	5.9	4.4
CCGT	2.8	2.2
Diesel	3.6	---
Bio-GT	0.05	---
Pumped storage	0.35	0.80
Solar PV	0.304	9.5
Wind	0.40	10.6

4.2. *Comparison with NREB's projected capacities*

Because this optimization does not include ocean technologies (e.g. OTEC), the targets for wind and solar are significantly higher than NREB's. The projected capacity for geothermal is in agreement with NREB's target but the selected scenario shows that there is no need to construct new capacity for gas turbines fueled by bioenergy and impound hydro capacity. However, the scenario shows that the capacity for pumped hydro storage should be increased by 2.3%.

5. Discussion

5.1. *Required flexibility for the selected scenario is already available in the present generation mix*

The results show that greater supply-side flexibility is needed when scenarios with a high proportion of renewables (with the dominance of variable renewables) are optimised. However, the selected scenario shows that the required flexibility for increasing solar PV to 9.5 GW and wind power capacity to 10.6 is already available in the present generation mix. Geothermal and impound hydro can provide the constant generation and load following, respectively, while CCGT and pumped hydro storage can provide the required flexibility, while coal-fired generators would ideally increase their ramping capacities. This may have implications on the present contracts that existing coal-fired generators have as this work suggests, there should be no new coal power plant built to 2030.

5.2. Increased need for pumped hydro storage

The study suggests that existing pumped hydro storage capacity has to be increased by 2.3% from the present capacity in order to achieve the chosen reliability level. Pumped hydro storage can also perform other functions such as short term energy balancing and frequency ancillary services. Its pattern of operation is to charge up during night times and weekends, and generate during high demand on weekdays. The snapshot of the supply-demand balance for a Friday shown in Figure 3 indicates that storage was used in the peak hours of the weekday (i.e. 11am to 3pm). Furthermore, the study suggests that diesel and gas turbines fueled by bioenergy are not part in the selected scenario for 2030.

5.3. Surplus energy management

Surplus energy from solar and wind could provide reserve capacity, although lack of inertia may be a concern if there is not sufficient synchronous generation operating during a contingency event. Table 2 shows that the optimal scenario has a total spilled energy from variable renewables of 7.4 TWh for the whole year and a surplus exists around 25.9 % of the time. This unused surplus energy could provide power for heating to some consumers (who place a high value on electric heating), power for gas production (which can be used for later input to gas turbines), and for electric vehicle charging, such as e-tricycles, which are slowly becoming more common in big cities such as in Metro Manila, Metro Cebu and Metro Davao. Mass transit in Metro Manila could also benefit from this surplus electricity. The market for heat, gas and e-vehicles in the Philippines would need to innovate and become more flexible to access the benefits of this excess energy. As more variable generators are integrated in the generation mix to improve cost, reliability and emission, more spilled energy is expected to occur.

5.4. Synergy of wind and solar PV in conventional power systems

This study suggests that huge volumes of wind and solar power could reduce cost, reduce emissions and could also potentially improve reliability by integrating more pumped hydro storage capacity. Conventional power systems would need to adjust to accommodate this huge volume of variable generation. Geothermal generation and impound hydro could provide baseload generation and load following, respectively, while coal, CCGT and pumped hydro storage could provide the required flexibility. Provision of flexibility is the only future role for coal in a low-carbon future. In order to track toward the solution modeled here, the Philippines should set targets to install around 9.5 GW solar PV capacity by 2030 (instead of only 0.304 GW according to NREB), and 10.6 GW wind in 2030 (instead of only 0.40 GW according to NREB) With this huge volume of variable generation, the capacities for pumped hydro storage should also be augmented to 0.80 GW from the present capacity of 0.35 GW.

5.5. Synergy of on-grid and off-grid solutions

This study shows that least cost options and low emissions for grid applications can be achieved at low reliability levels if high capacity factors of generators and low spilled energy are desired. Through NEMO optimisations, emissions can be reduced and reliability is improved with high RE penetration through increased storage capacity and increased ramping capacity of conventional generators such as coal, hydro and geothermal. CCGT capacities can also add to the flexibility required by high RE penetration, with dominance of variable generation. In this paper, a reliability of 0.998% unserved energy can provide an average \$70.41/MWh generation cost for 2030 (as compared to the present average ~\$150/MWh generation charge) and a 19.50 $MTCO_{2-eq,}$ in which the emission is reduced to ~20% from ~70% in the present generation mix. The unserved energy could be addressed by off-grid applications in the form of renewable distributed generation, energy efficiency and isolated mini/micro-grids.

6. Conclusion, further work and policy recommendation

This study models a scenario for the Philippines' 2030 energy mix, based on optimization for energy sustainability, which is comprised of three equally important dimensions: energy equity, energy security and environmental sustainability. In this paper, energy equity was quantified in the form of affordability ($/MWh), energy security in the form of reliability (% unserved energy) and environmental sustainability in the form of greenhouse gas emissions ($MTCO_{2-eq}$). Through the use of NEMO software, least cost optimization of energy mix for the scenarios that pursue high RE penetration with storage at the reliability level comparatively equivalent to the present anecdotal reliability level was performed. The scenario with highest average capacity factor for variable generation and least system's spilled energy is chosen. In this paper, the scenario that is identified has a generation cost of $70.41 per MWh, 19.50 million tonne of emissions, and an unserved energy of 0.998% of the total annual demand in 2030. This scenario is described in this paper in terms of both installed capacity and energy supplied as a proportion of baseload, flexible and variable generation, including the required storage capacity. The available reserve capacity, surplus energy and some reliability statistics (e.g. LOLE, outage events), capacity factors and LCOE for this scenario are identified. The paper shows that there is a need for greater flexibility. If this is to be met by the supply-side, this would mean increasing the ramping capacity of coal power plants. Cost can also be reduced by reducing the target reliability levels, which may be desirable, given the low levels of reliability currently experienced in the Philippines. The study also identified the additional capacity of each generation type required in each of the Philippines grids by 2030 to meet the selected scenario. The study identified a volume of potential surplus renewable energy that could be addressed through load shifting or could potentially have applications such as power to heat, power to gas, and power to mobility markets, although at the moment these markets are not yet developed in the Philippines. The synergy between variable generation and the conventional generations are explored in this paper as well as the synergy between on-grid and off-grid solutions.

Further work could be done on exploring optimal scenarios using different weightings for the trilemma goals, and identification of the required flexibility in those scenarios. These weightings should be based on the value that consumers in the Philippines place on the trilemma goals, and would be useful input to recommend appropriate policy for the context of the Philippines. This paper recommends the exploration of frameworks for developing countries electricity markets (using the Philippine context) that would facilitate greater flexibility in generators and accelerate the innovative use of surplus energy.

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