Energy 147 (2018) 142–154

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

The Philippines energy future and low-carbon development strategies

Md Alam Hossain Mondal*, Mark Rosegrant, Claudia Ringler, Angga Pradesha, Rowena Valmonte-Santos

International Food Policy Research Institute (IFPRI), 2033 K Street, NW Washington DC, USA

A R T I C L E I N F O

Article history:
Available online 4 February 2018

Keywords:
Energy future
Optimization
Climate change
Energy security

A B S T R A C T

This paper presents an assessment of alternative, long-term energy supply and low-carbon strategies for the Philippine power sector from 2014 to 2040 using TIMES model. It examines the potential contribution of renewable energy to diversify the Philippine energy supply-mix to meet future electricity demands. The reference scenario compares the impact of four alternative policy goals: (1) carbon tax, (2) targeted renewable-based power generation, (3) limited coal share in supply-mix, and (4) renewables subsidy. The reference scenario shows a significant increase of the share of coal-based power generation and import dependency of fossil-fuel increases from 227 PJ in 2016 to 1073 PJ in 2040. The model results for the alternative policy scenarios show a large potential for renewable energy-based power generation. The alternative policy options show a significant decrease of import dependency in the energy supply-mix for power generation. Most alternative policy scenarios project a higher total system cost, with the exception of the subsidy scenario. System cost increases only 2.6% in the renewables target scenario relative to the reference scenario. However, long-term benefits from investing in the alternative policy options would need to be considered, including diversification of energy supply-mix, improved energy security, and progress toward a low-carbon society.

1. Introduction

Energy consumption drives economic growth and is a key input for socio-economic development [1]. Access to clean energy is considered vital for modern living and a necessary element for all production sectors to function well [2]. The Philippines' energy sector faces the dual challenges of (1) heavy reliance on fossil fuels and imported energy and (2) high energy demand. The average annual growth of Philippine gross domestic product (GDP, a notation list is given in Table 1) in the past ten years has been 5.4% [3] and the country plans to increase its GDP growth to 7% by 2040 [4]. The planned, higher GDP growth will drive higher energy demand growth.

The country's primary energy supply consists of 60% fossil fuels and 40% renewable energy. The share of oil in the total energy supply-mix is significant, at about 31% in 2014 [5,6]. The country's self-sufficiency in primary energy supply has decreased in recent years. The renewable energy share declined from 43% in 2012 to 40% in 2014 [6]. Total primary energy supply and final energy consumption were 36.01 million tons of oil-equivalent (mtoe) and 22.36 mtoe in 2006, and increased to 47.5 mtoe and 28.57 mtoe in 2014, respectively [5]. Total imported energy was 14.26 mtoe in 2006 and increased to 20.86 mtoe in 2014; this represents a share of 44% in the primary energy supply-mix. About 75% of fossil-fuel demand is met through imports [7]. Coal imports increased about two-fold between 2006 and 2014 [5]. Fuel consumption by the Philippine power sector accounts for about 46% of total primary energy. The country's demand-supply outlook between 2015 and 2030 shows an additional 7 gigawatt (GW) capacity required to meet the expected electricity demand by 2030 [6].

The Philippine power sector currently relies largely on fossil-fuels (about 77%) and is expected to increase use of coal-based plants to meet future energy demand, which would negatively affect environmental outcomes. Coal consumption in the power sector increased from 7 million tons (mt) in 2006 to 15.5 mt in 2014. Due to heavy reliance on coal-based power generation, greenhouse gas (GHG) emissions are expected to grow rapidly. CO_2 emissions from coal power plants amounted to 26 mt and are projected to increase to 92 mt of carbon dioxide per year if all planned coal plants are installed [8].

The country has been suffering electricity outages or shortages, particularly during the summer months, since the 1990s. Electricity

* Corresponding author.
E-mail address: a.mondal@cgiar.org (M.A.H. Mondal).

https://doi.org/10.1016/j.energy.2018.01.039
0360-5442/

Table 1
Notation list.

CC: Combined Cycle	MARKAL: MARKet Allocation
CDM: Clean Development Mechanism	MESSAGE: Model for Energy Supply Strategy Alternatives and their General Environmental Impact
CO_2: Carbon dioxide	mt: million tons
CSP: Concentrated Solar Power	mtoe: million tons of oil-equivalent
DOE: Department of Energy	NO_x: Nitrogen oxides
EFOM: Energy Flow Optimization Model	NREP: National Renewable Energy Program
ETSAP: Energy Technology Systems Analysis Program	PJ: Peta joule
FiT: Feed-in Tariff	POLES: Prospective Outlook for Long-Term Energy. Scenarios
GDP: Gross Domestic Product	PSC: Pulverized Sub-Critical
GHG: greenhouse gas	PV: Photovoltaics
GW: gigawatt	RES: Reference Energy System
GWh: gigawatt hours	SO_2: Sulfur dioxide
IGCC: Integrated Gasification Combined Cycle	ST: Steam Turbine
IMF: International Monetary Fund	T&D: Transmission and Distribution
INDCs: Intended Nationally Determined Contributions	TIMES: Integrated MARKAL-EFOM System
IPCC: The Intergovernmental Panel on Climate Change	WASP: Wien Automatic System Planning Package

demand was about 25.6 GWh (GWh) in 1991 and increased to about 53 GWh in 2003 and 77.3 GWh in 2014 [5]. Primary energy supply is expected to double between 2011 and 2030. Energy scarcity has detrimental impacts on economic growth. Current challenges in the electricity sector in the Philippines include a supply-demand gap characterized by unmet demand; high electricity prices; under-investment in generation; reduced self-sufficiency; and expected high growth of GHG emissions levels. A national renewable energy program was adopted to dramatically increase (three-fold) the generation capacity of renewable energy technologies for power generation by 2030 [9]; this help to substantially mitigate GHG emissions from the power sector.

To help reduce global climate change, the government of the Philippines has made a commitment to limit the future growth of GHG emissions by implementing alternative policy options, such as carbon taxes, improvement of energy efficiency in both generation and consumption, diversification of the energy supply-mix, and accelerated development of renewable energy [10]. The country intends to reduce emissions by about 70% from different sectors, such as energy, transport, waste, forestry, and industry, by 2030, compared to the business-as-usual scenario of emission levels between 2000 and 2030 [11].

Potential ways to address these challenges include diversification of the energy supply-mix and inclusion of climate-change mitigation strategies in energy development and infrastructure support. These efforts should support national economic development through employment generation, increased food security, and reduced poverty.

The renewable energy potential of the Philippines is relatively high and could contribute to the supply of modern reliable energy services and improved overall energy security. The government's energy reform agenda highlights the importance of access to a more reliable energy supply, using indigenous energy resources while minimizing imported fossil fuels in an optimal and cost-effective way. The government's energy reform agenda focuses on (1) ensuring energy security, (2) achieving optimal energy pricing, (3) diversifying sources of fuel, and (4) developing a sustainable energy system.

The feasibility of this type of diversification of the energy supply-mix, integration of renewable energy into the energy system, and policy implications for long-term sustainable energy policy development can be assessed by applying bottom-up energy optimization models. This can provide important insights into the implications of prospective technologies that can be pursued by the Philippine government to improve energy security and develop a low-carbon society in a cost-efficient and effective way. Energy planning using a comprehensive modeling tool helps national governments anticipate and respond to the rapid changes occurring in the energy sector, including changes in technology learning curves in lowering costs for clean energy technologies and introduction of innovative technologies. However, comprehensive energy assessment, designed to support long-term energy policy development, is currently lacking in the Philippines.

Relevant energy supply modeling tools for national and regional scale analysis include: MARKAL/TIMES, MESSAGE, POLES, and WASP [12]. The TIMES model (a successor of the MARKAL model) used in this study is the most widely used energy systems optimization model. The MARKAL/TIMES model has been used for many national [13—18], regional [19—22], and global studies [23—25].

This study develops a TIMES (The Integrated MARKAL-EFOM System) modeling framework for the Philippines to identify least-cost solutions for alternative technology selection and policy options to meet the projected electricity demand over 26 years (20142040). The main objective of this study is to identify alternative energy development pathways applying the TIMES optimization framework that meet the Philippines' rising electricity demand while improving energy security, promoting access to reliable modern energy, and mitigating GHG emissions. Sensitivity analysis is performed considering variation of key parameters such as discount rates, coal price, investment cost of renewable energy technologies and impacts on natural gas supply curve.

The intention of this study is not to predict future developments of the energy sector, but rather to provide insights into the implications of different technology and energy options that can be pursued by the government of the Philippines in a sustainable way over the long term.

2. TIMES model

TIMES combines advanced versions of the MARKAL (market allocation) model. The MARKAL model is a linear programming model developed shortly after the oil crisis in 1976 by a consortium of members of the International Energy Agency's Energy Technology Systems Analysis Program (ETSAP) to serve as an energy-system planning and optimization tool in order to understand whether: (1) alternatives to oil were technically feasible and economically and environmentally sustainable, (2) solutions were global or dependent on national circumstances, and (3) global energy research and development paths were possible or advantageous. TIMES is the successor of MARKAL and the executive committee of ETSAP began promoting the TIMES model for new users starting in 2008.

The TIMES model is a linear programming bottom-up energy model. The model computes an economic equilibrium for energy markets, from the supply to end-use energy services. TIMES computes both the energy flow and energy prices in such a way that the suppliers of energy produce exactly the amount of energy needed to meet demand. It is a demand-driven model.

The main building blocks of the model are the processes (types of power plants or technologies) and commodities (energy carrier, cost, emissions, etc.), which are connected by commodity flows in a network called reference energy system (RES). This approach facilitates graphical analysis of the whole energy system—from primary energy resources at the start to sector-wide energy services at the end—using different conversion processes.

The TIMES model determines the energy and technology mix needed to meet the energy demand of an energy system, given specific limitations regarding available technologies and energy sources. It then determines an optimal energy supply mix (in economic terms) based on technological and economic parameters, such as the minimum cost for the technologies selected. (The schematic structure of the TIMES model is presented in Fig. 1.) Key exogenous input parameters are: techno-economic database, energy demand, energy prices, emission coefficients, targets, subsidies, and taxes. Key endogenous outputs are: technology investments, annual activities of technologies, energy requirement, marginal energy prices, levelized cost of electricity, import/export of energy, emission trajectories, emissions permits, and total discounted system costs.

The model consists of a set of constraints and one objective function, which is usually chosen to minimize the long-term discounted system cost of the energy system. The constraints (equations or inequalities) and objective function (criterion to be minimized or maximized) are expressed by decision variables and parameters, where decision variables are unknown or endogenous quantities, which TIMES determines, and parameters are known or exogenous quantities that are specified by the modeler. The configuration of the supplied RES is dynamically adjusted by TIMES in such a way that all model equations are satisfied and long-term system cost is minimized. The objective function is the sum of all region objectives, all discounted to the same modeler-selected base year, as shown in equation.

$$OBJ(z) = \sum_{r \in REG} [REG\_OBJ(z,r)] \tag{1}$$

where $OBJ(z)$: The total system cost, discounted to the beginning of the year z, r: region.

Each regional (REG) objective $OBJ(z)$ is decomposed into the sum of nine components that can be presented as equation.

$$REG\_OBJ(z,r) = \sum_{r \in (-\infty,+\infty)} DISC(y,z) \times \begin{bmatrix} INVCOST(y) + INVTAXSUB(y) + INVDECOM(y) \\ +FIXCOST(y) + FIXTAXSUB(y) + VARCOST(y)+ \\ ELASTCOST(y) - LATEREVENUES(y) - SALVAGE(z) \end{bmatrix} \tag{2}$$

where $DISC(y,z)$:value, discounted to the beginning of year z using general discount factor, the regional index r is omitted from the nine components for simplicity of notation. The 1st and 2nd terms are linked to investment costs, 3rd one is related to decommissioning capital costs, the 4th and 5th terms are linked to fixed annual costs, 6th term is to all variable costs, 7th one is demand loss

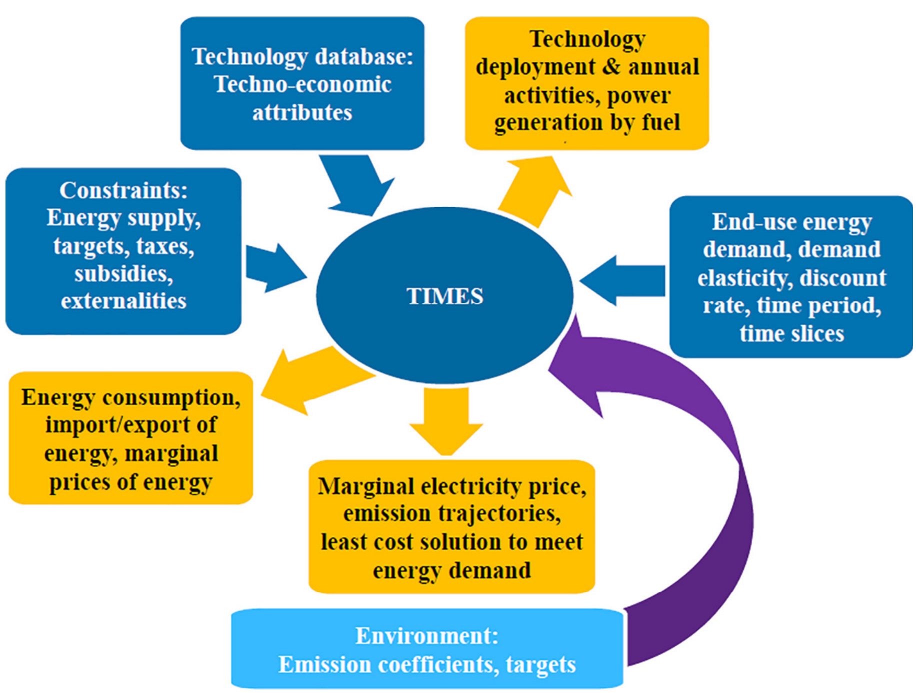

Fig. 1. Schematic structure of the TIMES model.

costs, the 8th term is actually a revenue that accounts for commodity recycling occurring after the end of horizon (EOH), and the 9th term is the salvage value of all capital costs of technologies whose life extends beyond EOH.

Table 2 shows short-listed elements (basic equations) of the TIMES model. Details of the TIMES objective function, equations, variables, and parameters are discussed in the Energy Technology Systems Analysis Program's documentation for the TIMES model [26].

3. Development of the Philippines TIMES framework

3.1. Philippines reference energy system

The reference energy system (RES) is the structural background of the TIMES model and provides an illustrative impression of the nature of an energy system. The development of a RES for the Philippines is a key contribution of this study. The RES includes all energy activities, from the source to the final end-use energy demand. The RES can be extended to show emissions from energy activities when primary energy is transported or converted from one form to another. The TIMES model consists of a large set of energy technologies, linked together by energy flows that mutually form the RES. Fig. 2 presents the Philippines RES for the power sector. All feasible energy resources such as coal, oil, gas, wind, solar, biomass, hydro, and geothermal are incorporated in the RES, including respective conversion technologies, transmission, and distribution as well as sector-wise electricity demand. The TIMES model finds the routes, energy-mix, and technologies presented in RES that are best fit to meet the electricity demand in terms of minimizing the system cost and optimizing energy resource use to meet the overall objectives of the energy system. Techno-economic parameters of each technology are included in this system to identify the least-cost solution. The various constraints listed in Table 2 are incorporated into this framework.

3.2. Exogenous electricity demand

The TIMES model needs projected energy service demands over the time horizon of analysis. It is possible to project energy demand in TIMES using macroeconomic forecasts as a demand driver. The Philippines' future electricity demand was recently evaluated by a comprehensive study applying detailed microeconomic factors [28,29]. The study projected electricity demand for two alternative GDP growth scenarios: (1) strong growth and (2) weak growth for the Philippines up to 2040. The study shows that electricity demand is expected to grow at an annual rate of 4.3% in the strong growth scenario. Year-wise, projected demand growth is high in 2015 at 6% and declines to 4.5% in 2020, 4.3% in 2030, and 4.2% by 2040 in the strong growth scenario. The identified year-wise electricity demand growth based on the strong economic growth scenario is adopted in this TIMES modeling, because it best reflects the pattern of recent economic growth. Table 3 presents projected regional and sector-wise electricity demands. About 75% of electricity demand is in the Luzon region, where the commercial sector dominates overall consumption. Total electricity consumption was 63.4 TWh (TWh) in 2014, and is projected to grow to 194.4 TWh in 2040.

3.3. Primary energy resources

Primary energy resource costs need to be determined along with their availability and supply limits for the modeling. Energy supply prices and availability limits for electricity generation in the Philippines are presented in Table 4. Fossil-fuel supply data for 2014 and 2015 are taken from the Philippines' energy balance sheets supplied by the Department of Energy (DOE). The upper bounds of coal and gas production for power generation in the Philippines is expected to be 272 PJ and 301 PJ, respectively, by 2040. Due to the lack of energy prices for power generation in the Philippines, the authors used the energy prices reported by the International Monetary Fund (IMF) for the years 2014, 2015, and 2016 [30]. All costs are in 2014 US dollars (US$1 = 46 Philippine pesos). The imported coal price decreased from US$2.59/gigajoule (GJ) in 2014 to US$1.96/GJ in 2016. Gas prices declined from US$3.26/GJ in 2014 to US$1.83/GJ in 2016. Imported crude oil prices declined from US$15.78/GJ in 2014 to US$6.93/GJ in 2016 [30]. An annual increase rate of 2.00%, 3.25%, and 4.00% for coal, gas, and crude oil, respectively, is considered from 2016 to the end of the analysis period [37–39]. Renewable power generation capacity growth in the Philippines is very large—solar, wind, and biomass-based power plant capacity increased from 26 MW in 2005 to 434 MW in 2014 [5]. Conventional renewable technologies, such as large hydro and geothermal power generation capacity, increased slightly from 5200 MW in 2005 to 5461 MW in 2014. Considering recent renewable energy technology development in the Philippines and the global growth standard, a maximum annual growth of 30% is applied for solar photovoltaics (PV) and wind-power plants [31]. An annual growth of 10% is also applied for hydro and geothermal power plants for new investment.

3.4. Conversion technologies

The characteristics of all conversion technologies need to be developed in the reference energy system. These technologies convert energy from primary resources to electricity to meet the specified end-use electricity demand. The Philippines TIMES model incorporates a fairly representative set of conversion technologies, including all existing and planned technologies as well as a total of 12 different conversion technology types: pulverized coal subcritical, integrated gasification combined cycle (IGCC), oil-based steam turbine (ST), diesel-based simple cycle, gas-based combined cycle

Table 2
TIMES basic short-listed equations [27].

Capacity transfer	The total available capacity is equal to the sum of investments at past and current periods plus capacity in place prior to the horizon
Activity definition	Equates an overall activity variable with the appropriate set of flow variables, properly weighted
Use of capacity	The activity of the technology may not exceed its available capacity, as specified by the user defined availability factor
Commodity balance	The disposition (consumption and export) of each commodity balances its procurement (production and imports)
Efficiency definition	The ratio of the sum of some of its output flows to the sum of some of its input flows is equal to a constant efficiency
Flow share	Limit the flexibility by constraining the share of each flow within its own group
Peak	There must be enough installed capacity to exceed the required capacity in the season with largest demand for commodity by a safety factor (peak reserve)
User constraints	Impose annual or cumulative bounds on commodities (emissions or fossil fuel reserves limit) limit the share of processes in the total production of commodity, limit investment in a process, dictate a percentage of a fuel for electricity generation such as renewable sources

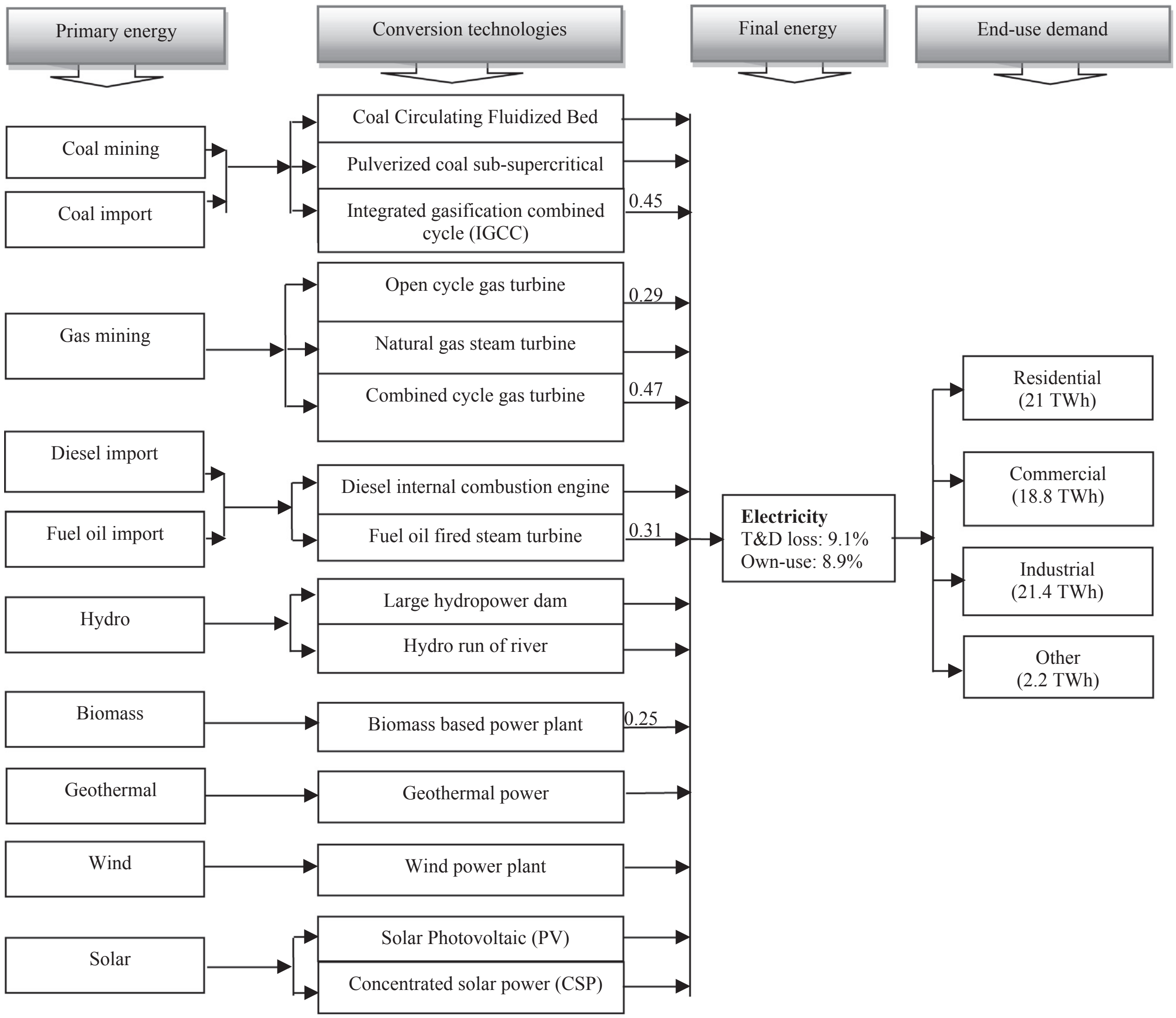

Fig. 2. Simplified reference energy system for the Philippines power sector. **Notes:** Values shown indicate conversion and transmission efficiency as well as demand in 2014.

Table 3
Electricity demand (TWh) by sector and by region.

Region	Sector	2014	2016	2020	2025	2030	2035	2040
Luzon	Residential	15.3	16.9	20.3	25.1	30.9	38.1	47.0
	Commercial	16.1	17.8	21.3	26.4	32.6	40.1	49.4
	Industry	15.0	16.5	19.8	24.5	30.2	37.2	45.8
	Others	0.9	1.0	1.2	1.5	1.8	2.2	2.7
	Total	47.3	52.3	62.5	77.4	95.5	117.7	144.9
Visayas	Residential	2.8	3.1	3.7	4.5	5.6	6.9	8.5
	Commercial	1.3	1.4	1.7	2.1	2.6	3.2	4.0
	Industry	3.2	3.6	4.3	5.3	6.5	8.0	9.9
	Others	0.8	0.8	1.0	1.2	1.5	1.9	2.3
	Total	8.0	8.9	10.6	13.2	16.3	20.0	24.7
Mindanao	Residential	2.9	3.2	3.8	4.7	5.9	7.2	8.9
	Commercial	1.4	1.5	1.8	2.2	2.7	3.4	4.2
	Industry	3.3	3.6	4.3	5.4	6.6	8.2	10.0
	Others	0.5	0.6	0.7	0.9	1.1	1.3	1.7
	Total	8.1	8.9	10.7	13.2	16.3	20.1	24.7
Subtotal		63.4	70.1	83.8	103.8	128.1	157.8	194.4

(CC), gas-based ST, hydropower, biomass-based plant, solar photovoltaic (PV), concentrated solar power (CSP), wind, and geothermal. Planned power plants that are expected to be installed

Table 4
Primary energy resource limits and cost [5,30,32,37–39].

	2014	2016	2020	2025	2030	2040
Mined natural gas:						
Cost (US$/GJ)	3.26	1.83	2.08	2.44	2.86	3.94
Upper bound (PJ)	126	136	163	198	232	301
Mined Coal:						
Upper bound (PJ)	153	165	183	205	228	272
Cost (US$/GJ)	1.94	1.47	1.59	1.76	1.94	2.31
Imported Coal:						
Cost (US$/GJ)	2.59	1.96	2.12	2.34	2.59	3.08
Imported oil cost[a]:						
(US$/GJ)	15.78	6.93	8.11	9.86	12.00	17.76
Biomass, solar and wind	Resource bound for biomass: 100 PJ. New wind bound: 3.3 GW and no limit imposed for solar					
Hydro and geothermal	An upper bound of new hydro and geothermal capacity of 10 GW					

Notes.
[a] Taxes and subsidies in the power sector are a debated issue in the Philippines [33]. Diesel and fuel oil process are heavily subsidized to retain a certain percentage of power generation share. Diesel and fuel oil prices are considered 73% and 74% less, respectively, than imported oil price.

by region in the next five years are incorporated into the model.

Existing conversion technologies and their capacities, including government planned installation capacity by technology for the next 5 years, are presented in Table 5. These technologies and capacities are included in the modeling.

Techno-economic parameters for fossil-fuel based power plants are reviewed and incorporated in the modeling, mainly from Refs. [34–38]. Renewable technologies are also reviewed and incorporated in the modeling from Refs. [35,38–43]. No upper bounds are specified for solar PV and CSP. The installed power generation capacities of solar PV, wind power and CSP are permitted to grow up a rate of up to 30% every year after their introduction if they are selected by the TIMES model [12,18].

Table 6 presents techno-economic characteristics of selected key conversion technologies. The total transmission and distribution (T&D) losses were 9.1% in 2014 in the Philippines [44] and this loss is incorporated in this modeling. In addition to the T&D losses, utility own-use of electricity was about 8.9% of total electricity generation in 2014. For each technology type, values are given for efficiency, capital cost, operations and maintenance (O&M) costs, utilization factor, peak demand contribution factor, and plant lifetime. A T&D charge of US$0.0025/kWh is assumed.

3.5. Other model characteristics

The analysis covers a 26-year period from 2014 to 2040. The year 2014 is used as a base year due to the availability of data and annual reports by the energy utilities in the Philippines. A discount rate of 6% is applied in this modeling. Due to lack of information on emissions factors, the Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories emissions factors for coal, oil, and gas are considered in this modeling [46–48]. Emissions factors such as carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NO_x) from fossil fuels are incorporated.

Only centralized-grid electricity was considered. TIMES determines how much electricity must be generated to feed to the national grid in order to meet the domestic demand to support strong economic growth. End-use demand technologies were merged into the electricity demand allocated to their sector.

A regional approach is applied in the Philippines TIMES model. The regions modeled include Luzon, Mindanao, and Visayas. Existing technologies and planned technologies that are expected to be installed by 2020 are included in the model. New technologies can be selected by any region based on model choice to meet least-cost, optimal solutions, and regional electricity demand. The energy balance sheet for 2014 is disaggregated based on power generation-mix by region. Bilateral electricity trade across the regions are allowed applying a trade (transmission investment) cost of US$0.03/kWh. Fossil-fuel prices and technology investment costs are assumed to be the same for all regions because most of the technologies are imported.

The model assumes that all existing power plants will continue production at current levels, which further assumes that operation and maintenance continue into the future. This analysis assumes that sufficient infrastructural support will be available for transportation and installation of new power plants. No constraint is imposed on the availability of financial resources as the private sector is expected to be involved in future power sector development.

4. Scenario development

Drawing on the Philippines energy and environmental policy

Table 5
Existing and planned conversion technologies and their capacity (MW).

	Luzon	Mindanao	Visayas	Total capacity	Planed (2015–2020)
Coal pulverized sub-critical (PSC)	4.406	0.196	0.232	4.834	3827
Gas combined cycle	2.661	0	0	2.661	50
Gas steam turbine	0.2	0.001	0	0.201	
Diesel simple cycle	1.419	0.615	0.799	2.833	18.9
Oil based steam turbine	0.72	0.055	0	0.775	0
Biomass based plant	0.05	0.096	0.036	0.182	84.9
Hydro dam	1.265	0	0.806	2.071	222
Hydro run of river	1.2	0.011	0.255	1.466	0
Wind	0.283	0.09	0	0.373	14
Solar	0.057	0.052	0.001	0.11	200.5
Geothermal	0.844	0.965	0.108	1.917	0

Table 6
Overview of key conversion technologies[a].

Technology	Year of introduction	Investment cost (US$/kW)	Fixed O&M cost (US$/kW/yr)	References
Pulverized coal subcritical	2020	2012	40.24	[34–36]
Integrated gasification combined cycle	2025	2770	69.25	[34]
Fuel-oil steam turbine	2020	825	9	[24,35,36,45]
Diesel-based simple cycle	2016	461	70	[37]
Natural gas steam turbine	2020	800	35	[38]
Natural gas combined cycle	2020	917	13.17	[35,36,38]
Hydro	2020	3210	96.30	[35,38,39]
Biomass	2020	3323	73.12	[40]
Solar PV	2020	3959-3150[b]	60	[41,42]
Concentrated solar power	2020	4565-3939[b]	67.26	[38,41]
Wind	2020	2800-2500[b]	36	[35,40–42]
Geothermal	2020	4066	101	[35,43]

Notes.
[a] Most of the investment costs for new technologies are based on anticipated cost data from the Department of Energy.
[b] The later value shows investment cost in 2030 as technology learning cost effects are considered in modeling, i.e. the investment costs for these technologies decrease during the investment periods.

goals outlined in (1) the *Philippine Energy Plan (2012–2030)* [49], (2) the intended nationally determined contributions of the Philippines (INDCs) [11], (3) the National Renewable Energy Program (NREP) [50], (4) the carbon pricing report [8], (5) the energy demand projections policy brief [29], and other key documents on the development of the power sector [29], the following alternative policy scenarios were developed in the TIMES model (summarized in Table 7):

1. Reference scenario: This scenario does not impose any policy interventions and assumes the continuation of existing energy-economic dynamics. It serves as a reference for comparing alternative policy options and technology choices, as well as investments, technology capacity, energy requirements, cost, and GHG emissions.
2. Renewable portfolio standard (renewable-target) scenario: This is the "what if" scenario, in which a certain share of renewable-based power generation is targeted to meet electricity demand. This scenario assumes an accelerated development of renewable-based power generation from 30% of the country's total electricity demand by 2025 to 50% by 2040. This alternative policy option is based on the NREP, which outlines the government's renewed commitment to promoting renewable energy use to contribute to power generation.
3. Carbon-tax scenario: This scenario is based on a recent proposal on carbon pricing. A carbon tax of US$10/ton, US$20/ton, and US$30/ton is imposed in 2020, 2030 and 2040, respectively
4. Subsidized renewable-based power generation (renewable-subsidy) scenario: To promote renewable-based power generation, the Philippines currently imposes a feed-in tariff (FiT). This scenario is the "what if" in which a subsidy is applied instead of the FiT for wind, solar, biomass, and hydropower generation. A subsidy of US$0.04/kWh for hydro and biomass, US$0.05/kWh for wind, and US$0.06/kWh for solar (30% of existing FiT) in 2020; and in 2030, US$0.03/kWh for hydro and biomass, US$0.04/kWh for wind and solar (20% of existing FiT).
5. Limited coal-based power generation (coal-share) scenario: This scenario assumes the government's current policy of maintaining future coal-based power generation at about a 30-percent-share of total power generation. It assumes a 40-percent coal-based generation share in 2016, which is expected to decrease to 30% by 2030 to minimize imported coal use for power generation.

5. TIMES optimization results

The TIMES model results for the reference scenario show that the Philippines power generation capacity is expected to increase from 18.4 GW in 2014 to 37.3 GW in 2040 in order to meet the forecast electricity demand during the modeling period (Table 8). The growth rate of the power generation capacity is 2.75% per year. Projected year-wise installation capacity is relatively lower than the projected electricity demand growth due to selection of more efficient power plants. The structure of generation capacity changes significantly with heavy dependence on coal-based technologies. Coal-based generation capacity increases from 5.8 GW in 2014 to 17.9 GW in 2040, an average growth of 4.4% per year. In the reference scenario, new pulverized coal subcritical (including planned) power plant capacity selection increases from 1.4 GW in 2016 to 4.8 GW in 2040.

Gas combined cycle, hydro, and geothermal plants were also chosen by the model in the later period of this analysis. The model finds some potential for geothermal and hydropower to contribute to electricity production in the reference scenario. Integrated gasification combined cycle, solar PV, CSP, and wind-, oil-, and biomass-based generation capacity are not selected for new investment in the reference scenario. The model outcomes show that there is an opportunity to develop hydro and geothermal power plants in the future given the expected increase in imported coal prices. Technology learning cost effects of solar PV, CSP, and wind-power generation did not work in the reference case and could not compete with coal and available other sources of energy.

Electricity generation by plants increases from 76.6 TWh in 2014 to 234.9 TWh in 2040 under the reference scenario (Table 8). Similar to the installation capacity, electricity generation from coal-based power plants increases from 36.2 TWh in 2016 to 135 TWh in 2040. This represents a growth in coal generation share from about 43.0% in 2016 to 57.5% in 2040. Conventional renewable energy technologies (hydro and geothermal) generation shares decrease from 31% in 2016 to 24% in 2040. The TIMES modeling fuel-share-mix for power generation under the reference scenario closely follows the policy scenario of temporary utilization of the lesser-cost (policy 2) scenario under the FILIPINO 2040 strategy report titled *Energy: Power Security and Competitiveness* [28]. A comparison of power generation shares by fuel type from TIMES and FILIPINO 2040 is presented in Table 9.

The TIMES results under the reference scenario show that fossil-fuel consumption significantly increases from 535 PJ in 2014 to 1646 PJ while import dependency sharply grows from 257 PJ in 2014 to 1073 PJ in 2040—an average growth of fuel dependency of about 7% per year. The model suggests that the Philippines need to import energy for power generation to meet the future electricity demand. The CO_2 emissions are also expected to increase by 3.3 times in 2040 compared to the base year of 2014. In the reference scenario, the model did not find feasibility of electricity trading across the studied regions of Luzon, Mindanao, and Visayas.

Fig. 3 shows the least-cost technology capacity choices by fuel type for all alternative policy scenarios. The total capacity is slightly higher than under the reference scenario, due to the increased contribution from renewable energy technologies, such as solar PV, concentrated solar power, and wind, which have more limitations due to daylight hours and wind speed, respectively. Capacity increases from 18.4 GW in 2014 to 41.5 GW, 42 GW and 48 GW in 2040 under the renewables-target, carbon-tax, and renewables-subsidy scenarios, respectively.

The capacity share of coal-based power plants decreases from about 32% in 2014 to 25%, 20%, 28%, and 17% in 2040 in the renewables-target, carbon-tax, coal-share, and renewables-subsidy scenarios, respectively. The renewable energy technology capacity

Table 7
Summary of scenarios analyzed in the Philippines TIMES model.

Scenarios	Constraints/policy implications
Reference	No policy implications. Considers only current energy-economic dynamics
Renewables-Target	30% by 2025 and 50% by 2040 renewable based power generation
Carbon-Tax	10, 20 and 30 USD/ton by 2020, 2030 and 2040, respectively
Renewables-Subsidy	As discussed (US$ 0.03/kWh to 0.06/kWh)
Coal-Share	30% coal based generation by 2030

Table 8
Generation capacity development, electricity generation, energy demand, and GHG emissions in the reference scenario.

Technology capacity (GW) by fuel	Reference scenario (without any policy intervention)					
	2014	2016	2020	2025	2030	2040
Coal	5.84	7.22	8.22	8.22	9.40	17.93
Oil	3.61	3.64	3.64	3.64	3.64	3.63
Gas	2.86	3.33	3.33	3.34	3.84	5.00
Biomass	0.18	0.22	0.23	0.23	0.23	0.21
Geothermal	1.92	1.92	1.92	1.92	1.92	3.82
Hydro	3.54	3.57	3.66	3.96	5.51	6.06
Solar	0.11	0.26	0.26	0.26	0.26	0.26
Wind	0.37	0.39	0.39	0.39	0.39	0.38
Total capacity (GW)	**18.43**	**20.55**	**21.65**	**21.96**	**25.18**	**37.30**
Electricity generation (TWh)						
Coal	31.49	36.21	50.95	56.69	67.20	135.07
Oil	7.57	2.58	0.00	10.88	14.40	0.43
Gas	16.31	17.61	21.17	25.50	29.96	39.08
Biomass	0.96	0.19	0.64	1.26	1.26	1.13
Geothermal	10.07	10.07	10.07	10.07	10.07	23.41
Hydro	8.79	16.16	16.59	19.18	30.03	33.90
Solar	0.29	0.72	0.72	0.72	0.72	0.72
Wind	1.14	1.18	1.18	1.18	1.18	1.16
Total production (TWh)	**76.62**	**84.73**	**101.32**	**125.50**	**154.83**	**234.90**
Fossil fuel consumption (PJ)						
Coal	307.7	354.4	504.3	563.9	672.0	1340.6
Oil	102.36	37.2	0.00	139.71	190.41	5.04
Natural gas	124.98	136.0	163.38	197.85	232.07	300.51
Total (PJ)	535.10	528.1	667.66	901.43	1094.50	1646.12
Imported fuel	256.97	227.3	321.44	498.41	634.92	1073.41
Import share (%)	48.02	43.2	48.14	55.29	58.01	65.21
GHG emissions (“000” tons)						
Carbon dioxide (CO_2)	43749	43922	56870	74894	90801	144057
Nitrogen oxides (NO_x)	938	956	1277	1646	1996	3390
Sulfur dioxide (SO_2)	86	87	112	148	179	286

Table 9
Comparison of power generation share (%) by fuel type.

Generation by fuel type	2016		2040	
	Policy Brief: Policy 2	TIMES: Reference	Policy Brief: Policy 2	TIMES: Reference
Coal	44	42.7	57	57.5
Natural gas	20	20.8	16	16.6
Conventional (hydro and geothermal) renewable	32	31	24	24.4
Variable renewable (biomass, wind and solar)	1	2.5	1	1.3
Others (diesel and heavy fuel oil)	3	3	2	0.2

share dramatically increases from about 32% in 2014 to 55%, 59%, and 67% in 2040 in the renewables-target, carbon-tax, and renewables-subsidy scenarios, respectively. Geothermal contributes significantly in the carbon-tax, coal-share, and renewable-target scenarios. Subsidies help to promote the contribution of hydro, wind, and solar technologies. CSP is chosen at the end of the analysis period (2040) by the model only in the renewables-target scenarios. Oil-based power plants were not selected by the model due to the oil price and lower efficiency of technologies. The decreasing cost of solar PV and wind power over time increases the attractiveness of these technologies and leads to a higher diffusion rate in the Philippines' power sector under the renewables-target, carbon-tax, and renewables-subsidy scenarios.

Under the renewables-target scenario, the contribution from renewable-based power increases from 21 TWh in 2014 to 117 TWh in 2040. Geothermal power generation is the second highest at 44 TWh, and coal remains as the highest, at 77 TWh in 2040 (Fig. 4). Coal-based generation decreases in the renewable-target scenario to about 43% (58 TWh) in 2040 compared to the reference scenario. Renewable energy production shares shift from 29% to 30% to 37% to 43% to 50% by 2020, 2025, 2030, 2035, and 2040, respectively, in the renewables-target scenario. The model completely follows the constraints applied to produce 30% and 50% of renewables-based power generation by 2025 and 2040 (Fig. 4). Electricity generation from solar PV, CSP, and wind is anticipated to grow from 1.4 TWh in 2014 to about 39 TWh in 2040. The model also selects CSP to produce about 4.4 TWh in 2040 to meet the goal of 50% renewable share by 2040.

The maximum contribution from renewable energy is expected in the carbon tax and renewables subsidy scenarios. Due to the absence of subsidies on geothermal power generation, the model did not show feasibility to invest in new geothermal plants in the renewables-subsidy scenario. On the other hand, the carbon-tax scenario shows a growing contribution of geothermal, with a projected increase from about 10 TWh in 2014 to 59 TWh in 2040 (Fig. 4). Due to the scenario specifications of a carbon tax and subsidies for renewables, the model finds alternatives to fossil fuels, specifically coal. Renewable energy dominates generation with 57% and 60% in 2040 in the carbon-tax and renewables-subsidy scenarios, respectively. This shrinks cumulative coal-based power generation during the analysis period from 2243 TWh in the reference scenario to 1553 TWh in the carbon-tax and 1444 TWh in the renewables-subsidy scenario. Gas-based generation maintains almost similar shares in all scenarios, likely due to reaching

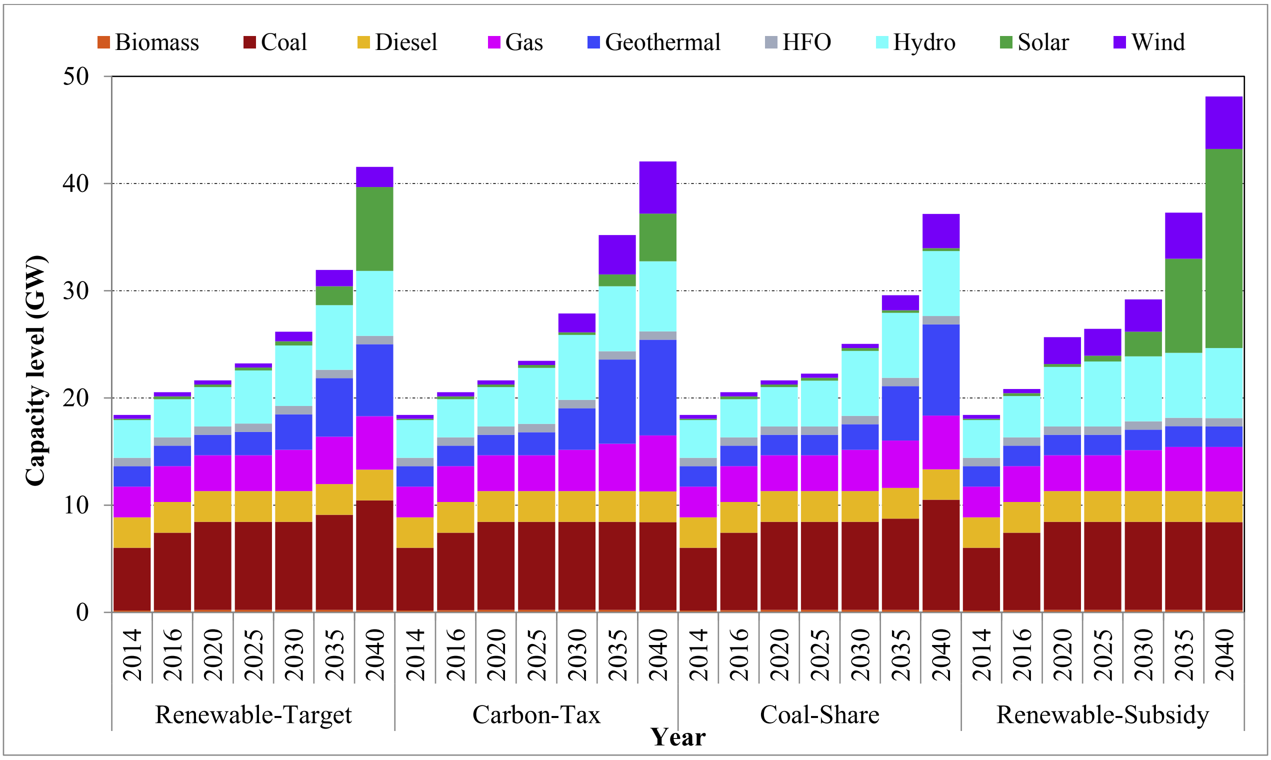

Fig. 3. Power generation capacity selection.

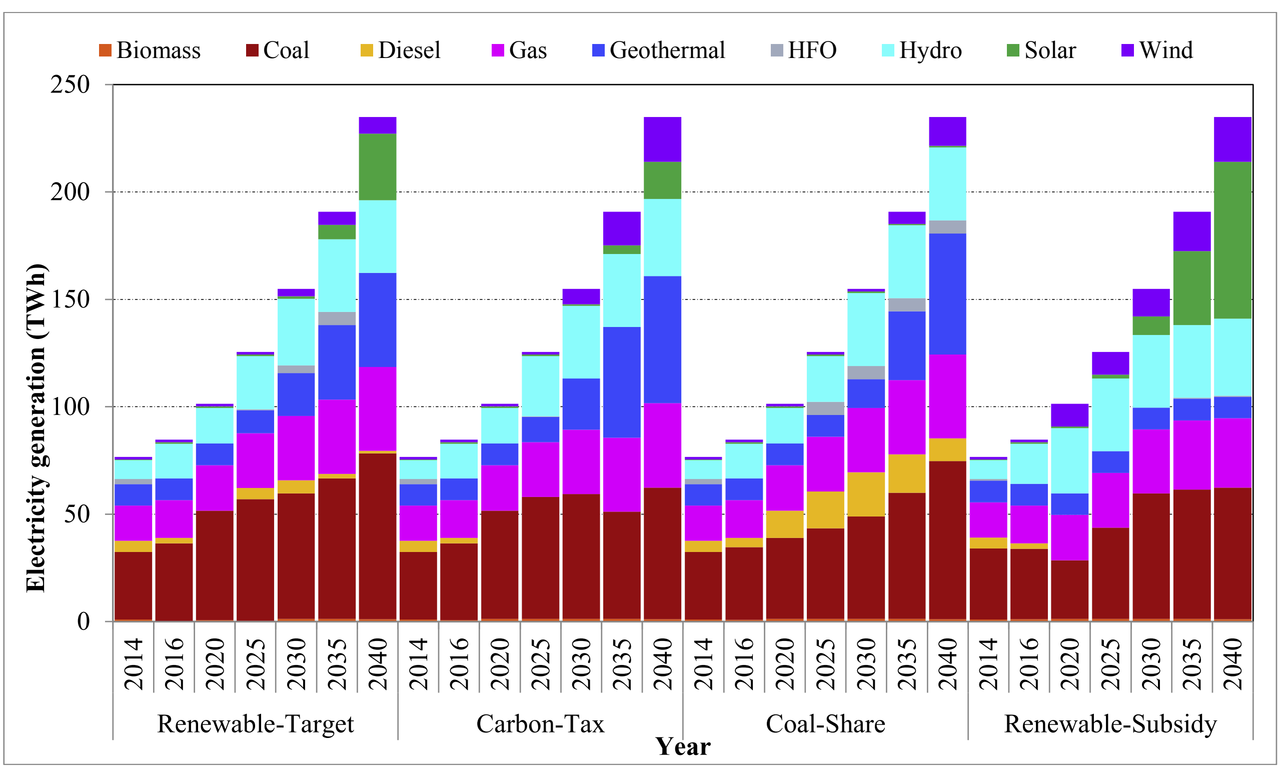

Fig. 4. Electricity generation by fuel type.

maximum availability for power generation in the Philippines.

Fig. 5 recapitulates the wide-ranging results that are generated by the TIMES model for each of the alternative sustainable power sector development strategies for the Philippines. The optimal primary energy supply-mix for 2040 is considered as a principal metric to compare the relative role of various energy sources under all developed scenarios (Fig. 5). This metric presents a clear indication of the amount and types of primary energy choices by the

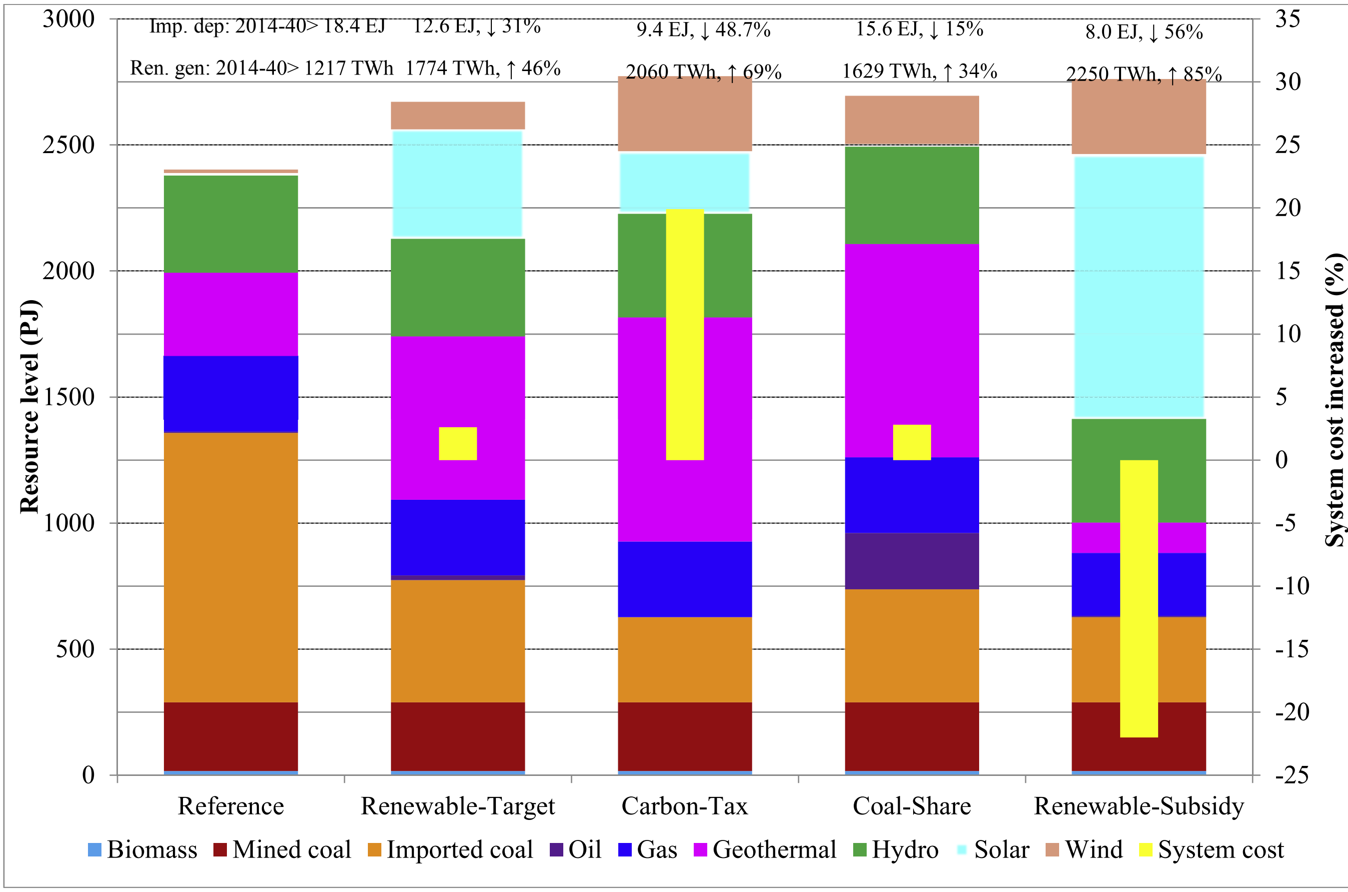

Fig. 5. Primary energy supply-mix in 2040 and percentage change of total system cost (2014–2040). **Notes:** Fig. 5 also demonstrates the amount of cumulative imported energy and renewable-based generation, including the percentage change compared to the reference scenario.

model under the specified policy constraints on power-sector development using least-cost solutions to meet projected electricity demand. The colored bars (except the inside yellow thin bar) show the breakdown of primary sources of energy in PJ that are expected for use to produce electricity in 2040, under the reference and alternative policy scenarios. Total fossil-fuel use in 2040 reduces from 1646 PJ in the reference scenario to 1076 PJ in the renewables-target, 910 PJ in the carbon-tax, 1244 PJ in the coal-share, and 864 PJ in the renewables-subsidy scenario. Alternatively, implications of renewable energy in the year 2040 increase from 757 PJ in the reference scenario to 1594 PJ in the renewables-target, 1863 PJ in the carbon-tax, 1450 PJ in the coal-share, and 1897 PJ in the renewables-subsidy scenario. Coal dominates the energy supply-mix in the later period of this study, which shifted into a more diverse use of renewables in all the alternative policy options. Diversification of the supply mix is one of the co-benefits of the alternative energy development options.

The numbers above each scenario in the first row of Fig. 5 show the amount of import dependency in PJ (cumulative from 2014 to 2040) and the percentage change of dependency of the alternative policy options compared to the reference scenario. The numbers in the second row present cumulative renewable-based power generation in TWh for each scenario and the percentage increase of generation from renewables in the alternative scenarios compared to the reference scenario.

The thin yellow internal bar in the alternative policy scenarios in Fig. 5 represents the percentage change of total "system cost" when compared to the reference scenario.[1] The model estimates that a total of US$69.7 billion of investment is required in the reference scenario from 2014 to 2040. In order to compare the costs of the alternative policy options, the total system cost for the reference scenario is used as a reference point from which percent changes in total cost are measured for the alternative policy scenarios. The total system cost increases by 2.6% in the renewables-target, 19.9% in the carbon-tax, and 2.8% in the coal-share scenario when compared with the reference scenario. In the renewables-subsidy scenario, the total system cost decreases by 22% relative to the reference scenario due to the incentive for power generation from biomass, hydro, wind, and solar energy resources. This incentive contributes to substantial additional investment in these technologies. Electricity generation increases from 11 TWh in 2014 to 131 TWh in 2040 from the technologies in the renewables-subsidy scenario. Compared to the reference scenario, cumulatively 1099 TWh are added from renewable energy in the renewable-subsidy scenario. Said different, a US$15.6 billion subsidy supports the addition of 1099 TWh from renewable energy to power sector development during 2014–2040.

The alternative energy development options can make important contributions to improve energy security for the Philippines. The energy security issue is evaluated through an assessment of the diversification of the primary energy supply-mix and self-sufficiency of resource use for future power generation. A key indicator of this is reduced dependency on imported fuels and

[1] The "system cost" represents all costs during the study period (2014–2040) related to energy technologies investment, fuel, operation and maintenance, import, transmission, distribution, and other costs.

integration of available renewable resources, which helps to improve overall energy security.

The TIMES model finds internal, regional trading of electricity in the carbon-tax, coal-share, and renewables-subsidy scenarios. In the carbon-tax scenario, there is a potential for trade of electricity from Luzon to Visayas in the later periods of this study—7 TWh in 2035 and 22 TWh in 2040. From Visayas to Mindanao, it is only feasible to trade 7 TWh in 2040 under the carbon-tax scenario. Cumulatively, 94 TWh in electricity trading (from Luzon to Visayas and Visayas to Mindanao) are expected between 2030 and 2040 in the coal share scenario. In the renewable-subsidy scenario, the data suggest a cumulative 73 TWh of trading electricity among the regions between 2014 and 2040.

An additional co-benefit of these policy scenarios is helping to reduce GHG emissions (CO_2, NO_x, and SO_2) through the selection of efficient and clean technologies and optimal use of primary energy resources. In the reference scenario, GHG emissions are about 2752 mt between 2014 and 2040. The level of CO_2 emissions increases from about 44 mt in 2014 to 144 mt in 2040 under the reference scenario—a more than three-fold increase in emissions in 2040 compared to the base year of 2014. Fig. 6 shows the percentage change in CO_2 emissions for all alternative policy scenarios compared to the reference scenario. CO_2 emissions go down from 100% (144 mt in 2040) in the reference scenario to 50% (72 mt in 2040) under the renewables subsidy scenario. CO_2 emissions drop by 38%, 50%, and 29% in the renewables-target, carbon-tax, and coal-share scenarios, respectively (Fig. 6). Total CO_2 emissions between 2014 and 2040 decrease by 20%, 30%, 13%, and 36% in the renewables-target, carbon-tax, coal-share, and renewables-subsidy scenarios, respectively, from the reference scenario emissions levels.

Due to the increased use of renewable energy technologies in the energy system for power generation, the marginal electricity price in the renewable-target and carbon-tax scenarios is relatively higher than the price in the reference scenario (Fig. 7). In the reference scenario, the marginal distributed electricity price increases from US$0.09/kWh in 2016 to US$0.2/kWh in 2040 due to heavy reliance on imported fuels in the later period of the analysis. The marginal electricity price in the coal-share scenario is almost identical to the reference scenario price. The carbon tax significantly increases the marginal electricity price in the carbon-tax scenario—by US$0.27/kWh by 2040.

6. Sensitivity analysis

The sensitivity of these results to changes in the assumptions is presented in this section. The analysis considers the implications for power generation of alternative discount rates and alternative investment costs of new renewable energy technologies (solar PV, wind, and CSP), coal prices, and gas supply. Because the model's objective function is to minimize total system costs, the discount rate becomes more significant over the length of the study period. Two alternative discount rates—of 4% and 8 percent—are applied, with a 6-percent rate applied in the reference scenario. A 20-percent increase in the coal price is assessed, as well as a 20-percent increase and decrease in growth of gas production, to see the impact on the selection of technologies. The impact of a decrease of 10% in investment costs for renewable energy technologies is also analyzed, given that the cost of these technologies has been falling is known to fall as experience with them increases.

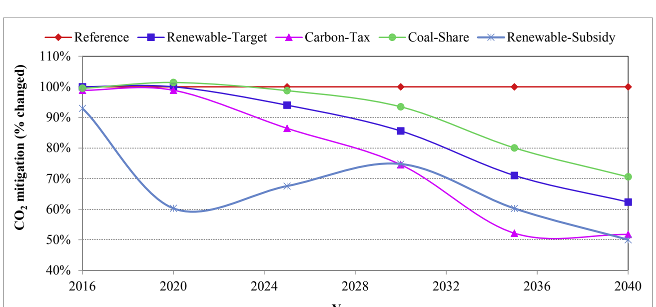

Fig. 6. Percentage change in CO_2 emissions.

With a discount rate of 4%, the model finds more investment in geothermal and wind power and less investment in coal-based power plants from 2030 to 2040. Geothermal capacity increases significantly, from 3.82 GW in the reference scenario to 7.95 GW in 2040 with a 4-percent rate. The lower discount rate allows for investment in wind-power plants late in the analysis period (2035–2040). There are no changes on hydro capacity allocation.

A higher discount rate (8%) suggests more investment in fossil-fuel-based plants. Solar and wind technologies are not selected and geothermal capacity decreases from 3.82 GW in the reference scenario to 2.30 GW in 2040. Investment in hydro power decreases slightly in 2030, from 5.5 GW to 4.3 GW. A 10-percent decrease in the investment cost of new renewable technologies—solar PV, CSP, and wind power—contributes to an increase in new wind capacity of 3 GW in 2040. Investment in wind power replaces geothermal capacity and, to a lesser extent, coal-based power plants between 2035 and 2040. However, solar PV and CSP are still not selected. Total generation capacity in 2040 reaches 38.5 GW with the 8% discount rate instead of 37.3 GW, as in the reference scenario.

Production of natural gas for power generation has limited impacts on selection of renewable energy technologies. It only allows substitution of fossil-fuel-based technologies for future technology investment. A 20-percent reduction in the annual growth of the natural gas supply promotes coal-based power generation. The model suggests a reduction in investment in gas-based power plant capacity of about 1 GW in 2040, mainly replaced by coal plants. Opposite outcomes are found when annual growth of the natural gas supply is increased by 20% compared to the reference scenario.

The coal price has a significant impact on technology selection. A 20-percent increase in the coal price decreases installed coal-based power plant capacity by a total of 5.6 GW in 2040. Natural-gas plant capacity reaches 5 GW by 2040 and uses the upper limit of gas supply. Geothermal and hydro power are chosen as least-cost and optimal solutions to replace coal plants. Even in this case, the model did not find investment in solar technologies feasible.

7. Conclusions

The TIMES model findings demonstrate how different technologies and energy resources can be identified to meet projected electricity demand and national policy priorities, namely achieving energy security, diversifying the energy supply-mix, promoting renewable energy technologies, and improving energy self-sufficiency. Each of the alternative policy options also has implications for energy system cost, energy requirements, and environmental impacts. All of these considerations must be weighed carefully to invest in the Philippine power sector for long-term sustainability.

The model suggests that the current energy supply-mix must be diversified to minimize import dependency on fossil fuels. Solar PV, wind, and conventional renewable technologies play an important role in contributing to power generation. The cost of promoting renewable energy technologies to reach the renewable targets and coal shares set forth in the policy goals is reasonable. The total system cost during the modeling period (2014–2040) increases by

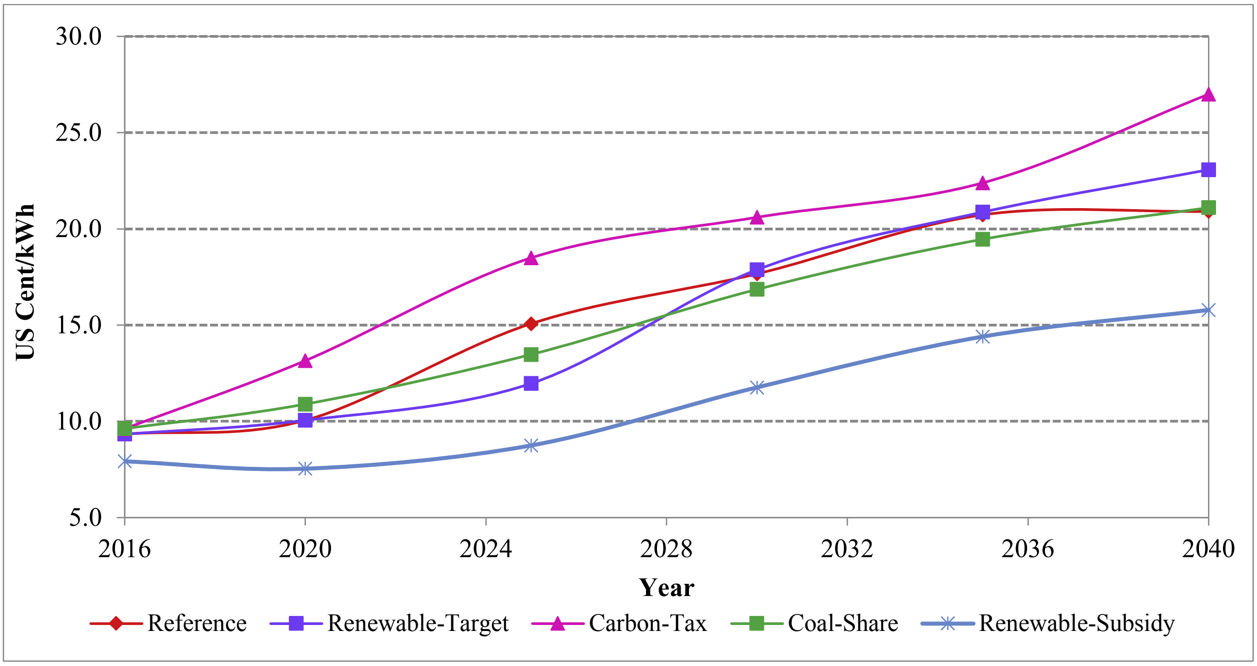

Fig. 7. Marginal distributed electricity price.

2.6% in the renewable-target scenario and 2.9% in the coal-share scenario compared to the reference scenario cost of US$69.7 billion. The additional goals of energy security and GHG mitigation would also be achieved. The total system cost increases by about 19.9% in the carbon-tax scenario and decreases by 22.5% in the renewable-subsidy scenario. The government of the Philippines could impose a carbon tax on fossil-fuel use to encourage clean energy use and raise funds for the promotion of renewable energy technologies. Optimization results show that 20–30% of the existing FiT or subsidies on renewable energy would help to promote renewable technologies and reduce 22.5% of total system cost.

The optimal energy supply-mix and technologies selected by the model in all alternative policy scenarios would allow the Philippines to meet their own sustainable energy development goals as well as the INDC mitigation target. Accelerated development of the renewable energy scenario does not have huge additional cost implications, considering that the long-run investment cost of these technologies is expected to decrease rapidly. In this renewables target scenario, import dependency and GHG emissions drop significantly when compared to the reference scenario. The mitigation cost of CO_2 emissions is about US$3.5/ton in the renewables-target scenario, which below typical costs in developed countries. Therefore, it is attractive to the private sector for clean development mechanism (CDM) projects and also for developed countries to invest in renewable energy technologies in the Philippines—to reduce their own committed CO_2 emissions. All alternative policy scenarios show that the Philippines could promote renewable energy technologies for power generation to diversify the energy supply-mix, improve its energy security, and develop a low-carbon society.

To achieve these promising goals, however, the Philippines needs a vision and strong policy support. In addition to this energy assessment, it is necessary to assess the trade-offs across other sectors from investment in sustainable energy. This energy assessment also requires strong links across other sectors of the Philippine economy in order to identify and define the impacts of alternative energy development strategies. Future steps involve linking this bottom-up energy modeling approach with a top-down national computable general equilibrium model. Such a study is already planned.

Acknowledgements/Funding

This research was supported by the CGIAR Research Programs on Policies, Institutions and Markets, Water, Land and Ecosystems and Climate Change, Agriculture and Food Security.

References

[1] Mondal MAH, Denich M. Assessment of renewable energy resources potential for electricity generation in Bangladesh. Renew Sustain Energy Rev 2010;14:2401–13.
[2] Daway SL, Quiao L. Toward inclusive and sustainable energy development: issues and challenges. In: EPDP conference 2016; 2016.
[3] WB. World development indicators 2015. Washington DC: World Bank; 2015.
[4] Danao RA, Ducanes GM. EPDP policy brief 2016-04: forecasting aggregate electricity consumption in the Philippines. 2016.
[5] PSA. 2015 philippine statistical yearbook. Philippine Statistics Authority, Republic of the Philippines; 2015.
[6] MONSADA ZY. Energy prospective for the Philippines; EPDP conference 2016: toward inclusive and sustainable energy development 13 January 2016, Makati city, Philippines. 2016.
[7] ADB. Energy outlook for asia and the pacific. 1550 Metro Manila, Philippines: Asian Development Bank (ADB); 2015.
[8] EPDP. Proposed energy policy paper on carbon pricing: overview and application in the philippine energy sector. Initial working brief for consultation. GIZ support CCC Phase II. 2016.
[9] Roxas F, Santiago A. Alternative framework for renewable energy planning in the Philippines. Renew. Sustain. Energy Rev. Rev. 2016;(59):1396–404.
[10] Cabalu H, Koshy P, Corong E, Rodriguez U-PE, Endriga BA. Modelling the impact of energy policies on the Philippine economy: carbon tax, energy efficiency, and changes in the energy mix. Econ. Anal. Policy 2015;(48):222–37.
[11] UNFCCC. Republic of the Philippines: intended nationally determined contributions (INDCc) communicated to the UNFCCC on october 2015. 2016 [Online]. Available: http://www4.unfccc.int/submissions/INDC/Published Documents/Philippines/1/Philippines-Final INDC submission.pdf.
[12] Mondal MAH. Implications of renewable energy technologies in the Bangladesh power sector: long-term planning strategies. Ecology and Development Series No. 74. 2010.
[13] Rout UK, Voß A, Singh A, Fahl U, Blesl M, Ó Gallachóir BP. Energy and emissions forecast of China over a long-time horizon. Energy 2011;36(1):1–11.
[14] IRG. Pakistan integrated energy model (Pak-IEM). Final report volume II:

policy analysis report. Prepared by International Resources Group (IRG); 2010.
[15] Amorim F, Pina A, Gerbelová H, Pereira da Silva P, Vasconcelos J, Martins V. Electricity decarbonisation pathways for 2050 in Portugal: a TIMES (The Integrated MARKAL-EFOM System) based approach in closed versus open systems modelling. Energy 2014;69:104–12.
[16] De Laquil P, Wenying C, Larson ED. Modeling China's energy future. Energy Sustain. Dev 2003;7:40–56.
[17] Nguyen KQ. Long term optimization of energy supply and demand in Vietnam with special reference to the potential of renewable energy. PhD Thesis. Germany: University of Oldenburg; 2005.
[18] Mondal MAH, Kennedy S, Mezher T. Long-term optimization of United Arab Emirates energy future: policy implications. Appl Energy 2014;114:466–74.
[19] Panos E, Turton H, Densing M, Volkart K. Powering the growth of sub-saharan Africa: the jazz and symphony scenarios of world energy council. Energy Sustain. Dev 2015;26:14–33.
[20] IEA. Nordic energy technology perspectives 2016. 2016.
[21] Forsell N, Guerassimoff G, Athanassiadis D, Thivolle-Casat A, Lorne D, Millet G, et al. Sub-national TIMES model for analyzing future regional use of biomass and biofuels in Sweden and France. Renew Energy 2013;60:415–26.
[22] Pietrapertosa F, Cosmi C, Di Leo S, Loperte S, Macchiato M, Salvia M, et al. Assessment of externalities related to global and local air pollutants with the NEEDS-TIMES Italy model. Renew Sustain Energy Rev 2010;14(1):404–12.
[23] Gracceva F, Zeniewski P. Exploring the uncertainty around potential shale gas development - a global energy system analysis based on TIAM (TIMES Integrated Assessment Model). Energy 2013;57:443–57.
[24] Vaillancourt K, Labriet M, Loulou R, Waaub JP. The role of nuclear energy in long-term climate scenarios: an analysis with the World-TIMES model. Energy Pol 2008;36:2296–307.
[25] Føyn THY, Karlsson K, Balyk O, Grohnheit PE. A global renewable energy system: a modelling exercise in ETSAP/TIAM. Appl Energy 2011;88(2):526–34.
[26] Loulou R, Remne U, Kanudia A, Lehtila A, Goldstein G. Documentation for the TIMES model: Part III. IEA Energy Technology Systems Analysis Programme (ETSAP); 2005.
[27] Gargiulo M. Elements of energy technology systems analysis and introduction to the TIMES model generator. IEA-ETSAP VEDA-TIMES Training; 2015.
[28] R.D.M.M. Ravago, R. Fabella, R. Alonzo, "Filipino 2040 energy: power security and competitiveness; working paper, EPDP, University of the Philippines."
[29] Danao RA, Ducanes GM. An error correction model for forecasting philippine aggregate electricity consumption; working paper 2016-05. EPDP, University of the Philippines; 2016.
[30] IMF. Commodity price outlook & risks, research department, commodities team. International Monetary Fund (IMF); 2016.
[31] Mondal MAH, Denich M, Vlek PLG. The future choice of technologies and co-benefits of CO2 emission reduction in Bangladesh power sector. Energy 2010;35:4902–9.
[32] DOE. Energy balance table 1990-2015. Department of Energy (DOE), Republic of the Philippines; 2015.
[33] Fabella RV. The Market Testing of Power Supply Agreements: Rationale and Design Evolution in the Philippines. In: Working paper - 2016-03R. National Academy of Science and Technology (NAST) and Energy Policy and Development Program (EPDP); 2016.
[34] EC. ETRI 2014: energy technology reference indicator projections for 2010-2050; Joint research centre (JRC). European Commission (EC); 2014.
[35] DOE. Department of energy (DOE). Republic of the Philippines; 2016.
[36] ERC. Generation cost benchmarking; consultation paper, energy regulatory commission (ERC). Republic of the Philippines; 2015.
[37] IEA-NEA. Projected Costs of Generating Electricity, 2010 Edition: IEA and NEA, OECD, Paris. Atom Energy 2010;118(Suppl):218.
[38] EIA. Updated capital cost estimates for utility scale electricity generating plants. Washington DC: U.S. Energy Information Administration (EIA); 2013.
[39] EEPC. Ethiopian Electric Power: Power Sector Development Powering Africa 2014. In: Presented by Ethiopian electric power corporation (EEPC); 2014.
[40] IPCC. Renewable energy sources and climate change mitigation: summary for policymakers and technical summary. Special Report of the Intergovernmental Panel on Climate Change (IPCC). 2012.
[41] IEA. Energy technology perspectives 2012 pathways to a clean energy system. Paris: International Energy Agency; 2012.
[42] Salvatore J. World energy perspective. Cost of Energy Technologies; 2013.
[43] NREL. Renewable electricity future study: renewable electricity generation and storage technologies, vol. 2. USA: National Renewable Energy Laboratory (NREL); 2012.
[44] DOE. Philippine power statistics. Department of Energy (DOE), Republic of the Philippines; 2015.
[45] Mallah S, Bansal NK. Allocation of energy resources for power generation in India: Business as usual and energy efficiency. Energy Pol 2010;38(2):1059–66.
[46] IPCC. Revised 1996 IPCC guidelines for national greenhouse gas inventories; workbook, vol. 2. Intergovernmental Panel on Climate Change (IPCC); 1996.
[47] IPCC. Revised 1996 IPCC guidelines for national greenhouse gas inventories; reference manual. Intergovernmental Panel on Climate Change (IPCC); 1996.
[48] IPCC. In: Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. 2006 IPCC guidelines for national greenhouse gas inventories, prepared by the national greenhouse gas inventories programme. Japan: Published: IGES; 2006.
[49] DOE. Philippine energy plan 2012-2030 'energy access for more'. Department of Energy (DOE), Republic of the Philippines; 2012.
[50] DOE. Renewable energy plans and programs (2011-2030). Department of Energy (DOE), Republic of the Philippines; 2011.