SUSTAINABLE LONG-TERM ELECTRICITY SUPPLY-DEMAND: BOTTOM-UP MODELS REVIEW AND OVERWIEW OF THE PROPOSED FRAMEWORK

Yusak Tanoto[1] and Ekadewi A. Handoyo[2]
[1]Electrical Engineering Department, Petra Christian University
[2]Mechanical Engineering Department, Petra Christian University Jalan Siwalankerto, Surabaya, Indonesia
E-Mail: yusak.tanoto@gmail.com

ABSTRACT

Long-term electricity supply-demand can be generally represented into bottom-up models in order to perform optimization with regard to available energy resources and demanded power. The main objective of such models is usually to minimize energy system cost as well as sectoral cost. The aim of this paper is to present a brief review of the commonly used bottom-up energy models and the overview of the proposed framework which describes a sustainable long-term electricity supply-demand. The framework is mainly developed using Long-range Energy Alternatives Planning System (LEAP). In the proposed framework, Demand Side Management is considered as one of system's scenario in the demand side whereas utilization of locally available renewable energy resources is taken into account in the supply side.

Keywords: electricity supply-demand, demand side management, sustainable, renewable energy.

INTRODUCTION

Energy development in a country or region can be studied in a form of energy system model that represents a relation between historical as well as projection data of energy supply-demand and other relevant. It further gives influence on the model output. Existing condition of country's or region's energy profile can be captured in a good designed model. As such, it gives the opportunity to study what will happen in the future through projection taking into account some key parameters. The bottom-up models are hence prefered to find model optimization with regard to available energy resources and demanded power. Example of this type of model include MARKAL (Market Allocation), MARKAL-MACRO, ENPEP (Energy and Power Evaluation Program), and LEAP (Long-range Energy Alternatives Planning System). The main objective of this kind of models is usually to minimize energy system cost as well as sectoral cost.

Representation of renewable energy and Demand Side Management (DSM) in an integrated resource planning energy system modelling is quite challenging since many important attributes of renewables should be taken into account. Only few studies reported integration of renewables into the developed energy system. A framework and methodological development to improve the representation of renewables was presented in [1]. Study on integration of renewable energy into the transport and electricity sector through electric vehicle was reported in [2]. However, lack of reference nor report have been discussed the role of DSM in the all sectoral-energy system modelling, particularly in the national electricity supply-demand model.

This paper is intended to firstly, discuss commonly used bottom-up energy models in terms of framework, benefits, and utilization example and secondly, to present an overview of the proposed framework related to a long-term electricity energy supply-demand. The framework is tried to explain on how the electricity energy could be developed in a sustainable way which include both supply and demand scheme. In the supply side, available renewable energy is considered to be put in the power generation whereas DSM is seen as prominent option to serve the demand side in an efficient way. The proposed framework is developed under LEAP, as one of bottom-up energy modelling tool. This paper is organized as follows; brief review of the bottom-up energy models is presented in the next section along with example of the available bottom-up energy modelling. Overview of the LEAP proposed framework and a highlight of the case study is followed. Finally, conclusion is presented.

BOTTOM-UP ENERGY SYSTEM MODELS

An energy system may consist of the following subsystems: electricity, heat-power, gas energy, solid fuels, and liquid fuels [3]. Unlike the top-down models which are intended to study energy policies for mitigation, the bottom-up energy system models is useful for studying options which impact sectoral end use as well as technological issue. It is commonly used to assess costs and benefits of projects or scenarios. Since then, the models can explicitly include any costs imposed in the selected projects od scenarios altogether with the technical attributes of energy sector. In general, bottom-up energy system models can be futher classified into four types as follows [4].

A. Optimization Models

In optimization models, mathematical linear optimization is used to calculate the minimized cost of energy system of a country or list of country. The least costs configuration is performed within defined constraint, such as emission limit, tax imposed, technology limitation, etc. The optimization could be performed within certain long-term period of yearly based. Optimization model is useful where many options need to be analyzed and future costs are known. Example on this model is MARKAL.

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Developed by The Energy Technology Systems Programme (ETSAP), The International Energy Agency (IEA) [5], it is a dynamic program with a wide range of application used for energy and environmental planning. The characteristic of MARKAL is given in [6]. The program represents energy system which includes available primary energy resource, energy conversion technologies, end-use demand, and technology options to be used in end-use. However, since it does not contain an in-built database, user has to enter a number of input parameter to enable MARKAL choosing the combination of technologies with minimize total costs of the energy system. In each configuration, the model finds the cheapest mix of technologies and energy carrier to meet the demand, that can be devided into several end use sector.

A network of energy resources and demand so-called Reference Energy System (RES) should be firstly prepared to proceed MARKAL. It presents the flow of energy that is originated from resources to the demand. As such, user should define the time horizon of the analysis, energy sourves and carriers, energy conversion technologies, and economic data such as interest rate. Block diagram of MARKAL is shown in Figure-1 [6].

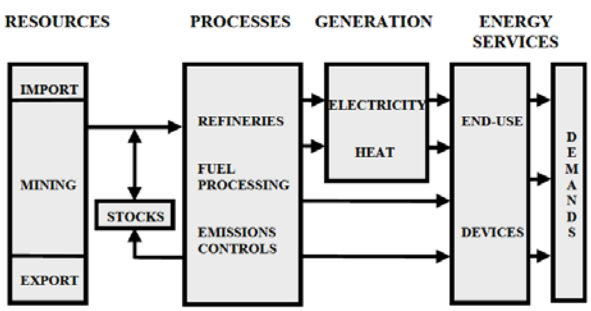

Figure-1. Block diagram of MARKAL [6].

Figure-1 shows the MARKAL family of models. There are some addition or collaboration to the model, such as MARKAL-MACRO, MA RKAL with multiple regions, and MARKAL with material flows.

MARKAL is one of the most popular model. The example of MARKAL utilization can be seen in [3]. The model found that the technological option based on hard coal has the lowest cost of the entire energy system. This is because hard coal is the ceapest energy carrier for Silesia, Poland within the time horizon of 2005 – 2030. Gas fuels is ranked as the second with a share of over 10% whereas oil shown a decrasing contribution from 7% in the base year to 2% in 2030.

B. Iterative Equilibrium/Simulation Models

Simulation models perform a simulation of energy in the demand side as well as supply side under various attributes, for instance price, income level, and constraints. In this kind of models, non-price factors is easier to be included in the analysis compared to optimization models. Iterative calculations of endogenously adjusted prices and quantities is performed to seek equilibrium prices. These models do not assume energy is the only factor affecting technology choice. Example of this model is ENPEP-BALANCE. Developed by Argonne National Laboratory USA, it is a non-linear, equilibrium tool that match the demand for energy with available resources and technologies.

The model is a set of ten integrated energy, environmental, and economic analysis tool. A market-based simulation approach, BALANCE, is used to determine the response of various segments of energy system to changes in energy prices and demand level [6]. To work with the tool, energy network that traces the flow of energy should be created through nodes and links. Nodes represent resources, conversion processes, demands, and economics processes whereas information among nodes is connected via links [4]. As example, the model was used to analyze Mexico's future energy demand and associated environmental impact [7], developing greenhouse-gas emissions projection in Turkey [8], greenhouse-gas mitigation analysis for Bulgaria [9], and simulation of electricity production from renewable energy resources in an energy system [10]. Nodes and Links in BALANCE can be seen in Figure-2 [4].

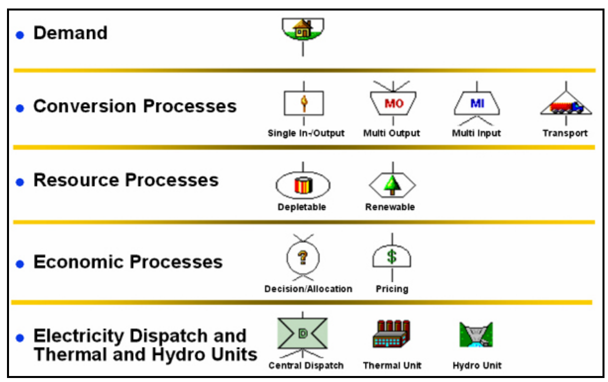

Figure-2. Nodes and links in BALANCE [4].

C. Hybrid Models

Hybrid models maximize present value of utility of a representative consumer. In addition to energy system optimization, macroeconomic impacts of energy system is going to be examined where changes in the energy system can feedback to effect macroeconomic growth and structure. Example of this model is MARKAL-MACRO, which is an extension of the MARKAL model that simultaneously solves the energy and economic systems, and solved by nonlinear optimization. This is an integration of a bottom-up model and a top-down model in a single modelling framework. The model has price responsive demands and maximizes consumer welfare over the time horizon as well as provides least cost energy system configurations [4]. Example of MARKAL-MACRO report can be seen in [11]. An overview of MARKAL-MACRO is shown in Figure-3 below.

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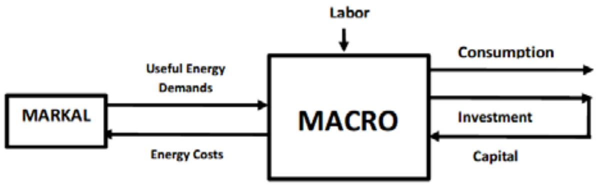

Figure-3. An overview of MARKAL-MACRO [11].

Example on the use of MARKAL-MACRO can be seen in [12], in which the model was used in the integration of energy system optimization with the macroeconomic growth model to analyse two-way linkage between energy system and the economy. According to the study, the capability of macro-economy oriented models are opposite to technical models. Hence, combination of such models became the best solution for complex analyses.

D. Accounting Frameworks

In this framework, flows of energy in a system is taken into account based on simple engineering relationship. Outcomes of decisions is accounted, for instance, environmental and social cost implications of alternative future energy scenarios rather than simulating the decisions such as market share based on prices and other variables. The costs, emission reductions, and savings in terms of fuel and energy that would be achieved in investing in more energy efficient and renewables versus investing in new power plant could be revealed. Due to its simplicity, flexiblility, and lower data requirement, the framework is capable of examining impacts that is potentially resulted from the selection of technology. However, the least cost energy system is not automatically identified since the framework is not working based on optimization technique.

A well-known example of accounting framework based tool is LEAP, which is developed by Stockholm Environment Institute [13]. LEAP is an integrated annual-time step modelling tool that can be used to track energy consumption, production, and resource extraction in all sectors in national energy system [14]. LEAP structure and calculation flows is presented in Figure-4 [15]. Advantages of LEAP include easiness to be linked with MS-Office and the applicability to model local, national, and regional energy system in medium to long-term time frame. Moreover, a number of different modelling methodologies can be supported with. It ranges from bottom-up, end-use accounting techniques to top-down macroeconomic modelling on the demand side, and a range of accounting and simulation methodologies for modelling electricity generation and capacity expansion planning on the supply side [14].

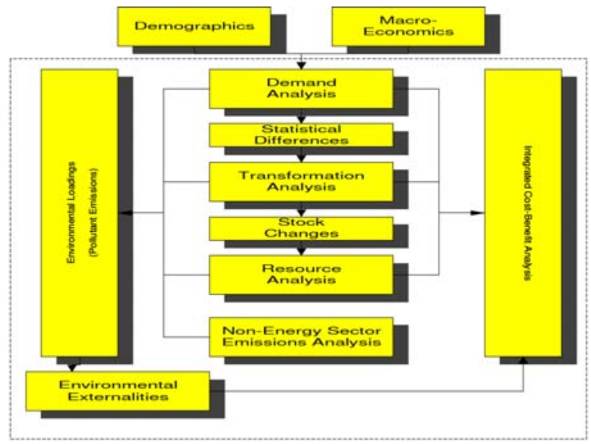

Figure-4. LEAP Structure and calculation flows [13].

Numerous reports and peer-reviewed journal papers have been published involving LEAP, including analysis of the potential reductions in China's road transport energy demand and emissions [16], identification of feasible penetration of sustainable energy on Greek Island of Crete [17], investigation of the improved building energy efficiency in China [18], in addition to a list of reports that can be obtained in [13].

THE ROLE OF DEMAND SIDE MANAGEMENT

DSM could play a significant role in the study of energy system as well as to develop energy system modelling, particularly for the case of electricity supply and demand. Implications of DSM scenarios over the projected demand and end-use technologies could be very usefull towards energy policy establishment. The increasing attention on DSM has been greatly influence by the need of efficient use of finite energy resources. DSM has been viewed as promising approach to reduce electricity consumption in the demand side. Moreover, it is beneficial to defer high investment in generation expansion and effective to contribute toward reduction in greenhouse gas emission. Up to now, no other method better than the DSM in providing efficient use of electricity has been introduced. In real world, one of DSM most successful achievement was the implementation of lighting DSM program in Thailand during 1993-1997. The national campaign was successfully reduced peak demand by over 238 MW and cummulative annual energy saving of 1,427 GWh [19].

Regarding to national electricity supply-demand model, there is lack of publication in which DSM is included as part of scenarios proposed into the model, to the best author's knowledge. It have been reported that the DSM scheme was used in the investigation of electrical energy efficiency and environmental sustainability and as options to reduce power and energy consumption as well as CO_2 emission in household sector [20-22]. As reported, the reduction in power and energy consumption would be achieved through the present of energy efficient-technology appliances that built the improved demand loading patttern. In this sense, the technology was applied as a representation of DSM purpose, that is to reduce power and energy consumption in the observed sector rather than to introduce DSM techniques to reduce the whole sectors's power and energy demand.

The Proposed Sustainable Electricity Supply-Demand ModeL

In this research, a long-term sustainable electricity supply-demand model is proposed within the bottom-up energy system model framework. The sustainability condition is introduced from the at once-involvement of renewable energy resources in supply side and DSM on the demand side. The aim of the proposed framework is to investigate the potential benefit of applying renewable based power generation and DSM towards overall sectors of energy system. To, establish such a model, the accounting framwork is chosen considering its relative benefit over the other types of framework, as described earlier. The optimization in terms of least cost energy system may not be taken into account in the proposed model, since it is not the ultimate purpose of it, rather than to explore implications in terms of resources, energy demand, environment, and costs of applying available renewable energy resources and DSM into the model, and compare to other scenario, which is likely the basecase condition that is projected over the model's time frame. Moreover, implications of potential power and energy saving from introducing DSM itself is the main focus to further explore appropriate policy.

Based on the aforementioned considerations, the proposed long-term sustainable electricity supply-demand model is developed using LEAP. The model is then constructed incorporating energy supply data, which is data of renewable energy resources in terms of capital and other costs, capacity and other technical specification, energy demand data, which include all user sectors, end-use and technology, economic data, and other relevant data related to energy end-user. Other scenario may include "bussiness as usual". In the energy demand data, we introduce the principle of DSM in so called general and specific approach. In general approach, the DSM can play a role through creation of least growth of demand in selected or all sectors whereas in specific approach, DSM is manifested through the utilization of energy efficient technology that in turn reduce the demand. The overview of the proposed model is presented in Figure-5. Three types of energy supply data which is related with resources and power generation data are considered, i.e. based on fossil fuel only, mixed, and based on renewables only.

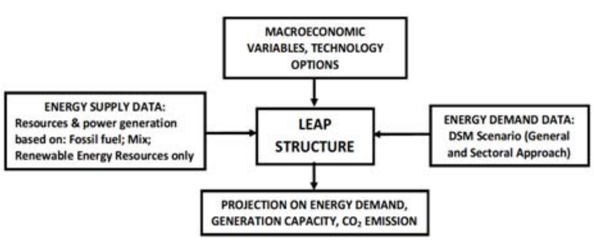

Figure-5. The proposed model using LEAP structure.

The proposed model with corresponding types of energy supply data is then used to perform a local long-term sustainable electricity supply-demand model. The selected areas are Jember, Situbondo, Bondowoso, Banyuwangi, and Lumajang. Each of area is so-called a district of East Java province. Existingly, all areas are supplied by a coal fired power plant called PLTU Paiton, nearly localted close to Situbondo district. This power plant is one of the largest in term of capacity in Java-Madura-Bali interconnection system. Besides, significant potential of renewable energy is feasible in the form of geothermal energy of Mount Ijen in Bondowoso. Historical and base year macroeconomic and other relevant data in terms of regional GDP, population, sectoral power demand are provided into the structure. The DSM scenario is then imposed over the model time frame to obtain projection on sectoral as well as whole area energy demand, required power generation capacity and renewable penetration, and environmental impact in terms of CO_2 emission.

CONCLUSIONS

Various bottom-up energy system models along with some example are briefly reviewed in this paper in terms of their framework, benefits, and limitations. This paper presents the application of the powerfull bottom-up energy system modelling in the case of long-term electricity supply-demand. Sustainability approach in the supply and demand side is applied keypoint into the LEAP framework. As previously highlighted in section four, analysis of the case study along with the results and implications derived form the DSM scenarios shall be provided in the coming paper due to more rigorous data collection and compilation is being done. However, the proposed framework has been sucessfully tested with the smaller scope of data and selected sector.

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