Energy Strategy Reviews 2 (2013) 153–160

Contents lists available at SciVerse ScienceDirect

Energy Strategy Reviews

journal homepage: www.ees.elsevier.com/esr

ANALYSIS

Power generation and cross-border grid planning for the integrated ASEAN electricity market: A dynamic linear programming model

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A R T I C L E I N F O

Article history:
Received 10 September 2012
Received in revised form
21 November 2012
Accepted 5 December 2012
Available online 8 January 2013

Keywords:
ASEAN Power Grid
Integrated ASEAN electricity market
Cross-border power trade
Renewable energy
Dynamic linear programming

A B S T R A C T

The central question raised in this study is how to meet the growing power demand in ASEAN countries in the next two decades. Uneven distribution of energy resources and uneven paces of economic development among ASEAN countries complicate the question. The ASEAN Power Grid (APG) that interconnects all ASEAN countries and enables cross-border power trade could potentially provide cost-saving solutions. This study builds a dynamic linear programming model and simulates optimal development paths of power generation capacities in ASEAN countries. Scenarios are built around the assumptions about the power trade policy regimes. It is found that more open power trade regime encourages development of renewable sources of power generation, and accrues more savings in the total cost of meeting the growing future power demand from 2010 to 2030.

1. Introduction

Electricity demand in the ASEAN region is projected to grow 6.1–7.2% per annum. At such speeds, according to the Institute of Energy Economics Japan (IEEJ) [1], it would arrive at 3–4 times of current level by 2030. Comparing to the Asia Pacific region as a whole for which the electricity demand grows at 3.4% per annum, as Asian Development Bank (ADB) [2] predicts, ASEAN's demand for electricity is growing especially fast, thanks to the exceptionally high economic growth prospect of the region.

Meeting such high growing demand will be extremely challenging although ASEAN countries are considered rich in energy resources. ASEAN Center for Energy [3] and ASEAN Ministers Meeting [4] estimated that the ten member countries of ASEAN have 22 billion barrels of oil reserve, 227 trillion cubic feet of natural gas reserve, 46 billion tons of coal reserve, 234 GW of hydropower potential and 20 GW of geothermal capacity. However, the distribution of the resources is unbalanced. Most of the hydropower resource is located within the Greater Mekong Subregion that includes Cambodia, Lao PDR, Myanmar, and Viet Nam, as well as Yunnan and Guangxi Provinces in southern China. Coal resource concentrates in Indonesia and Malaysia. Most of the gas and oil reserves are in Malaysia and Indonesia. Apart from uneven energy resource endowment, Atchatavivan [5] argued that the unbalanced level of economic development among the ASEAN countries adds to the difficulty in utilizing these resources to meet the fast-growing electricity demand.

In vision of the above situation, an ASEAN Power Grid (APG) that links the energy resource-rich and the energy resource-poor countries could potentially play an important role in reducing the overall cost to the region to meet its growing electricity demand. The ASEAN 2020 Vision adopted in 1997 by the heads of state at the 2nd ASEAN Informal Summit held in Kuala Lumpur envisioned an energy-interconnected Southeast Asia through the APG and the Trans-ASEAN Gas Pipeline (TAGP) Projects, as reported by the ASEAN Secretariat [6]. A working group was established in 2000 to undertake an ASEAN Interconnection Master Plan Study (AIMS), completed in 2003. Based upon an optimization study, eleven potential power grid interconnection projects were selected for potential implementation through 2020. The Heads of ASEAN Power Utilities/Authorities (HAPUA), a specialist organization under the ASEAN Center for Energy (ACE), monitors the implementation of the APG.

The quantitative analysis of regional power market integration in ASEAN has not been studied extensively, and a few existing studies have focused on the institutional and policy aspects of regional development in relation with energy cooperation. The policy and institutional barriers to the formation of the Greater Mekong Sub-region (GMS)

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2211-467X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.esr.2012.12.004

energy cooperation is discussed by Yu [7] and an update on the progress of GMS power market integration is provided by the Economic Consulting Associates [8]. Adopting the Purdue Electricity Trade Model — a cost minimization model for energy resource planning, Yu et al. [9] assesses the potential of hydropower development and free power trade between China and ASEAN countries. Using an energy-engineering model, Watcharejyothin and Shrestha [10] analyze the power development planning of Lao PDR and Thailand and explore the power trade opportunities between the two countries, focusing on hydropower. In sum, a systematic analysis on the planning of power development and the economic benefits with an integrated ASEAN power market has not been conducted.

This study serves to quantify the economic benefits of the APG, as well as to propose an optimized development plan of power generation capacity in the region, based on the APG. Accordingly the purposes of this study are on the one hand to justify the investments on the APG, and on the other hand to identify the priorities in developing new power generation capacity and transmission lines to meet the growing demand over time. For these purposes, a dynamic linear programming model is built to simulate the demand and supply of electricity in the ASEAN region in the next few decades. The following section presents more details about our methodology.

2. Methodology

Answering how to prioritize increasing generation capacity and expanding grid networks, this study applies a well-established dynamic linear programming model to the power planning of the ASEAN countries for the next few decades, assuming that the corresponding APG infrastructure would be in place. In this way, this study delivers implications on the optimal timing of investment in both the power generation capacity and the cross-border power grid infrastructure. In our framework, being optimal would imply the least cost of power generation while catering to meet the growing electricity demand.

This study intensively scans and collects data about exploitable energy resources in each member country of ASEAN as well as the operation cost and capital cost of monetizing the resources for power generation using different technologies. Our dynamic linear programming algorithm suggests the optimal timing of investing and monetizing each type of energy resource of the ASEAN countries.

A few scenarios are constructed to reflect different assumptions about power trade policies: no power trade, 20% of demand allowed to be met by power trade, and 50% of demand allowed to be met by power trade.

The study adopts a dynamic linear programming framework in power generation first developed by Turvey and Anderson [11] and later adapted by Chang and Tay [12]. In this study, significant extensions of the original models are made. A new country dimension is added to allow an international framework with cross-border electricity trade. The new model also adds the cost of cross-border power transmission as well as transmission loss into account. Last but not least, the model covers the issue of carbon emissions from power generation as well as the carbon cost of power generation. The model is solved using General Algebraic Modeling System (GAMS).

The study serves two important purposes, one of which is to examine the least-cost development of different types of energy resources using dynamic optimization and the other is to comprehensively scan alternative combinations of energy resources needed for power generation in each time period.

In such a model, taking a long-time horizon, the planner's objective is to choose plant capacities and outputs so as to minimize the present value of total costs.[1] The levelized cost of generating electricity is therefore embedded in this model. The sets of constraints to be satisfied are as follows. First, available installed capacity needs to be sufficient to meet the expected peak demand plus an allowance for demand above expected levels. Second, the total plant output must be sufficient to meet the instantaneous power demand levels. Third, the output from each plant cannot exceed its available capacity. Details about the model could be found in Appendix A.

Adapting and modifying the dynamic linear programming framework, this study quantifies external economic, technological, and institutional shocks in different scenarios and develops power planning strategies accordingly.

3. Data description

3.1. Scope

This study covers the ten member countries of ASEAN, which are Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam.[2] Technologies or means of power generation covered in this study include coal, diesel, natural gas, hydro, geothermal, wind, solar PV, and biomass.[3]

3.2. Data inputs

The main items of data required for this study include existing capacities of the eight types of power generation, the capital expenditure (CAPEX) and operational expenditure (OPEX) of these types of power generation, the load factor and life expectancy of each vintage of each type of power generation, the energy resources available for power generation in each country, the peak and non-peak power demand and duration of power demand of each country, projected growth rate of power demand, and transmission cost and transmission losses of cross-border power trade.

Data are collected from the Energy Information Administration (EIA), the International Energy Agency (IEA), HAPUA, the ASEAN Center for Energy (ACE), the World Energy Council (WEC), the Solar and Wind Energy Resource Assessment project, and other country-specific sources. Detailed data and sources of data are presented in Appendix B from Table B1—Table B5.

3.3. Scenario parameters

Growth in power demand is derived from the Third ASEAN Energy Outlook. Different countries grow at their own paces, from 2010 to 2030, as shown in Table 1.[4]

Projections of future economic activity are always built on assumptions of different scenarios. In this model, the parameters to reflect different visions about future technology evolutions and social

[1] The model is one with cost-minimization of power development planning over long-time horizon. Unlike a dynamic CGE model, it does need to assume a steady state solution.

[2] It is understood by the authors that Yunnan province of China has been conducting cross-border power trade with Viet Nam and Lao PDR. However, the maximum of the power trade between Yunnan and Viet Nam is 800 MW, and in the case of Lao PDR it is much smaller. We therefore think these cross-border power trade activities are not going to bring major impacts to the pattern of cross-border power trade within ASEAN, as estimated by our model.

[3] Nuclear is not covered in the scope of this study for two reasons. First, after the Fukushima nuclear power station accident, the attitude of the world has changed drastically against nuclear power generation. Second, the risks embedded with nuclear power generation are hard to estimate and therefore not reflected in the data about its costs reported publically.

[4] If legitimate forecasts on the growth of power demand are available, a kind of sensitivity analysis such as lower growth or higher growth cases could be done. As the focus of this research, however, is to examine the impact of regional power trade policy regime and corresponding power development planning, it does not consider alternative growth rates of power demand.