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Optimizing long-term investments for a sustainable development of the ASEAN power system

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ABSTRACT

The electricity consumption in the ASEAN (Association of East Asian Nations) region is one of the fastest growing in the world and will lead to a dramatic increase in greenhouse gas emissions in the next decades. A decarbonization of the region's electricity supply is thus a very important measure when taking action on global climate change. This paper defines cost-optimal pathways towards a sustainable power system in the region by employing linear optimization. The proposed model simultaneously optimizes the required capacities and the hourly operation of generation, transmission, and storage. The obtained results show that all different kinds of renewable sources will have to be utilized, while none of them should have a share of more than one third. The findings give reason for setting up an ASEAN power grid, as it enables the transportation of electricity from the best sites to load centers and leads to a balancing of the fluctuations from wind and solar generation. We suggest fostering a diversified extension of renewables and to elaborate on political and technical solutions that enable the build up an transnational supergrid.

1. Motivation and related work

The economic development of the ASEAN (Association of Southeast Asian Nations) countries has induced a tremendous growth of the energy demand in the last decades. The primary energy demand in the region increased from 223 Mtoe (million tons of oil equivalent) in 1990 to 549 Mtoe in 2011, which is an average growth rate of around 5% per year [1]. This trend is expected to continue at high rates in the next decades [1] and might even be accelerated by global warming [2]. The increase of wealth will lead to an increased percentage of electricity in energy demand: electricity is expected to account for more than 50% of future growth in energy demand [1]. All those aspects emphasize the importance of an economic viable, environmental friendly, and secure electricity supply.

Currently, the region is relying on four major sources for electricity production: coal, gas, oil, and hydro [1] (see also Fig. 1). Other sources only play a minor role so far, and fossil fuels were responsible for 85% of the generated electricity [3]. The consequence is a high level of CO_2 emissions which is increasing further at a high pace. The region's energy related CO_2 emissions are expected to grow from 1.2 Gt in 2011 to 2.3 Gt in 2035, resulting in a share of 6.1% of all global emissions [1]. At the same time, the region is highly vulnerable to hazards from climate change, such as increased sea-level, more frequent extreme weather, and agricultural challenges [4]. In order to combat those environmental hazards, a transformation of the ASEAN power system towards higher percentages of low-carbon energy sources is inevitable and should be a constitute of global climate policies.

ASEAN has several economically viable RE (renewable energy) resources. However, they are unevenly distributed across the countries and mostly are distant from the load centers in the megacities like Singapore or Bangkok [5,6]. It is therefore a non-trivial task to find the best locations for the utilization of the renewable resources in a cost-effective and political viable way. However, organizing the transformation into a low-carbon power system at low costs is important for maintaining the prosperous economic growth.

Finding cost-optimal pathways for this transformation towards a low-carbon power system is the main contribution of this article. The optimal configuration of a future power system includes the locations and capacities of the renewable and fossil generation

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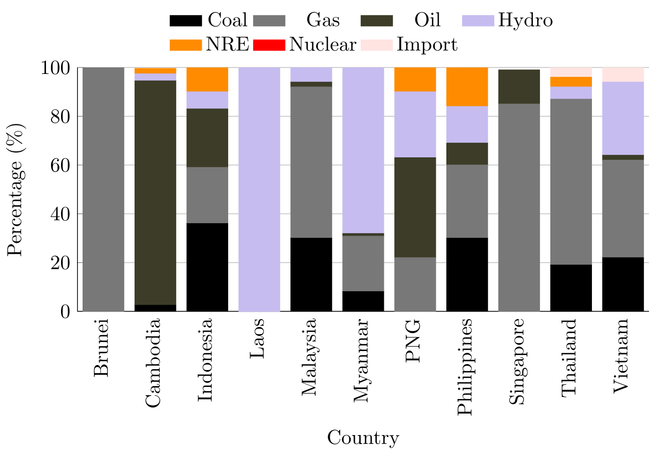

Fig. 1. Current generation mix in the ASEAN countries [24] (NRE = new renewable energies).

facilities, the placement of storages, and the transmission connections. In this paper, we model the cost-optimal build-up of this infrastructure for different levels of maximally allowed CO_2 emissions. Modeling the evolution from a mainly fossil-fuel-based generation mix towards a zero-emission system is essential for policymakers and investment planners. The results give them both a completely emission free target scenario as well as several intermediate steps. We know that our results are not a prediction about the future system and that unforeseen breakthroughs in technology could completely change the picture. The history of energy models and especially of resource optimization models showed that scenarios have to be considered very carefully and often turned out to be wrong in several aspects. To give a prominent example, the scenarios modeled by Nordhaus in the 70's [7] did not foresee the current fracking boom in the US at all. Still, the suggested approach of optimizing the allocation of resources is necessary in order to get an idea of the infrastructure required.

Several energy system models of Southeast Asia were developed in recent years for policy analysis. Following the historical development of these models, the first examples are bottom-up optimization-based models, such as MARKAL (MARKet ALLocation) [8] and bottom-up accounting models, like LEAP (Long-range Energy Alternatives Planning system) [9]. An early example of the application of a LEAP model can be found in Ref. [10]. Recently, some new model types that find cost-optimal power generation configurations were published. Major existing models are summed up in Table 1, of which we will discuss the three most relevant ones and compare them to our approach below.

Table 1
Overview of employed energy models in the ASEAN region.

Location	Type	Year & source
Indonesia, Philippines	MARKAL	1999 [8]
Indonesia, Malaysia, Philippines, Thailand, Brunei, Vietnam, Singapore	LEAP	2002 [10]
ASEAN except Brunei and Singapore	MARKAL	2002–2006 [11]
ASEAN and southest China	min cost	2005 [12]
GMS	MESSAGE	2008 [13]
GMS	MARKAL	2009 [14]
Laos, Thailand	MARKAL	2009 [15]
ASEAN	LEAP	2009–2010 [16]
ASEAN	Dynamic programming	2012 [17]

The MARKAL-based model of Watcharejyothin et al. [14] includes five countries of the GMS (greater Mekong subregion) and is built upon their national MARKAL models. The model analyzes the benefits of integrating more local energy sources into the energy system, whereby electricity is one among all energy sectors. The dynamic linear programming model of Chang [17] is the first top-down model for ASEAN with a focus on the integration of RE. Based on macroeconomic data (fuel prices, CAPEX and OPEX of generation, demand growth, among others), the model identifies the priorities for developing new power capacities in order to meet the growing energy demand. The approach, however, does not account for the time-dependent generation and availability of renewable sources such as wind and solar energy.

Another model that analyzes the integration of renewable sources was developed by Yu et al. [12]. It includes the temporal dimension in form of typical days as well as the spatial dimension by considering 21 regions. The main focus of this model is the evaluation of new hydro resources. Our model is an improvement over that approach by allowing for more details in both dimensions: a higher number of regions and the use of 12 complete weeks with each 168 hourly time steps in a row instead of a few representative time steps [12]. We extend the research of Yu et al. [12] by analyzing the integration of all relevant renewable energy sources: hydro, wind, solar, geothermal, and biomass. Furthermore, we evaluate storage technology and its competition to transmission extension which could become an important design question for future power systems [19,18]. We apply the URBS methodology that was developed by Richter [20] and was employed for several studies on renewable integration and optimal grid extension [21,22]. URBS allows for the simultaneous optimization of operation and the extension of generation, storage, and transmission on high temporal and spatial resolution.

Stich et al. [23] apply the URBS methodology for the first time in the region, but with limited scope to Singapore, Malaysia, and Indonesia. The researchers were mainly looking at short term investments whereas the research in this article goes beyond that by modeling the complete ASEAN region and looking into long time investments.

All existing modeling approaches focus on a time span ranging from the current status to the next 20 years. A precise model of the current infrastructure with complete databases is required in order to achieve validity in such models. The optimal capacity extension of power plants and transmission mainly depends on the current capacity and location of power plants. In our article, a time horizon reaching to the year 2050 is considered. Therefore, the results concerning new infrastructure will not depend on current facilities and data quality anymore but on the generation structure of renewable sources as well as on the development of load in the regions. Our model has three main features that distinguish it from former approaches:

1. the consideration of temporal fluctuations in RE generation as well as demand,
2. the geographical distribution of load and RE resources in 33 subregions,
3. a technological bottom-up approach considering generation, transmission, and storage.

With this model setup, we aim at giving answers to several of the most important questions for policy makers and systems planners: Which resources should be utilized where? What are the most important transmission lines for fostering renewable generation? Should countries cooperate or are self-sufficient solutions