RENEWABLE ENERGY INTEGRATION, SYSTEM FLEXIBILITY AND DECARBONIZATION

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Overview

Energy is one of the essential components of sustaining decent living. The number of people without access to electricity in Southeast Asia is over 200 million (International Energy Agency, 2014). Achieving sustainable energy is one of the key components of sustainable development as presented in the Sustainable Development Goals (United Nations, n.d.). The Association of South East Asian Nations (ASEAN) has been working on utilizing its energy resources scattered across the region through the integrated grid networks. The ASEAN Power Grid and the Trans ASEAN Gas Pipelines are the backbone of the integration efforts. The power trade in the Great Mekong Sub-region is a good example of successful power trade in the region.

Energy market integration has been suggested as a way of achieving sustainable energy and development (e.g., Wu et al, 2012; Kimura et al, 2013; Chang and Li, 2013; Li and Chang, 2015). Energy market integration in East Asia appeared to help meet surging energy demand and ease demand shocks in the region. It also appeared to remove some subsidies in the electricity sector (Wu, Shi and Kimura, 2012). The possible benefits of energy market integration could be huge even after taking account the costs of and losses in transmission (Chang and Li, 2013). If the costs of grid interconnection are taken account in real terms, the possible benefits could be negative as the costs of transmission infrastructure are high. Nevertheless, the resulting benefits, after taking account the costs of grid interconnection, transmission costs and losses, could be positive although the amount appears to be marginal (Li and Chang, 2015).

The ASEAN has huge potential in renewable energy such as hydropower, solar energy, wind energy and biofuel (Chang and Li, 2015). One country in the region cannot afford the total costs required for the development and the country may not able to absorb the entire amount of electricity supply from its renewable potential. This raises a need for a regional power grid-based market. Despite strong support from literature for integrating energy market in the region, integrating renewable energy into a power grid in the region has been slow due mainly to the intermittent availability of electricity from renewable sources. There are some possibilities of flexibility in supply of and demand for electrcity that can promote the integration of renewable energy into the grid. Possible supply components of flexibility are conventional generators, renewable generators and storage. Wind and solar energy added variability to the supply side. Possible demand components of flexibility are building end uses, electric vehicles and storage. Grid flexibility is the necessary condition for more integration of renewable energy into the fuel mix in ASEAN nations (Huang et al, 2019) and accessing such flexibility appears to be a key to renewable energy integration into the grid.

This study aims to examine how the integration of renewable energy incorporating system flexibility into the regional power trade affects the total cost of meeting the energy demand of the ASEAN as a whole and the amount of carbon dioxide emissions. It takes the ASEAN power trade model developed by Chang and Li (2013 and 2015) and Li and Chang (2015) as a base and modifies it to incorporate system flexibility. The modified AEAN power trade model includes a flexibility option and explicitly considers the effect of renewable energy integration and system flexibility on the trajectory of carbon dioxide emissions and the cost of carbon in the region. Using the General Algebraic Modelling System (GAMS), the study solves the model, verifies whether and how system flexibility shapes the process of decarbonization in the region and derives policy implications.

Methods

The model of this study consists of an objective function and various constraints such as resource endowments, technologies, capital and operation costs, and carbon emissions and corresponding taxes, among others. Altogether they make power trade in the region feasible and realistic. The objective function is to minimize the cost of meeting energy demand by taking account all resource endowments, available technologies and constraints. The constraints considered are resource endowments, electricity generation technologies, capital and operation costs, carbon emissions and corresponding taxes, and cross-border transmission costs. Optimising the above objective function should meet the following critical conditions. First, total power capacity should meet total power demand in the region. Second, the power supply of all countries to a certain country must be greater than the country's power demand. Third, the total supply of power of one country to all countries (including itself) must be smaller than the summation of the country's available power capacity at the time. Fourth, power traded across border should be subject to the constraint of transmission capacities available at a certain point of time. This study includes an electrical storage system in a country to see how this affect the trajectory of carbon emissions and the total cost of meeting the demand for electricity in the region.

This study constructs two scenarios. A first scenario is a case without system flexibility. Along with the base case in which no system flexibility is considered, this study builds a second scenario that specifically considers the system flexibility. The system flexibility enters into the model in the form of electrical storage system. It shows how system flexibility affects the transformation of power system and the cost of meeting ever-increasing energy demand in the ASEAN. It also presents how environmental considerations such as the imposion of carbon taxes on fossil fuels will influence the transformation of power generation mix in the region as a whole and the amount of carbon dioxide emissions that is the negative environmental consequence of conventional generators. For each scenario, this study considers three cases – no power trade, power trade up to 50% and 80% of the total power demand in the region.

Results

This study presents two key findings. First, integrating regional electricity market enabling power trade in the region appears to increase the amount of carbon dioxide emissions and the value of the objective function, meaning the total system cost higher than that of no-trade case. Unlike the cases of no or lower levels of power trade such as 50% power trade, the case of 80% power trade presents an almost non-decreasing trajectory of carbon dioxide emissions. This implies that the higher level of power trade appears to utilize all possible sources of generation technologies regardless of whether generation technologies are carbon-intensive or not. This led to higher amounts of carbon dioxide emissions and higher total system costs but higher levels of economic output. This finding seems to be against the common perception that an integrated electricity market is expected to decrease the amount of carbon emissions. The integration of regional electricity market is considered the good way of utilizing all potential sources of power generation but seems to have negative impacts on the amount of carbon emissions. More aggressive policies are required to address such seeming negative consequences of integrated regional electricity market.

Second, incorporating system flexibility into a power trade model in the form of electrical storage system appears to decrease the amount of carbon dioxide emissions and flatten the trajectory of carbon dioxide emissions compared to the case without system flexibility. Like the case of integrated regional electricity markets without system flexibility, it appear that the higher level of power trade is, the flatter the trajectory of carbon dioxide emissions is. The lower level of power trade is, the more fluctuations in the trajectory of carbon dioxide emissions are. This implies that lower cost generation technologies are utilized first as these are cheaper and followed by higher cost generation technologies such as renewable energy sources. Once the low cost, low carbon-emitting generation technologies are exhausted, the more carbon-emitting expensive fossil fuel-sourced generation technologies are utilized. This makes the shape of the trajectory of carbon dioxide emissions a cubic form of increasing, decreasing and increasing. An interesting point observed is that the gap between the highest trajectory of carbon emissions and the lowest one (i.e., the case of no-trade) under the case with system flexibility is slightly wider than that of the case without system flexibility.

Conclusions

This study examines how system flexibility affects the integration of renewable energy into the grid and influences the amount and trajectory of carbon dioxide emissions. It takes an electrical storage system as a form of system flexibility and Singapore as a country. Singapore has planned to install 6,480MW of electrical storage system by 2050. This study presents two key findings. First, the more power trade is allowed in the integrated regional electricity market, the higher amount of carbon emissions is. This seems to be against common perception. The integrated regional electricity market, however, pushes under-utilized generation technologies mainly fossil fuel-fired generation ones to the limit and hence more carbon emissions as higher levels of power trade are allowed. Second, when system flexibility is incorporated into the integrated regional electricity market, it appears to decrease the amount of carbon emissions. It also appears to flatten the trajectory of carbon dioxide emissions.

References

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