



Regional power connectivity in Southeast Asia: the role of regional cooperation

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Abstract: ASEAN is an interesting case study of regional power connectivity in Asia and the Pacific due to its geographic location and ongoing power connectivity within and beyond ASEAN. This paper reviews ASEAN's power connectivity within ASEAN and between ASEAN and its neighbours (hereafter ASEAN connectivity). Through literature survey, it identifies challenges to the ASEAN connectivity from political, legal, economic and technical perspectives. Based on these analyses, it then explores what, how and when regional cooperation may be able to facilitate ASEAN power connectivity.

Keywords: Power connectivity, ASEAN, China, ASEAN Power Grid, GMS.

1 Introduction

ASEAN located in a strategic position that connects energy deficit in Northeast Asia, mainly China, Japan and North Korea, to the rest of the world. It is also located in the Southeastern part of Asia and at the junction of Asia, Oceania, Pacific Ocean and Indian Ocean. ASEAN and China has been long connected through cross-border power grids in the Greater Mekong Subregion (GMS) and ASEAN is in dialogue of connecting South Asia under

the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC). Five ASEAN countries, Cambodia, Laos, Myanmar, Thailand and Viet Nam, are members of the GMS. Two ASEAN countries, Myanmar and Thailand, are also members of the BIMSTEC group. The recent initiative of connecting China's grid with India, Pakistan and Bangladesh has further highlighted the bridging role of ASEAN in Asia's regional connectivity. In the more ambitious vision of the Asia Pacific Super Grid, ASEAN will become the gateway that exports Australian electricity to ASEAN and other Asian countries [1,2]. This paper reviews the energy sector, particularly power grid sector within and beyond ASEAN, identifies the challenges and barriers to power connectivity in ASEAN and gives suggestions regarding to what and how regional cooperation can advance ASEAN power connectivity. The existing literatures mostly focus only on power grids interconnection and power trading within the border of ASEAN, with no

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inter-regional perspective. Ahmed et al [3] review the energy resources and the future energy utilization projection for ASEAN. They analyze the major barriers and technical challenges for establishing an APG and argue that the efficient utilization of clean energy resources can facilitate the construction of transmission lines. They also suggest possible technologies to overcome the limitations of the establishment of APG. IEA [4] argues that the APG would help ASEAN member states increase supply security, meet their rising energy demands and improve access to energy. Therefore, ASEAN countries should work together to harmonize grid codes and reliability standards and establish an independent regional regulator to facilitate such harmonization. Owen [5] examine power interconnection in Southeast Asia and analyze and compare multi-lateral power markets in the world including the Southern African Power Pool and the Nord Pool. By studying the experience elsewhere in the world, they explore the challenges of ASEAN power grids interconnection and provide a template for appropriate practice to meet the financial, technical, and political requirements of APG.

Further, in the institutional sense, Aalto [6] assesses energy market integration in East Asia by comparing the role of institutions in Southeast Asia and Northeast Asia. The Southeast Asian energy market integration and the relevant regulatory harmonization are hampered by the unresolved status of sovereignty within ASEAN. In Northeast Asia, the interconnection projects and the regional integration have been overshadowed by its dependence on global energy markets. The institutional structure in both regions allows for step-wise infrastructure integration while the overall structure of informal institutions hinders deeper energy market integration in a number of ways. In the technical sense, Ahmed et al. [7] conduct a feasibility study of high voltage alternating current (HVAC) and high voltage direct current (HVDC) transmission option for APG. The study shows that APG can increase power generation from countries with abundant renewable resources. It is also revealed that in some transmission lines of APG, HVDC would be more economically beneficial than HVAC. Boëthius [8] compares the political forces that drive electricity grid expansion in the EU and ASEAN. He concludes that there are compelling economic, environmental and energy security benefits of electricity market integration, despite the political and economic barriers to the market integration. All these existing literatures either focus on the power grid system within ASEAN, or analyze ASEAN's electricity market integration from a specific point of view, such as the institutional, technical, or political aspect. To the best of our knowledge,

no study has been done for ASEAN's power connectivity with a reference to the inter-regional angle, i.e., power connectivity between ASEAN and its neighbours.

To bridge this gap, our study discusses the role of regional cooperation by reviewing ASEAN's power connectivity within ASEAN and between ASEAN and its neighbours, identifies challenges to the ASEAN connectivity from political, legal, economic and technical perspectives, and explores what, how and when regional cooperation may be able to facilitate ASEAN power connectivity. Our paper proceeds as follow: after the introduction, Section 2 overviews ASEAN energy sector, ASEAN power grid connectivity and power trading. Section 3 discusses power grid connectivity within and beyond ASEAN. Section 4 identifies the barriers and challenges to such connectivity. Section 5 gives suggestions regarding regional cooperation to advance ASEAN power connectivity. Section 6 concludes the paper.

2 ASEAN energy sector overview and power connectivity

2.1 ASEAN energy sector overview

The ASEAN energy growth has been substantial and the trend is expected to continue. ASEAN total primary energy supply (TPES) had an average annual growth of 3.4%, much faster than a global average growth rate of 2.1% between 2000 and 2015. TPES in ASEAN increased from 383 Mtoe in 2000 to 628 Mtoe in 2015. The fast growth of ASEAN energy supply was primarily driven by fossil fuels. In 2015, fossil fuels accounted for 74% of the TPES. In contrast, other renewables and hydro power accounted for only 24% of the TPES [9].

The growth of TEPS and the dominance of fossil fuels are expected to continue to 2040 in various outlooks. According to the latest ASEAN Energy Outlook published in 2017 [10], under Business-as-Usual Scenario (BAU), TPES is expected to reach 1,450 Mtoe by 2040, increasing by a factor of 2.3 and fossil fuels will account for about 70% in the energy mix in 2040.

In 2015, electricity accounted for 15% of the total final energy consumption of 442 Mtoe [9]. In 2015, ASEAN possessed an installed capacity of 205 GW, of which 75.7% were thermal power plants based on fossil fuels [coal, 63 GW; gas, 76.5 GW; and oil, 16 GW (see Fig. 1)].

In 2015, the non-fossil installed capacity was dominated by hydro at 86% or 2.7 GW, while other clean energy resources such as solar and wind, were in the early stages of development. The statistics of installed capacity categorized by country is shown in Table 1.

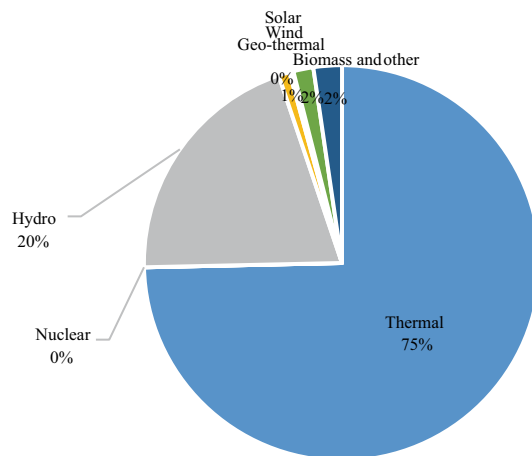


Fig. 1 ASEAN installed capacity structure in 2015

Source: ASEAN Database System, ASEAN Centre for Energy.¹

Electricity demand will grow faster than the TPES. The latest energy outlook for Southeast Asia shows that the electricity demand will almost triple by 2040, and coal will remain the largest source of electricity generation. Under the business as usual (BAU) scenario, ASEAN total installed capacity in 2040 will increase three-fold to 629 GW, with an annual growth rate of 4.6%, compared with the figure in 2015. Among the 424 GW capacity added, 42.4% will be from coal, while renewable energy will contribute 29.2%. In this BAU, the capacity of coal power will rise from 63 GW in 2015 to 267 GW in 2040 with a higher annual growth rate

(5.9%) than the growth rate of total electricity. Renewable energy capacity will increase from 50 GW in 2015 to 183 GW in 2040 [10].

Coal is projected to be the dominant source of the electricity generation in BAU. The electricity generation in ASEAN is projected to increase from 927 TWh in 2015 to 2,638 TWh in 2040. Coal power generation will increase from 308 TWh in 2015 to 1,062 TWh in 2040, while its share increases from 33.3% to 40.3% during the same period. Electricity generation from renewable energy in 2040 is projected to account for 26.4% of the total ASEAN electricity generation, increasing from 201 TWh in 2015 to 696 TWh in 2040. Natural gas will have a similar share of renewable power in 2040. Electricity generated by natural gas will be 772 TWh in 2040 [10].

In any sense, the imbalance between supply and demand of energy and electricity provide opportunities of electricity generation and power cooperation among ASEAN countries. Currently, a few ASEAN member states have achieved power cooperation by building up cross-border power grids, such as the transnational power transmission lines between Malaysia and Indonesia, Malaysia and Thailand, Malaysia and Singapore and Thailand and Laos [2]. The next section elaborates the power interconnections and power trading among ASEAN member states.

2.2 ASEAN power connectivity

ASEAN member countries have long supported the idea of power grids interconnection to facilitate transnational

Table 1 Statistics of ASEAN power sector in 2015

Area	Installed Capacity(GW)							
	Total	Thermal	Nuclear	Hydro	Solar	Wind	Geothermal	Biomass and Others
ASEAN	206.1	153.9	0.0	41.5	1.9	0.7	3.4	4.9
Brunei Darussalam	0.9	0.9	0.0	0.0	0.0	0.0	0.0	0.0
Cambodia	1.6	0.7	0.0	0.9	0.0	0.0	0.0	0.016
Indonesia	55.5	48.8	0.0	5.3	0.0	0.0	1.4	0.0
Lao PDR	5.8	1.9	0.0	3.9	0.0	0.0	0.0	0.0
Malaysia	30.5	23.5	0.0	5.7	0.2	0.0	0.0	1.0
Myanmar	4.8	1.6	0.0	3.2	0.0	0.0	0.0	0.0
Philippines	18.8	12.4	0.0	3.6	0.2	0.4	1.9	0.2
Singapore	13.4	13.1	0.0	0.0	0.0	0.0	0.0	0.3
Thailand	38.1	30.1	0.0	3.1	1.4	0.2	0.0	3.2
Vietnam	36.7	20.9	0.0	15.8	0.0	0.0	0.0	0.1

Source: ASEAN Database System, ASEAN Centre for Energy.

¹ ASEAN Database System is available at <http://aeds.aseanenergy.org/>.

electricity trade and to improve access to electricity. Realization of regional interconnection and all-round regional cooperation in electricity and energy was proposed at three levels including bilateral, sub-regional and the entire ASEAN, as reiterated in the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025. Currently, 16 interconnection systems were identified under the ASEAN Power Grid (APG) program and were divided into three sub-systems. They are: Upper West System located in the Greater Mekong Sub-region (GMS); Lower West System, located in Thailand, Indonesia (Sumatra, Batam), Malaysia (Peninsular), and Singapore; And East System, locating in Brunei, Malaysia (Sabah, Sarawak), Indonesia (West Kalimantan), and the Philippines [10].

In terms of voltage level, only seven of the existing cross-border transmission lines (one between China and Myanmar, six between Lao PDR and Thailand) are 500 kV lines. The other transmission lines are lines of 230 kV, 110 kV and below. Despite this, the power interconnection capacity within the ASEAN member states have reached about 5,500 MW, in which the added capacity between 2015 and 2016 was more than 1,700 MW (Fig. 2).

Transboundary power trade is quite common between countries in ASEAN. With the construction of cross-border transmission lines, there is increased power trade in Southeast Asia. In 2016, the power trade reached a total amount of 5.2 GW, equivalent to around 2.5% of the total installed capacity, and the share increased to 2.7% of the total capacity in 2017. However, the cross-border power trade in Eastern Malaysia, Indonesia and the Philippines are relatively small due to the barrier of ocean. Therefore, interconnections with those islands have not yet been established. Under the GMS power framework, ASEAN has exchanged about 51.7 TWh electricity with Yunnan and Guangxi provinces in China by the end of 2017². ASEAN expects that power exchange and purchase among ASEAN countries will triple from 3.5 GW in 2014 to 10.8 GW in 2020, and further increase to 16 GW post-2020 [12].

So far the electricity trading has been focused on bilateral interconnections, yet the new strategy under APAEC 2016-2020 is to develop the first multilateral connection and to initiate multilateral electricity trade in at least one sub-region [12]. The pilot project, “Lao PDR, Thailand, Malaysia, Singapore (LTMS) Power Integration

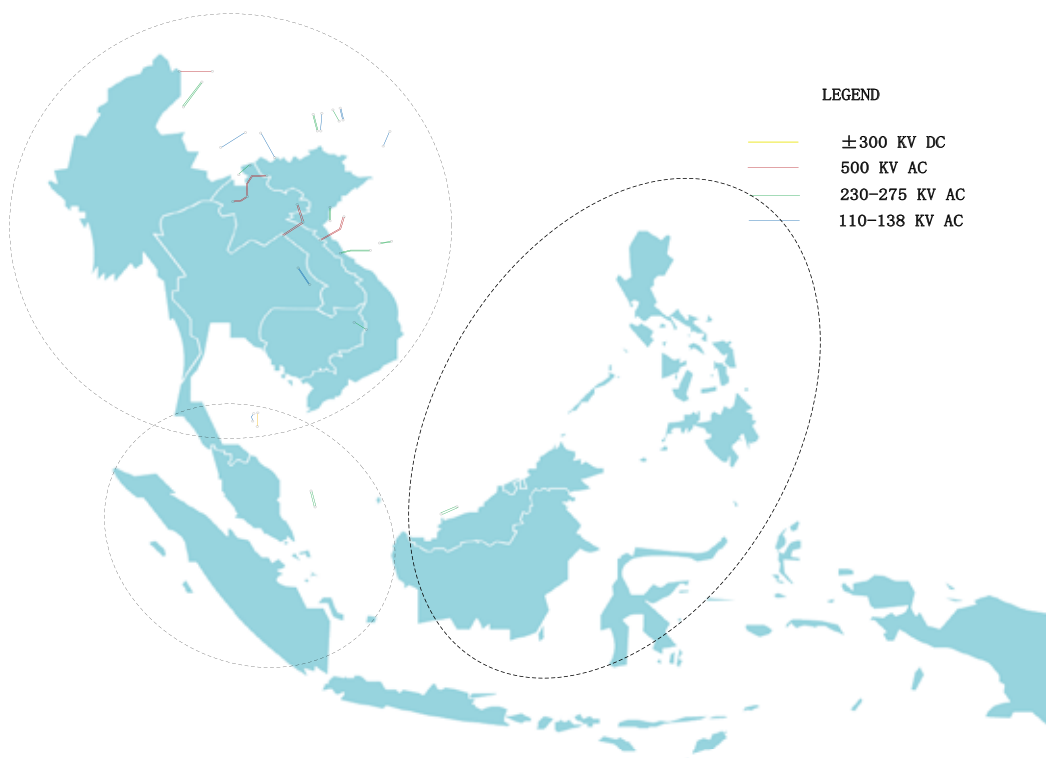


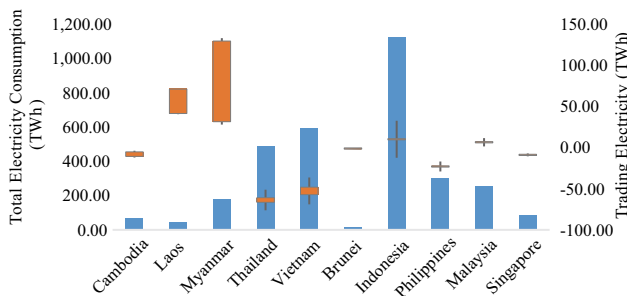
Fig. 2 Existing cross-border interconnections in ASEAN

Source: GEDICO, UNESCAP, ACE [11]

² China Southern Power Grid, Social Responsibility Report, 2017.

Project (PIP)” that can enable Malaysia to purchase up to 100 MW electricity power from Lao PDR using Thailand’s existing transmission grid is expected to be a pathfinder for multilateral electricity trading towards the APG across neighboring borders [13]. Lao PDR-Thailand-Malaysia (LTM) signed the Cross-Border Power and Transmission Agreement in September 2017 [13]. The first power trade through the LTM interconnection was initially planned to start on 1 January 2018, but was reportedly postponed and the second phase is expected to trade another 100 MW power between Lao PDR and Singapore by 2020 [14].

Power trade is expected to be increasing over time. In 2050, Myanmar and the Lao PDR will be power exporter while Thailand, Viet Nam, the Philippines and Singapore will be power importers. Fig. 3 shows the potential power trading in ASEAN countries in 2050 [24].



Note: Blue bars are total electricity consumption by country (the left Y-axis). Red bars represent the range of electricity trade (the right Y axis). The upper boundary of the red bars is maximum of the unbalanced generation in wet or dry seasons, and the lower boundary is the minimum of the unbalanced generation in wet or dry seasons. Positive values are export, negative values are import while the vertical black line in the middle is the margin of the trade, which is 2% of the total consumption.

Fig. 3 Potential power trade in ASEAN in 2050

Source: GEDICO, UNESCAP, ACE [11]

3 Connecting ASEAN with its neighbors

The ASEAN power grid is also desirable to be connected with neighboring countries such as Bangladesh, China, India and even Australia. China has vast power market that can facilitate access to electricity in ASEAN as well as providing market and stability for ASEAN power system. Australia has large potential of clean energy capacity. Bangladesh and India, which are in power shortage, can provide market for excess generation of hydropower from ASEAN during the rainy season. The large amount of gas generation in Bangladesh offers flexibility interconnecting the power pool. Therefore, it has been initiated to extend the ASEAN connections to its neighbors. Australia is actively studying the possibility of exporting solar electricity to ASEAN [2].

The ASEAN-China connections are currently progressing based on the GMS economic cooperation. In South Asia, countries are also seeking to enhance economic integration in order to increase free trade and to form a unified market through the BIMSTEC cooperation.

3.1 GMS power market integration

GMS has an advanced power market integration in ASEAN and beyond. The GMS cooperation started with the ADB Greater Mekong Subregion (GMS) Economic Cooperation Program (GMS Program) in 1992 and ADB has serviced as the program’s secretariat since. GMS currently has six countries—Cambodia, China (Yunnan and Guangxi Provinces), Lao PDR, Myanmar, Thailand, and Vietnam. The idea is that the GMS cooperation can link the GMS member states through improvements in infrastructure to promote trade and investment and promote economic growth. The GMS program has identified and implemented priority programs and projects in a range of sectors, including human resources development and environmental management [15]. In 2002, the GMS countries set up the GMS Strategic Framework (2002-2012), a comprehensive strategic framework that incorporated various sectoral programs and projects together for sub-regional development. The GMS strategic Framework has five strategic thrusts: strengthening infrastructure linkages, in which energy interconnection sits; facilitating cross-border trade, investment, and tourism; protecting the environment; developing human resources; promoting the sustainable use of shared natural resources; and enhancing private sector participation and competitiveness [15]. The framework of five thrusts was carried onto the current plan period up to 2022 by the Greater Mekong Subregion Economic Cooperation Program: Strategic Framework 2012-2022 (GMS SF-II) [16].

Power market integration is one of the top priorities of GMS energy cooperation and the overall GMS cooperation. One of the priority regional initiatives is related to the regional energy interconnections and aims to “continuing the development of a regional power market through a two-pronged approach: providing the policy and institutional framework for power trading, and developing the grid interconnection infrastructure to connect the various GMS power systems” [15].

Power interconnection in the GMS region has laid down the foundation of power market integration, which was planned to progress into four stages. Stage 1 is bilateral cross-border connections. In stage 2, there will be grid-to-grid power trading between any pair of GMS countries. Third country’s transmission facilities will be used for

such trading. Stage 3 involves transmission links for cross-border trading. During stage 4, a fully integrated GMS regional competitive power market will be established. Currently GMS countries have reached stage 1, where bilateral trade is ongoing, and are moving towards stage 2 with limited progress [16]. The Mid Term Review of the Strategic Framework 2012-2022 (GMS SF-II) concludes that the progress in building an integrated regional grid and establishing a regional power market is still constrained by technical, regulatory, and institutional challenges, including the operationalization of the Regional Power Coordination Center (RPCC) [16]. Recently, China, Myanmar, and Bangladesh reached an agreement on trilateral power trading, which uses ± 660 kV three-terminal DC with a capacity of 4 GW [17].

Similar to the institutional arrangements in ASEAN, the GMS Program has been pursued through an institutional arrangement consisting of: (i) a GMS leaders' summit at the political level, (ii) a ministerial-level conference supported by meeting of senior officials at the policy level, and (iii) sector forums and working groups at the project and operational levels. In each of the GMS country, there is a national inter-ministerial committee assisted by a designated focal point or national secretariat that coordinates the GMS activities. There is also a unit at ADB headquarter that provides overall secretariat support to the GMS activities in coordination with the national inter-ministerial committee in the GMS countries [15].

The GMS Sub-regional Energy Forum is responsible for overseeing the development of the power market integration program as well to ensure that social and environmental factors are taken into account of energy planning, and high level of private participation in major energy projects is also guaranteed [15]. The Regional Power Trade Coordinating Committee (RPTCC) was established as the institutional mechanism specifying the rules to govern sub-regional power trade. It has two working groups on regulatory issues and performance standards and grid codes, which are interim bodies for the RPCC that is expected to be fully established as an intergovernmental entity [16]. The center was expected to harmonize regional power investments and plans and coordinate regulatory regimes and sector reforms, as well as internalize social and environmental impacts to prepare for the GMS power expansion plans [15]. However, the GMS power interconnections have been suspended for a couple of years due to the disagreement on the host of the RPCC. To make further progress in moving to stage 2, the RPCC needs to be established to promote synchronized operations of the national power systems toward a unified, fair, and transparent regional electricity market [16].

3.2 BIMSTEC

The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC), created in 1997, is a regional organization consisting of seven countries in the littoral and adjacent areas of the Bay of Bengal. It constitutes five countries from South Asia, including Bangladesh, Bhutan, India, Nepal, Sri Lanka, and two countries from Southeast Asia, including Myanmar and Thailand. The Bangkok Declaration that established the BIMSTEC sets the institutional mechanism that allows for smooth operation of BIMSTEC, including the BIMSTEC Summit, Ministerial Meeting, Senior Officials' Meeting (SOM) and BIMSTEC Working Group Meeting.

During the Fourth BIMSTEC Summit in August 2018, the foreign ministers signed a Memorandum of Understanding (MoU) on the Establishment of the BIMSTEC Grid Interconnection. This MoU provides a general framework for the relevant parties to collaborate on the implementation of grid interconnections for power trade for promoting optimal and rational power transmission in the BIMSTEC region [18]. The MoU is expected to prepare for power trading among the BIMSTEC countries once the cross-country power grids are in place and to pave the way for energy cooperation among the member countries of South Asia and Southeast Asia. It would also promote economic, efficient, and secure operation of power system through regional electricity networks [19].

Also in the energy sector, the Energy Ministers meet once every two years while SOM on Energy meets at least once a year to follow up the energy cooperation. The First BIMSTEC Energy Ministers Conference, held on 4 October, 2005 agreed to set up a BIMSTEC Energy Centre (BEC) for sharing experiences in restructuring, reforms, regulation and best practices in energy sector. In the Joint Statement of the Fifteenth BIMSTEC Ministerial Meeting held on 11 August 2017, the Ministers agreed to explore the opportunities of promoting regional energy trade [18] [19].³

Further, BIMSTEC has set up a platform for intra-regional cooperation between the ASEAN countries and the South Asian Association for Regional Cooperation (SAARC). BIMSTEC has also identified fourteen priority sectors of cooperation and has established several BIMSTEC centres to focus on those sectors respectively. The main objectives of BIMSTEC are related to technological and economic cooperation among South

³ Joint Statement of the Fifteenth BIMSTEC Ministerial Meeting, 11 August 2017, Kathmandu, Nepal, 2017. Available at: <https://www.mea.gov.in/bilateral-documents.htm?dtl/28862/Joint+Statement+of+the+15th+BIMSTEC+Ministerial+Meeting+August+11+2017>.

Asian and Southeast Asian countries along the coast of the Bay of Bengal. Energy is one of the 14 priorities of cooperation under BIMSTEC and serves as a factor to enhance energy cooperation among BIMSTEC Member States through interconnection of electricity grids and natural gas pipelines, implementation of viable renewable energy projects, and sharing of experiences, knowledge and information on energy efficiency programs. The BIMSTEC Grid Interconnection program aims to expand energy trade among those member countries and accelerate development of new hydropower projects.

3.3 Australia-ASEAN power interconnection

There is some discussion on the outlook for an Australian-Asian electricity super grid, which will be an inter-continental connection of power grids between Australia and Asia [2]. Australia has incentives to export electricity and its only possible clients are Southeast Asian countries. Australia not only has rich resources in coal, gas and uranium, but also in hydro energy, and other renewable energy including solar and wind energy, tidal, wave and geothermal resources. The transmission power grids between regions, such as between Australia and ASEAN, will be based on high voltage direct current (HVDC) technology [2],[20]. In the envisioned Asia Pacific Super Grid, one third of the electricity will be provided from solar power in Australia through HVDC cable by 2050 [1]. A recent study [21] finds that it is technically feasible to build the Australia-ASEAN power interconnection through a 3000 MW bipole HVDC submarine transmission line using the present technologies. The ideally possible route will be about 1,500 km long, avoiding the deepest parts of the Java trench, yet it will still exceed 2,000 meters deep in several locations. While it is not commercially viable presently, it is likely to be economically favourable in the future when such a complex project can be designed, approved, and developed. Further, using scenario analysis, Gulagi et al. [20] find that the HVDC power grids play a role in electricity trading within ASEAN, where the electricity trading is more cost competitive than other energy technologies such as local energy storage.

3.4 Belt and Road Initiative and ASEAN energy interconnection

In addition to GMS power grid interconnection, Chinese BRI can also play an important role in the power grid interconnection in ASEAN, particularly in the continental Southeast Asia countries that are neighboring China, i.e., Laos, Thailand, Vietnam and Myanmar [22]. China has long

invested in the power sector in the continental Southeast Asia. In its neighboring countries Laos, Vietnam and Myanmar, Chinese companies have built national power grids that can be connected to China's power grid to enable electricity trading. These connections are beneficial to the power grid building of these continental Southeast Asian countries. Since BRI was initiated, one so-called 'first Belt & Road power grid cooperation project' has been put into operation in Laos. This power grid project links four provinces in northern Laos and is supposed to enhance regional connectivity [23].

ASEAN Energy Interconnection provides a pathway for achieving regional energy interconnection. It is hoped that by the year 2035, the power grid system in some of these continental countries in Southeast Asia could be connected to China's power grid through bilateral, multilateral and regional arrangements. The plan is in place to establish synchronous power interconnection within Southern China, Laos, Myanmar, and Thailand. In terms of voltage level, currently only 7 of the existing cross-border power grids are 500 kV. It is recommended to build a 500 kV alternating current (AC) synchronous interconnection covering Myanmar, Laos, Vietnam and Thailand by 2035. Based on the existing 500kV AC synchronization grids, further upgrading of the voltage is expected by deploying ultra-high voltage (UHV) interconnection technology [24]. Chinese companies, with their rich experiences in power grid building, would play a key role in serving Southeast Asian power grid interconnection.

Chinese companies, driven by BRI, can also invest in countries rich in non-fossil energy resources, since BRI has brought new opportunities for investment in renewable power capacity. The continental Southeast Asian countries, such as Laos, Vietnam and Thailand, remain an attractive destination for renewable energy investment. In Laos, the Power Construction Corporation of China has been constructing a large hydropower project with a proposed installed capacity of more than 1,000 MW [25]. In Thailand, Chinese companies have moved rapidly to its solar power sector since BRI started. They have built solar panel factories and solar power projects, making Thailand a construction centre of solar PV equipment and a country with a fast increasing solar power capacity. Malaysia has attracted several Chinese investments especially in solar and hydropower sector. In 2016, the largest investment in Malaysia's renewable sector was made by LONGi, one of the largest Chinese solar manufacturers. It is expected that LONGi would spend about US\$ 269 million on solar panel manufacturing in Malaysia [26].

With their experiences in the power sector in the

continental Southeast Asian countries such as Laos and Thailand, Chinese companies can provide direct support to the transmission lines interconnection. Through the construction of power generation transmission capacity, Chinese companies are continuing to contribute to the development of the APG in continental Southeast Asia. Nevertheless, progress of regional power connectivity in Southeast Asia may be hampered by a number of obstacles as identified below.

4 Barriers toward regional power connectivity in Southeast Asia

Initiating power trade and making it fluid among participants are not easy due to several barriers from legislation to operation, from political factors to technical standards, and from cross-boundary interconnection to domestic market structure. This section summarizes major barriers to regional power connectivity and trade.

4.1 Social and political barriers

The political barriers include national security concerns; domestically-centred energy policy; poor institutional structure; different political systems; public opposition; corruption; and religious or historical conflicts. People may be afraid of being unfairly treated by the economic arrangements related to power grids connectivity, such as suffering a diminution in their security of power supply or losing their national autonomy [27]. A lack of sense of ownership in foreign invested projects is also a challenge for energy projects in ASEAN [22].

Consequently, the desire of the member countries to maintain energy independence from a broader regional power trading system is an apparent obstacle to the potential full integration of power market. Despite great efforts on the ASEAN Power Grid, development of the ASEAN power connectivity is currently constrained by limited interconnections, and also constrained by concerns on energy security and affordability [28]. Due to lack of political trust, most ASEAN countries, if not all, will not accept relying on their neighbours for significant amount of power supply [29]. Concerns over national energy security in Brunei led to the drop of the Brunei-Sabah connection that was planned in APG [30]. The absence of forecasting systems and restricted electricity market access limit the grid flexibility that is needed to accommodate variable renewable electricity [31]. Even in the EU, the energy security concerns, when they are linked with other economic and political affairs, force the EU member states to significantly control their domestic energy markets and

their relationship with energy exporters [32].

4.2 Legal and regulatory barriers

Access to electricity markets is to a large extent determined by policy measures such as non-discriminatory access to networks, unbundling, competition in generation, and choice of suppliers [33]. Monopoly market structure and the competition and regulation issues that it raises are the biggest obstacle to electricity trade. High degree of national market monopolization (market concentration) and vertical integration of generation and retailing are detrimental to new entrants. For example, lack of national competitive market in Northeast Asia, due to non-liberalized electricity market, has made power market participants unable or unwilling to look for chances beyond their national borders [34].

A crucial market access issue of the electricity sector relates to the access to transmission and distribution networks. The lack of open access to such electricity networks has restricted the ability of electricity generators in one region to export electricity to another [33]. Many countries do not have policies to ensure that transmission facilities are open to third party [35,36]. Without adequate regulation, the national monopoly transmission networks may result in higher tariffs and lower service standards [27].

In the context of APG, major legal and regulatory barriers include expropriation of assets; licensing requirements; consumer protection and safety standards; contractual confidentiality; anti-competitive practices; information access; third party access; investment recovery; and the absence of Double Taxation Agreements (DTAs). Particularly, regulation gaps in taxation, transmission tariffs, and third-party access have impeded cross-border power trading [30,37].

More broadly, a weak regulatory environment in many small developing countries like those in Southeast Asia, could possibly lead to asset expropriation or regulatory capture [38]. Regulatory, environmental and taxation uncertainty [27] discourages private (including foreign) investment. The involvement of more than one jurisdiction multiplied the risks [39]. Long-term contracts between buyers and sellers may partly solve the uncertainty problem. However, against the background of progressive market liberalization, such contracts can be a barrier to the free choice of customers [33]. With the long-term contracts that limit transmission networks, the new entrants either face unfair status or even cannot access the networks [40]. Converting the growing connectivity into a sub-regional or regional market will be impeded by the predominance of 25-year PPAs in most of the power grids interconnection, particularly those between the GMS member states. With

these PPAs, the generators are able to exclusively use the transmission infrastructure with no third-party access [41]. This also prevents the development of power trade.

4.3 Economic barriers

The economic situation of developing countries, and more specifically their utilities' performance, make it difficult for them to obtain financing in general terms [42]. Although many projects may be economically attractive, the perception of risks related with country-specific or regional issues can lead to financial closure [36].

ASEAN will need about US\$ 690 billion in its transmission and distribution sectors in the next 25 years or so [43]. This lack of access to finance is even more serious for cross-border transmission interconnections since the scale of investment is huge and bankers often perceive regional power connectivity projects are at higher risks than they actually have [27]. Bankers are usually frustrated by complexity and are unwilling to accept completion risk when a new power grid project is to be developed [27].

State-owned utilities, particularly those with poor performance, are unable to fully conduct normal commercial activities. In many developing countries, state-owned utilities are still predominant in the power sector, which may not be performing well either technically or commercially. These companies are not creditable enough to get financing [42].

Electricity subsidies also discourage import and export of electricity that is priced on market basis. In terms of import, the importers often have difficulty in selling electricity to domestic customers; in terms of export, concerns on subsidy leakage prevent regional power trade. Most ASEAN countries, probably except Singapore and the Philippines, do not set their electricity tariffs according to market prices. Electricity subsidies mean that the level of final retailing tariff is too low to reflect costs, which often impedes the adoption of renewable energy, a source important to APG. In fact, many ASEAN countries have a level of energy subsidies above the global average. In 2011, the total cost of fossil fuel subsidies among the ASEAN countries amounted to \$51 billion, estimated by IEA [44]. ASEAN countries have been trying to reform their energy sector to more or less liberalize their energy markets. However, ASEAN's tendency to focus on reforms of individual countries rather than coordinating the reforms between countries may be a major barrier to the advancement of APG [4].

4.4 Technical and environmental barriers

Transnational electricity trading involves not only cross-border interconnectors or transmission lines, but also

domestic grids. These networks are necessary when trading starts to develop and domestic power grids are used for power transmission. In other words, the electricity trading is not done exclusively between neighboring countries. As transit countries, third countries also get involved in [42]. Yet all the participating countries for regional power trade might have diverse and sometimes conflicting standards, specifications and protocols of electricity transmission and distribution. Frequencies, voltages, information technology systems, and even consumer protection policy may be diversified within the regional countries. Therefore, both the APAEC [12] for ASEAN and the 'Ha Noi Action Plan' [16] for GMS highlight that the immediate action plans need to include harmonization of technical standards and regulations, such as grid codes and consumer protection policies. Moreover, some countries even lack connected national power grids. For example, Brunei and Cambodia do not have pan-nation interconnected power networks. Power grids in Indonesia and Malaysia are fragmented as well [45].

Further, although ASEAN has a central role in the regional connectivity of Southeast and South Asia, the weak APG limits the potential of trading electricity within ASEAN. An early GMS study found that planning for power transmission across the region is not being coordinated to make it optimal enough to minimize investment in the long-term, nor can it provide a technically sound operation of the transmission network for efficient dispatch of electricity [36]. This also impedes in the technical sense the electricity trading within the region. The ASEAN institutions, however, workable, it not efficient as the consensus building is slow. The involvement of all 10 countries also mix the technical challenges with other challenges and thus make the integration progress complicated. In contrast, in the GMS program, all the members are technically feasible to be connected and thus there are no technical challenges as those in the ASEAN level. Further, despite the global efforts in mitigating climate change impact, the lack of carbon prices in ASEAN also discourage the development of renewable energy, a key driver for regional connectivity [46], [29].

5 Regional cooperation to advance ASEAN power connectivity

To address the above barriers, this study proposes in table 2 the measures that may be adopted to advance regional power connectivity, including APG. The table is framed in two dimensions: one dimension consists of the

above-mentioned four barriers, plus a program specific item; and the other dimension consists of time horizon which is divided roughly into three stages. For each barrier, we present measures that could address these challenges. If a measure can be initiated immediately, it is considered as a short-term one. In contrast, those measures that need some kind of foundation building are either classified as middle-run or long-run ones. The classification of time horizon, however, is not necessarily precise.

On the political dimension, the measure is straightforward and should be carried out across time. On the economic dimension, the immediate measure is to know what the challenges are and to forge closer cooperation

between governments and banks. In the next stage, financial model, contract arrangements and private sector participation could be established. In the long run, power trade finance, fiscal and contractual model could be established. The technical dimension ranges from identifying challenges to harmonization, depending on the level of difficulty. On the regulatory dimension, apart from identifying challenges, the medium term targets are to establish third party access and dispute settlement regime. In the short to medium run, establishing a voluntary peer review mechanism of national policies and regulations is useful before harmonization of legal and regulatory regime is realized in the long run.

Table 2 Roadmap for facilitating regional energy connectivity (REC)

	Short run (<5 years)	Medium run (5-10 years)	Long run (>10 years)
Political	Streamline and strengthen regional dialogue platforms		
Economic	Identify challenges and possible solutions from finance and commercial perspectives. Forge close cooperation between governments and banks	Development financial models for REC Explore models for private participation Formulate contractual arrangements for multilateral power trade	Develop regional power trade finance, tax and trading guidelines Develop standardized power purchasing agreement
Technical	Identify conflicts in standards and operations Study potential of cross-border interconnections Capacity building for agencies related to REC	Establish compatible standards and grid code Initiate capacity building for stakeholders to be done by private resources	Harmonization of standards and grid codes
Legal and regulatory	Identify constraints at both national and regional level Designate institutions for REC Set up voluntary peer review mechanism of national policies and regulations	Establish Third Party Access regimes Establish dispute settlement regime (Investment) Set up voluntary peer review mechanism of national policies and regulations	Harmonize legal and regulatory regime pertaining to REC

Source: Authors' own deliberation.

Furthermore, to promote ASEAN power connectivity, it is needed to establish a regional cooperation mechanism that can integrate policy coordination, cross-border trading and network operation to accelerate the construction of APG. Fig. 4 illustrates the composition of the mechanism. This cooperation mechanism incorporates three dimensions: policy coordination, cross-border trading and network operation. Each dimension has some specific requirements to materialize the mechanism. Policy coordination needs regional dialogue institutions to govern regional connectivity and regional peer review mechanism to softly enforce agreements across countries. Cross-border trading requires harmonization of standards and establishment of regional trade arrangement to facilitate electricity trade. And network operation needs regional agency to manage interconnections and dispute settlement mechanisms (DSM) to protect investment.

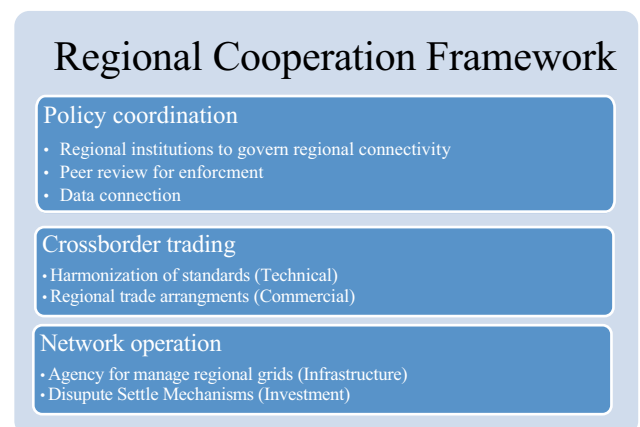


Fig. 4 Illustrative framework of regional mechanisms

Particularly, a multiple level of regional dialogue institutions, including ministerial meeting, senior official meeting and working groups, are needed to overcome

barriers of differences covering from political regimes to commercial frameworks. Successful integration initiatives have used regional institutions for coordination and supportive services, in addition to the implementation at the country level by the national institutions [47]. The regional institutions can build dialogues at various levels to resolve barriers and collect information and data that are the foundation for dialogues. One key reason that APG could move on, although slowly, is the existing of ASEAN Economic Community framework that includes summit and ministerial meetings which resolve political and policy barriers.

With regarding to the network connectivity, both infrastructure operation and investment protection regimes are needed. Firstly, an efficient operator is the key facilitator to guarantee smooth operation of a regional power grid. The GMS power trade has stalled due to lack of coordinating mechanism. To solve the problem, the RPTCC was established to manage regional power trade in the GMS and to facilitate the exchange of information on energy sector plans and projects. The GMS member countries agree that the progress to an integrated power market requires the establishment of a GMS regional power coordination center [15]. The establishment and full operationalization of the RPTCC is therefore an immediate priority for the GMS to move forward towards power market integration [16]. Secondly, investment protection is another key factor that facilitates power grid operation. An absence of law enforcement and dispute settlement mechanism for international trade would significantly discourage cross-border power trade [39]. An effective dispute settlement mechanism can make investors confident with their investment projects in the power sector.

With regarding to the power trading, both technical feasibility and trading arrangements are needed. Commercially, a basic framework for power trade and the establishment of a domestic power market in each country is needed as the first step towards the power grid interconnection [34]. Trading arrangements are needed once the power trading between neighboring countries is completed. More complex power trading is impossible if minimum trading arrangements are not in place. Both of the countries in trading and the regional institutions need to have agreements in arranging the power trading [42].

6 Conclusion

This paper extensively reviews the energy sector, particularly the power grid connectivity, within and beyond ASEAN. Many ASEAN countries have abundant energy

resources, such as hydro power and solar power. Power grid connectivity can better allocate energy resources and meet the needs of energy demand for economic development. Promoting and accelerating cross-border power connectivity within and beyond ASEAN is significant to sustainable development of the region.

The current and future possible situation of regional power grid highlights the barriers and problems for further development of regional power grid connection, including the construction of ASEAN Power Grid. The barriers include a variety of factors, such as political factor, legal and regulatory factor, economic factor and technical factor. Regarding the political factor, cross-border power connectivity requires relevant countries have strong political trust and these countries need to coordinate the demands of all stakeholders. Concerns on degrading energy security also impedes power grid connectivity. Further, since power sector projects normally need large investments and the payback period can be long and uncertain, power grid connectivity can be hardly accomplished especially under different legal and regulatory systems. As far as the technical factor is concerned, power grids connectivity requires different countries to coordinate the planning and operation of power systems.

Under the ASEAN context, in order to overcome these barriers, ASEAN needs to establish regional dialogue institutions, such as high official meetings and coordinating agency. Making use of the platform of the experts working group such as the Regional Power Trade Coordination Committee is also a desirable option to facilitate regional energy connectivity. Specifically, the ASEAN countries' governments shall coordinate power development policies and strategies and the enterprises may need to study technologies and business model of specific power connectivity projects, which will also help to advance ASEAN power connectivity.

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References

- [1] Blakers A, Luther J, Nadolny A (2012) Asia Pacific Super Grid–Solar electricity generation, storage and distribution. *Green*. doi:10.1515/green-2012-0013
- [2] Halawa E, James G, Shi X, et al (2018) The Prospect for an Australian–Asian Power Grid: A Critical Appraisal. *Energies*. doi:10.3390/en11010200

- [3] Ahmed T, Mekhilef S, Shah R, et al (2017) ASEAN power grid: A secure transmission infrastructure for clean and sustainable energy for South-East Asia. *Renew Sustain Energy Rev.* doi:10.1016/j.rser.2016.09.055
- [4] IEA (2015) Development Prospects of the ASEAN Power Sector: Towards An Integrated Electricity Market. Paris, France: OECD;. doi:10.1787/9789264247529-en
- [5] Owen DA, Finenko A, Tao J (2019) Power interconnection in Southeast Asia. Singapore: Routledge
- [6] Aalto P (2014) Energy market integration and regional institutions in east Asia. *Energy Policy.* doi:10.1016/j.enpol.2014.08.021
- [7] Ahmed T, Mekhilef S, Shah R, et al (2017) Investigation into transmission options for cross-border power trading in ASEAN power grid. *Energy Policy.* doi:10.1016/j.enpol.2017.05.020
- [8] Boëthius G (2012) Forging the ties that bind: comparing the factors behind electricity market integration in the EU and ASEAN. Singapore
- [9] ESCAP. Energy Information for the Asia-Pacific Region 2019. <https://asiapacificenergy.org/> (accessed January 6, 2019)
- [10] ASEAN Centre for Energy (2017) The 5th ASEAN Energy Outlook 2015-2040. Jakarta: ASEAN Centre for Energy
- [11] ACE, GEIDCO, ESCAP (2018) Energy interconnection in ASEAN for sustainable and resilient societies: Accelerating energy transition. Bangkok, Thailand
- [12] APAEC (2015) ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025
- [13] ASEAN Centre for Energy. ASEAN Energy Cooperation Report 2017. Jakarta: ASEAN Centre for Energy; 2017
- [14] ACE, CREEI (2017) ASEAN Power Cooperation Report. Jakarta
- [15] ADB (2011) The Greater Mekong Subregion Economic Cooperation Program: Strategic Framework 2012-2022. Mandaluyong City, Philippines: Asian Development Bank
- [16] ADB (2018) The Ha Noi Action Plan 2018-2022. Mandaluyong City, Philippines: Asian Development Bank
- [17] Xinhua (2019) Myanmar, China, Bangladesh agree on electric power trading 2019. <http://www.chinadaily.com.cn/a/201803/09/WS5aa27fd1a3106e7dcc140b8c.html> (accessed September 30)
- [18] Ministry of Power of India (2018) Memorandum of Understanding for establishment of the BIMSTEC Grid Interconnection 2018. <https://powermin.nic.in/en/content/memorandum-understanding-establishment-bimstec-grid-interconnection> (accessed November 12)
- [19] The Kathmandu Post (2018) Bimstec Summit: Leaders agree on regional power grid. *The Nation*
- [20] Gulagi A, Bogdanov D, Breyer C (2017) A cost optimized fully sustainable power system for Southeast Asia and the Pacific Rim. *Energies.* doi:10.3390/en10050583
- [21] Mella S, James G, Chalmers K (2017) Evaluating the Potential to Export Pilbara Solar Resources to the Proposed ASEAN Grid via a Subsea High Voltage Direct Current Interconnector. Pilbara
- [22] Shi X, Yao L (2019) Prospect of China's Energy Investment in Southeast Asia under the Belt and Road Initiative: A Sense of Ownership Perspective. *Energy Strateg Rev;* 25:56-64. doi:10.1016/J.ESR.2019.100365
- [23] Xinhua. Laos' northern 230 KV power grid put into operation 2015. http://www.china.org.cn/world/Off_the_Wire/2015-11/30/content_37190657.htm (accessed August 19, 2019)
- [24] GEIDCO (2018) Research Report of Southeast Asian Energy Interconnection Planning. Beijing
- [25] IRENA (2017) Renewable Energy Outlook: Thailand. doi:10.1016/b978-0-08-092401-4.50007-4
- [26] Pim LH. Chinese firm invests RM1 bln in Sama Jaya. Borneo Post Online 2016. <https://www.theborneopost.com/2016/03/25/chinese-firm-invests-rm1-bln-in-sama-jaya/> (accessed August 19, 2019)
- [27] APEC (2002) Addressing the Barriers to the Interconnection of Power Grids in APEC Member Economies. Singapore: APEC Secretariat
- [28] Shi X, Kimura F (2013) The Status and Prospects of Energy Market Integration in East Asia. In: Wu Y, KIMURA F, editors. *Energy Mark. Integr. East Asia Deep. Underst. Move Forw.,* London: Rutledge;p. 9-24
- [29] Shi X (2016) The future of ASEAN energy mix: A SWOT analysis. *Renew Sustain Energy Rev;*53:672-80. doi:10.1016/j.rser.201509.010
- [30] Shi X, Malik C (2013) Assessment of ASEAN Energy Cooperation within the ASEAN Economic Community. ERIA Discuss Pap Ser ERIA-DP-20
- [31] Huang YW (2019) Kittner N, Kammen DM. ASEAN grid flexibility: Preparedness for grid integration of renewable energy. *Energy Policy.* doi:10.1016/j.enpol.2019.01.025
- [32] Li Y, Kimura S (2016) Achieving an Integrated Electricity Market in Southeast Asia: Addressing the Economic, Technical, Institutional, and Geo-political Barriers
- [33] ECT (2003) Regional Electricity Markets in the ECT Area. Brussels: Energy Charter Secretariat
- [34] Yun W-C, Zhang ZX (2006) Electric power grid interconnection in Northeast Asia. *Energy Policy;* 34:2298-309
- [35] SEETEC Consortium. Study of the Obstacles to Trade and Compatibility of Market Rules in South East Europe. 2006
- [36] World Bank (1999) Power trade strategy for the Greater Mekong Sub-region. Washington D.C.: World Bank
- [37] Andrews-Speed P (2016) Energy Security and Energy Connectivity in the Context of ASEAN Energy Market Integration." *Energy Security and Connectivity: The Nordic and European Union Approaches.* Singapore: Energy Studies Institute, National University of Singapore, Singapore: Energy Studies Institute, National University of Singapore
- [38] Kessides I, Noll R, Benjamin N (2008) Regionalising Infrastructure Reform in Developing Countries. Washington, DC: World Bank
- [39] World Economic Forum (2014) Managing Transnational Infrastructure Programmes in Africa --Challenges and Best Practices. Geneva: World Economic Forum
- [40] Bhattacharyay BN (2011) Infrastructure for ASEAN Connectivity and Integration. *Asean Econ Bull;*27:200. doi:10.1355/ae27-2d
- [41] Antikainen J, Gebert R, Moller U (2011) Review of the Greater Mekong SubRegion Regional Power Trade. Stockholm

- [42] Mercados Energy Markets, Consulting NP, CEEST (2007) Institutional, Regulatory and Cooperative Framework Model for the Nile Basin Power Trade TT - -Annex 4: Deliverable 4--"Barriers to Power Trade and How to Solve Them". Nile Information System
- [43] IEA (2017) World Energy Outlook 2017. Paris: OECD Publishing
- [44] IEA (2015) Southeast Asia Energy Outlook 2015. Paris: International Energy Agency
- [45] Bannister H, McDonnell G, Thorncraft S, et al (2008) Energy Market Integration in the East Asia Summit Region. Jakarta: ASEAN Secretariat
- [46] Ji Q, Xia T, Liu F, et al (2019) The information spillover between carbon price and power sector returns: Evidence from the major European electricity companies. J Clean Prod. doi:10.1016/j.jclepro.2018.10.167
- [47] IDG (2007) The Development Potential of Regional Programs—An Evaluation of World Bank Support of Multicountry Operations. Washington DC: Independent Evaluation Group

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