ASEAN Grid Flexibility: Preparedness for Grid Integration of Renewable Energy

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ABSTRACT

In 2015, ASEAN established a goal of increasing renewable energy share in its energy portfolio to 23% by 2025. Renewable energy, especially intermittent and variable sources such as wind and solar electricity, present challenges for grid operations due to uncertain electricity generation timing and quantity. Grid flexibility, which refers to the electric grid's ability to respond to changing demands and supply, is key to addressing these uncertainties. Through a grid flexibility analysis, I developed a scorecard framework to assess ASEAN'S current grid flexibility using six quantitative indicators: grid reliability, electricity market access, load profile ramp, forecasting systems, proportion of electricity generation from natural gas, and renewable energy diversity. I found that ASEAN nations are clustered into three groups based upon grid flexibility score: better prepared nations, moderately prepared nations, and least prepared nations. Through this process, I identified ASEAN's key grid flexibility weaknesses, which include lack of forecasting systems and limited electricity market access. I also quantified and aggregated load profile ramp rates for each member nation. These factors limit individual ASEAN nations' ability to address changing demand and supply with renewable energy without regional coordination for power trade or increased investment. As ASEAN continues to pursue its renewable energy targets, regional cooperation remains essential in addressing identified challenges. Member nations will need to increase its current grid flexibility to adequately prepare for future scenarios of more renewable energy integrated into its electrical grid.

KEYWORDS

ASEAN Power Grid, flexibility analysis, grid operation, electricity market, variable renewable energy

INTRODUCTION

The International Energy Agency (IEA) predicts a 30% increase in world energy demand by 2040; developing nations are a major source of this increased demand and have the potential to incorporate more variable renewable energy (IEA 2016a). With IEA projecting 43% increase for global renewable energy capacity, grid flexibility is a key factor in integrating renewable energy into the electrical grid (Cochran 2015, Martinot 2016, IEA 2017, Hsieh and Anderson 2017). Grid flexibility refers to the grid's ability to respond to changes in supply and demand from different sources. As more renewable energy is integrated to the electric grid, the uncertainty in electricity generation by variable renewable sources challenges the standard grid operation and affects grid stability (IEA 2016b). Various countries have achieved 30% or higher of electricity generation within their grid system (Cochran 2015, Weiss et al. 2015). Although technological solutions have been developed to address the technical difficulties in integrating more renewable energy, grid operational changes are needed for increasing grid flexibility (Cochran 2015). A specific study on regional grid flexibility is needed to understand the current progress and preparation for renewable energy grid integration.

In 2015, the ten member nations of the Association of Southeast Asian Nations (ASEAN) established a goal to increase the share of renewable energy in its energy mix to 23% by 2025 (ASEAN Centre for Energy 2016). As a region with diverse renewable energy sources, the various levels of economic development and energy access of ASEAN member nation provide an opportunity for the region to benefit from adopting clean energy technologies. Nations with less investment into an electrical grid have the opportunity to leapfrog and adopt renewable energy, bypassing reliance on fossil fuel seen in more developed nations. Combined with the targets set by individual nations, each ASEAN nation will need a flexible grid to support and prepare for more grid integrated renewable energy. Through a quantitative adaption of United States Agency for International Development's (USAID) grid flexibility analysis, this thesis aims to identify individual ASEAN nation's preparedness for its near future of more renewable energy grid integration.

In order to integrate more renewable energy, ASEAN member nations and the region need to improve their grid operations. By developing a grid flexibility analysis as a proxy for preparedness, I identify member nation's strengths and weaknesses in terms of current practices, grid system operation, and grid characteristics (GIZ and USAID 2015). For ASEAN Power Grid (APG) to successfully incorporate a high renewable energy penetration rate with its larger pool of resources, nations can address the specific weaknesses identified through the results of a preparedness analysis.

The results from this analysis will aid the region's transition to clean energy through increased grid integrated renewable energy. Data collection for analyzing preparedness includes developing quantitative indicators for grid reliability, steepest ramp from electricity load profile, wind/solar forecasting practices, access to electricity trade, and diversity of renewable energy sources. I hypothesized that certain countries with greater income sources, such as gross domestic product per capita, and stronger renewable energy policies will be better prepared for a future with more grid integrated renewable energy.

BACKGROUND

ASEAN

ASEAN is an important region of study for renewable energy given its abundance of sources, and the future that ASEAN faces with energy security and demand. The region consists of ten-member nations: Brunei Darussalam (Brunei), Cambodia, Indonesia, Lao People's Democratic Republic (Laos), Myanmar, Malaysia, Philippines, Singapore, Thailand, and Viet Nam. Energy demand trends in the region are highly driven by economic and population growth. The IEA predicts an energy demand growth of 80% from 2015 to 2040, and 78% of generation in 2040 will be by fossil fuels (IEA 2015a). Additionally, the region currently faces an energy insecure future due to decreasing availability of fossil fuel reserves in the region and reliance on imported energy resources (Tongsopit et al. 2016). Renewable energy has the potential to address future demands and increase energy security of the region.

In 2015, ASEAN established a goal to achieve 23% of electricity generation from renewable energy sources by 2025. Each individual ASEAN nation has also established specific renewable energy targets (IRENA 2018). As of 2014, 9% of ASEAN's electricity consumption is from renewable energy, which includes large hydropower (IRENA and ASEAN Centre for Energy 2016). Integrating more renewable energy on a grid poses certain challenges (as discussed in renewable energy section later on). Nations can benefit from the current initiative in creating a regional interconnected grid, ASEAN Power Grid. The project will link individual member nations' electric grid through constructing a series of transmission lines between nations and form a regional market for electricity trade (Hermawanto 2016). Studies have shown the benefits of regional, interconnected grids to integrate renewable energy over a larger spatial area to cost-effectively transition toward a low carbon future (United Nations 2006, Wu et al. 2017). Specifically, an interconnected grid provides a larger resource pool to balance surplus and deficit generation through the electricity trade market when compared to an individual nation's grid. The trade system reduces the need for every nation to construct new fossil fuel generation plants to meet its energy demands. As APG develops and the region continues to increase electricity generation by renewable energy, it will be beneficial for the region to be prepared on a long-term basis for the challenges that nations will face in integrating renewable energy. APG is not a solution for all challenges, and higher grid integration of renewable energy will require other changes beyond an electricity market.

ASEAN is a unique region of study. As a regional organization, agreements formed at regional level are non-binding and thus have no mechanism to enforce nations to their goal (Tripathi 2015). In terms of electricity market, ASEAN has a mix of utility structures from state owned power utilities to privatized and independent utilities (IEA 2015b). It creates complexity for agreements and regional efforts in the electricity sector. This contrasts other international cases of regional cooperation such as European Union. However, characterizing each nations' grid flexibility and indicating practices to integrate more renewable energy can be applied to other nations with similar electricity market structures.

Renewable Energy

Renewable energy is most commonly defined as energy produced from natural processes, which are inexhaustible. Common renewable energy sources include solar, wind, geothermal, hydropower, and biomass. Sources can be further classified by dispatchability, which refers to the source's ability to adjust power output in response to system requirements (IRENA 2015). Non-dispatchable resources, also referred to as variable renewable energy, include intermittent sources whereby output is affected by an external factor. For the purpose of this thesis:

- Dispatchable, renewable sources are geothermal, biogas, biomass, and waste-to-energy (WTE),
- Non-dispatchable, renewable sources are solar, wind and small hydropower (SHP),
- Large hydropower will not be considered as a renewable energy source due to the extensive environmental impacts and associated emissions (Rosa et al. 2004),
- Ocean and tidal energy are not factored in due to the low technical potential in the region (ASEAN Centre for Energy 2016).

Challenges of integrating renewable energy

With a higher percentage of variable renewable energy sources, especially wind and solar, the uncertainty in electricity generation is an issue in maintaining grid stability (IRENA 2015, IEA 2016b). Solutions to uncertainties require increasing the grid's flexibility, a key factor to addressing stability and reliability issues (IRENA 2015, Martinot 2016). Grid reliability refers to the ability to supply electricity and meet demands. To achieve reliability, a grid needs to be stable by maintaining a balance of electricity demand and supply. Flexibility describes the grid's ability to respond to the changes in supply and demand from different sources (Cochran et al. 2014). Various solutions exist through system operation, markets, load, flexible generation, networks and storage (Cochran et al. 2014).

Cochran et al. (2014) indicates that increasing grid flexibility through system operations and market changes cost the least for grid operators and nations. Within system operations, technologies and solutions have been developed to address technical barriers of maintaining voltage quality, congestion management, power quality, and predicting electricity generation from renewable energy (Georgilakis 2008, Barth et al. 2014, Bullis 2014). Solutions include introducing controls on the distribution ends, advanced forecasting technology with artificial intelligence, and energy storage systems. In many regions, such as Denmark and Spain, electricity generation by renewable energy represents 30% or more within their grid system (Cochran 2015, Weiss et al. 2015). Other technical barriers require institutional and regulatory changes of grid operations.

Institutional and regulatory changes of grid operations aim to address the way grids are operated. These include forming grid codes, using forecasting systems for renewable energy, higher frequency in resource allocation to meet demands, coordination with other grids and curtailments (Cochran et al. 2014). These solutions can be categorized into four main categories: forecasting practices, system flexibility, operational flexibility, and grid reliability. Implementation of these solutions often depend upon funding and large investments, along with policy changes. Understanding the grid flexibility through these measures will indicate whether a nation's grid is adequately prepared to integrate more renewable energy into their power systems.

Current renewable energy research in ASEAN

ASEAN and ASEAN Power Grid

Many studies in the region have focused upon infrastructure issues related to APG. Li and Chang's study identifies the institutional barriers related to financing APG (Li and Chang 2015). The paper indicates the need for public-private partnerships as the steps beyond funding from intergovernmental organizations. With data from various energy agencies, the financial model produced uses a least cost approach and factors in transmission line costs, financing and power trade policies (Chang and Li 2012). The model has various trade levels between nations. The results, presented through a color-coded chart by construction year, indicate that Greater Mekong Subregion has financially viable interconnections at all percentages of optimal trade scenarios studied. Thus, implying a focus upon these interconnections will be beneficial for the region. Although the study is on APG, it is important to acknowledge that projects in the region require stable financial investments for project sustainability. This reflects possible financial struggles with changes needed to introduce greater flexibility to grid systems.

Focusing upon the institutional and political barriers, Li and Chang (2015) identify issues with developing an integrated electricity market in ASEAN. Using the European Union's electricity market integration as a success model, identified barriers include: political will to develop integrated power grid and incentivizing the private market through public private partnership. Although brief, the chapter highlights an important aspect in the development of APG, which is political will. This can translate to the challenges of integrating renewable energy amongst the member nations. With uncertain electricity generation by variable renewable energy, electricity market access is a means to cope with surplus and deficit electricity generation, which increases grid flexibility. ASEAN will need to overcome political barriers for APG to facilitate a regional electricity trade. Even if a systematic approach is developed in the region for enhancing grid flexibility, the non-binding nature of ASEAN agreements will require great political will for the region to benefit from integrating more renewable energy.

Renewable energy policies and effectiveness

In terms of renewable energy policy studies, ASEAN Centre for Energy's study on renewable energy policies in the region indicate varying levels of initiatives to deploy more renewable energy and policies' effectiveness. It indicates Vietnam as the country with the largest increase in renewable energy installed between 2006 and 2014. Across the region, common financial support policies used to support renewable energy include tariffs, subsidies and grid codes for integration of renewable energy (ASEAN Centre for Energy 2016). The study concluded that feed-in tariffs is a key policy for increasing the amount of renewable energy electricity generation, regardless of the country's involvement/policies. It is important to acknowledge that this study is conducted by ASEAN, and the feed-in tariffs effectiveness need to be further carefully studied. There are possibilities that indicated policies may not have been as successful as presented.

Although ASEAN's study on renewable energy policies suggests feed-in tariffs as the ideal policy, ASEAN's study does not explore renewable energy auctions. Auction is a mechanism governments use to procure specific renewable energy capacities through bids by project developers (IRENA 2013). It is a newer policy trend seen in countries previously invested in feed-in tariffs, such as Germany, and also ASEAN countries, such as Indonesia, Singapore and Philippines (IRENA 2013). Given the shift away from feed-in tariffs and other mixed experiences, such as Spain's experience that resulted in large financial burden upon the government, ASEAN needs to reconsider its future renewable energy policies (Institute for Energy Research 2012). Additionally, each individual nation will need to consider designing renewable energy policies to enhance grid flexibility through targeting specific traits.

Important studies on APG and ASEAN region have primarily focused upon the financial aspects and electricity market creation. The renewable energy policy analysis indicates that the region continues to show commitment towards increasing renewable energy in its fuel mix. The gap in literature on integration of renewable energy in ASEAN suggests that ASEAN needs to focus upon the challenges with increasing renewable energy in each nation.

Methodology

To provide the basis for identifying institutional and regulatory barriers, the preparedness analysis is used to provide a quantitative approach in understanding the system operations for each nation's grid. It is a quantitative adaptation of a scorecard method presented in a workshop session at Asia Clean Energy Forum (GIZ and USAID 2015). The main purpose is to provide an understanding of an individual nation's grid flexibility. Using peer-reviewed literature on integrating renewable energy and the USAID analytical framework, six indicators are developed: grid reliability, electricity market access, load profile ramp, forecasting systems, proportion of natural gas in electricity generation, and renewable energy diversity. Each indicator aims to characterize grid flexibility (Table 1).

Table 1. The six indicators used to characterize grid flexibility.

Indicator	Grid Flexibility Characteristic
Grid Reliability	How reliable, in terms of disruptions, is the current grid?
Electricity Market Access	How much access to electricity trade does a nation have for balancing surplus and deficit electricity generation?
Load Profile Ramp	How steep is the nation's worst-case scenario ramp in an average daily load profile?
Forecasting Systems	Are forecasting systems used to predict the expected generation from solar and wind energy?
Proportion of Natural Gas in Electricity Generation	What is the proportion of electricity generation by natural gas?
Renewable Energy Diversity	How many different renewable energy sources are currently grid integrated?

The analysis of preparedness uses a min-max normalization method, a linear transformation method used in data mining, to preserve the relationship between the data values. This is essential in understanding each nations' preparedness progress as most indicators do not have an ideal value for comparison. During the process of data collection, policies and practices documentation is essential in understanding potential explanation for the results shown in visualized data. It can indicate certain barriers and steps needed to achieve a more flexible grid in preparing for more renewable energy integration.

The radar chart is an effective visualization method given the multiple variables used. This visual representation shows the tradeoffs between studied variables. Additionally, comparison across countries can be done to understand the weakness, the variable with a value closer to 0, in a system. There are weaknesses in using a radar chart to visualize information. For example, if the analysis of preparedness is developed with more indicators, the chart may not be as useful and instead another data visualization may need to be considered. It is important to note that various methods for analyzing grid flexibility as a means of preparedness continue to develop (Cochran et al. 2014). However, there is no standard in the analysis and my method takes an approach by utilizing metrics used in the industry. Furthermore, the indicators considered represent a comprehensive view of preparedness and grid flexibility, ranging from the current reliability to the expected load profile ramp, and existing forecasting systems that aid planners and utility operators in managing intermittent renewable energy sources.

METHODS

Study system

Conducting a grid flexibility analysis in the ASEAN region indicates the region's preparedness in anticipation for higher percentages of renewable energy connected to the grid. During data collection, I documented policies and practices from each nation in regards to the categories and indicators. A quantitative analysis was conducted on grid operations data in each nation. With the results from the visualized data analysis, represented as radar charts, strengths and weaknesses were identified.

Methods

To analyze each nation's grid flexibility, I collected data for every indicator for the ten ASEAN member nations. The grid flexibility analysis is a quantitative adaptation of a workshop held by GIZ and USAID (2015) at Asia Clean Energy Forum. The workshop presented 7 questions (Table 2)

Table 2. Questions presented in GIZ and USAID workshop on grid flexibility (GIZ and USAID 2015).

Questions
What is the size of the balancing area?
How is wind and/or solar forecasting integrated into system operations?
How flexible is the system operator's scheduling and dispatch practice?
How flexible are the portfolio of generation and demand?
How geographically distributed are wind and solar resources?
Do system operators have access to additional balancing resources in neighboring interconnections?
How robust is the transmission system?

The six indicators used in my thesis are grid reliability, electricity market access, load profile ramp, forecasting systems, proportion of natural gas in electricity generation, and renewable energy diversity. In my analysis, I have included specific indicators for each category (Table 3). Through data mining, I reviewed documents and databases published by ASEAN Centre for Energy, World Bank Doing Business, National Renewable Energy Laboratory, and Asia Development Bank. Data used for the grid flexibility analysis are from 2012 to 2017; Brunei's load profile is the only exception with the latest available data from 2006. During the data collection, notable policies or situations for specific indicators were documented. For example, any nations that do not use forecasting as a tool for predicting energy generation and any formal agreements for electricity trade were noted.

Table 3. List of indicators used in grid flexibility analysis.

Indicator	Metric
Grid Reliability	System average interruption duration index (SAIDI)
	System average interruption frequency index (SAIFI)
Electricity Market Access	Capacity of interconnections currently operating and to be completed by end of 2018 in megawatts (MW)
Load Profile Ramp	Rate of demand increase in megawatt per hour (MW/hour)
Forecasting Systems	Yes or no
Proportion of Natural Gas in Electricity Generation	Amount of electricity generated by natural gas as proportion of total electricity generated
Renewable Energy Diversity	Number of renewable energy sources integrated into the grid

Some of the indicators required calculations for the data. Firstly, I quantified electricity market access through summing interconnection capacities for imports and exports through power purchase (long term trade), and interconnection capacities for energy exchange (short term trade). It is represented by the formula:

$$\text{Capacity of interconnection for import (MW)} + \text{Capacity of interconnection for import (MW)} + \text{Capacity for energy exchange (MW)}.$$

Secondly, load profile ramp refers to the rate of demand increase. The worst-case ramp rate of the average daily load profile was determined by using each nation's daily load profile. Due to the various forms of data provided by utilities, governing agencies and research institutes, an average daily load profile was calculated through using WebPlotDigitizer (Table 4) (Rohatgi 2018). I identified the maximum demand and minimum demand associated with the steepest slope and calculated the load profile ramp by

$$\frac{\text{Maximum demand of steepest slope (MW)} - \text{Minimum demand of steepest slope (MW)}}{\text{Time taken (hours)}}.$$

Graphically, it is represented as the slope's gradient and represents the largest demand increase in a small-time frame. Thirdly, the proportion of natural gas used for electricity generation was calculated by

$$\frac{\text{Electricity generated by natural gas}}{\text{Total electricity generated}}.$$

Table 4. Description of the data formats and method used to generate average daily load profiles for calculating load profile ramp. Where data was unavailable for day 15 of each month, the closest date available was used.

Country	Source Format	Method Used to Calculate Average Hourly Demand
Brunei	Average daily load profile graph (ERIA 2014)	WebPlotDigitizer used to extract hourly demand values
Cambodia	Average daily load profile graph (Electricite Du Cambodge 2015)	WebPlotDigitizer used to extract hourly demand values
Indonesia	Average daily load profile graph (ERIA 2014)	WebPlotDigitizer used to extract hourly demand values
Laos	Average daily load profile graph (ERIA 2014)	WebPlotDigitizer used to extract hourly demand values
Malaysia	Hourly demand values (Suruhanjaya Tenaga 2017)	First, I identified daily load profiles from day 15 of each month. Second, I calculated the average hourly demand from values provided by the source.
Myanmar	Average daily load profile graph (Japan International Cooperation Agency 2014)	WebPlotDigitizer used to extract hourly demand values
Philippines	Average daily load profile graph (Wholesale Electricity Spot Market 2017)	First, I identified daily load profiles from day 15 of each month and used WebPlotDigitizer to extract hourly demand values. Second, average hourly demand was calculated with the 12 data points.
Singapore	Half-hourly demand values (Energy Market Authority of Singapore 2017)	First, I identified daily load profiles from day 15 of each month. Second, I calculated the average half-hourly demand from values provided by the source.
Thailand	Average daily load profile graph (IEA 2016c)	WebPlotDigitizer used to extract hourly demand values
Vietnam	Average weekly load profile graphs (Electricity Regulatory Authority of Vietnam 2017)	First, I identified weekly load profiles every 4 weeks starting from week 3 of the year and used WebPlotDigitizer to extract hourly demand values. Second, average hourly demand was calculated with the 13 data points.

For data analysis, I conducted data transformation through a min-max normalization with a new range between zero and one (Han et al. 2011). The equations are listed respectively for min-max normalization and reverse min-max normalization:

$$Y = \frac{X - \text{minimum}}{\text{maximum} - \text{minimum}}$$

$$Y = \frac{X - \text{maximum}}{\text{minimum} - \text{maximum}}$$

The normalization method used depended upon the specific indicator, whether higher values are a positive or negative attribute. If a higher value is a positive attribute, min-max normalization was used and vice versa. For example, a higher number of interruptions in grid reliability is negative attribute and hence a reverse min-max normalization was used. To obtain a value for grid reliability, I calculated averages of both metrics' normalized values in the indicator. Radar charts were produced using the normalized data for each indicator and nation. The overall grid flexibility score is an average of all indicators' scores.

Using the radar charts created, I identified trends for ASEAN nations. This included noting any similarities in patterns between each nation's radar chart. For example, I identified poor performance in forecasting systems. With these trends, I researched into further policy or research initiatives for the indicator Additionally, to address my hypothesis, I collected data on GDP per capita from World Bank. This is used to further explain any trends found in the overall grid flexibility analysis.

RESULTS

Grid reliability

Using SAIDI and SAIFI scores averaged from 2013 to 2015, I found an uneven distribution of grid reliability (Arlet 2017). Six ASEAN nations have very reliable grids (grid reliability score ≥ 0.95), 2 nations have moderately reliable grids, and Cambodia has the least reliable grid in the region (Table 5).

Table 5. Normalized SAIDI and SAIFI Scores.

Country	Normalized SAIDI	Normalized SAIFI	Grid Reliability Score
Brunei	0.97	0.98	0.98
Cambodia	0.00	0.00	0.00
Indonesia	0.94	0.95	0.95
Laos	0.22	0.81	0.51
Malaysia	0.99	0.99	0.99
Myanmar[1]	-	-	0.00
Philippines	0.91	0.94	0.93
Singapore	1.00	1.00	1.00
Thailand	0.99	0.97	0.98
Vietnam	0.65	0.77	0.71
ASEAN	0.74	0.82	0.70

Electricity market access

With the total interconnections capacity available for electricity trade under the ASEAN Power Grid, Laos is ranked the top ASEAN nation for electricity market access. Overall, most ASEAN nations do not have large amounts of interconnections capacity for electricity trade. 80% of the countries have a score between 0 to 0.28, whereas Thailand and Laos perform significantly better at 0.79 and above (Table 6). Myanmar and Philippines are ASEAN's weakest performers with no access to electricity trade. Additionally, the countries have different forms of access to electricity trade market. Brunei, Indonesia, Malaysia, and Singapore only have access through energy exchange markets, which are spot markets for short term trades through bids. Cambodia, Laos, Thailand, and Vietnam have access to long term trade agreements through power purchase. Thailand is the only country that has access to all types of electricity trade.

[1] Myanmar does not measure grid reliability, however reports indicated Myanmar suffers from an aging infrastructure and unstable grid (KWR International (Asia) Pte. Ltd. 2015, Macleod 2017). Thus, I attributed a score of 0 for Myanmar.

Table 6: I reviewed through the interconnection capacities according to projects completed by 2018 ASEAN Power Grid for each ASEAN country (Andrews-Speed 2016).

Country	Interconnection Capacity (MW)				Electricity Market Access Score
	Energy Exchange	Import	Export	Total	
Brunei	200	0	0	200	0.04
Cambodia	0	600	0	600	0.12
Indonesia	230	0	0	230	0.04
Laos	0	0	5132	5132	1.00
Malaysia	1260	0	0	1260	0.25
Myanmar	0	0	0	0	0.00
Philippines	0	0	0	0	0.00
Singapore	450	0	0	450	0.09
Thailand	380	3584	100	4064	0.79
Vietnam	0	1248	200	1448	0.28

Load profile ramp

Laos and Brunei have the best load profile ramp. Both have gentlest ramp slopes, as indicated with its score of 1 (Table 7). 50% of the ASEAN nations have ramps less than 300 MW/hour. Thailand's load profile showed the steepest inclines out of all ten countries. At 3200 MV/hour, it is double the amount of Vietnam's increase rate in electricity demand, which is the second worst performer in ASEAN. Additionally, I compared each nation's load profile and found that ASEAN nations have similarities in when the steepest ramps occur. Almost all nations' steepest ramp occurred between 8am to 10am. I also noticed that all nations sustained the high electricity demand from 10am to 8pm (Figure 1).

Table 7: I calculated worst-case scenario for each nation and the associated normalized value. See Appendix A for each country's average load profile.

Country	Load Profile Worst Case Ramp (MW/hour)	Load Profile Ramp Score
Brunei	11	1.00
Cambodia	130	0.96
Indonesia	970	0.70
Laos	17	1.00
Malaysia	970	0.70
Myanmar	210	0.94
Philippines	580	0.82
Singapore	300	0.91
Thailand	3200	0.00
Vietnam	1600	0.50
ASEAN Average	800	0.75

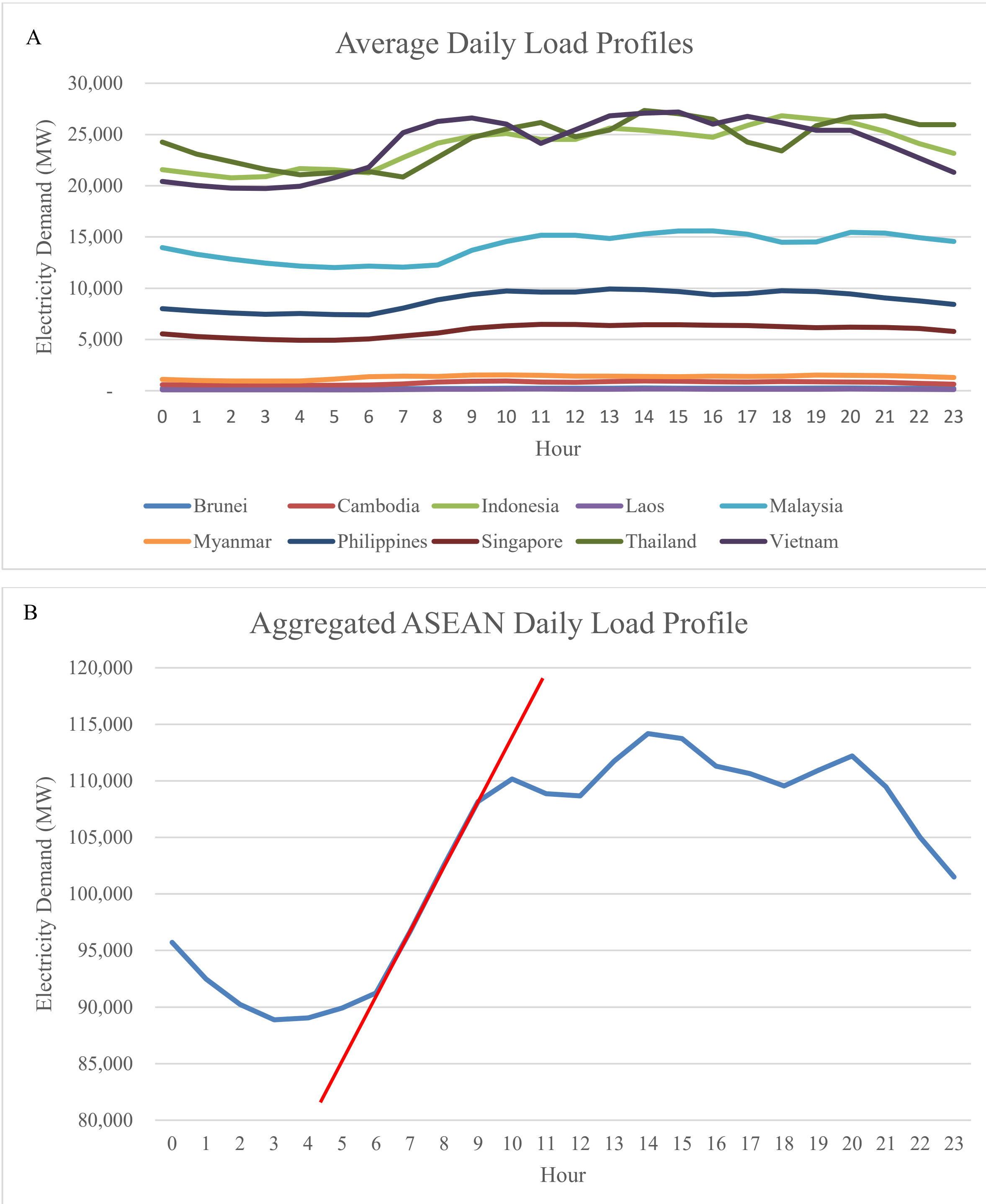

Figure 1: Average and Aggregated Load Profiles. A. Average daily load profile for each ASEAN nation. B. Aggregated ASEAN Daily Load Profile, which is the demand of each ASEAN nation summed. The red line indicates the steep ramp. See Appendix A for individual nation's load profile (ERIA 2014, Japan International Cooperation Agency 2014, Electricite Du Cambodge 2015, IEA 2016c, Energy Market Authority of Singapore 2017, Suruhanjaya Tenaga 2017, Wholesale Electricity Spot Market 2017).

Forecasting systems

I found that nine ASEAN nations do not have wind or solar forecasting systems in place. The Philippines is the only nation with a solar and wind forecasting system (Barrows et al. 2018). With the grid flexibility analysis, Philippines scored 1 and the rest of the nations in ASEAN scored 0 (Appendix B).

Proportion of electricity generation by natural gas

Using data from IEA, most ASEAN nations do not have a higher proportion of electricity generation by natural gas. Only three countries have more than 70% of electricity generation by natural gas, and other nations all have less than 50% of electricity generation by natural gas (Table 8). Natural gas power plants are the most flexible fossil fuel source due to its ability to increase or decrease electricity generation over a short time frame (Gonzalez-Salazar et al. 2018). Countries with higher amounts of natural gas for electricity generation complement the variability from solar and wind sources. This resulted in a more flexible grid. For example, Brunei has 99% of its electricity generated by natural gas. This means that when Brunei integrates more renewable energy, the complementary source for variability will be natural gas. Countries lacking natural gas for electricity generation, such as Cambodia and Laos, have the lowest score.

Table 8: Proportion of electricity generation by natural gas for each ASEAN nation (IEA 2015c).

Country	Proportion of Electricity Generation by Natural Gas	Natural Gas Electricity Generation Score
Brunei	0.99	1.00
Cambodia	0	0.00
Indonesia	0.25	0.25
Laos	0	0.00
Malaysia	0.47	0.46
Myanmar	0.39	0.39
Philippines	0.23	0.23
Singapore	0.95	0.96
Thailand	0.71	0.72
Vietnam	0.33	0.34
ASEAN Average	0.99	0.44

Renewable energy diversity

I found that ASEAN nations do not have large diversity in renewable energy sources (Table 9). Only Indonesia, Philippines and Thailand have more types of renewable energy source integrated in its grid. More renewable energy diversity reflects higher grid flexibility as it represents more sources available to meet electricity demands. Most ASEAN nations only have two types of renewable energy integrated.

Table 9: I counted the different types of grid integrated renewable energy and conducted min-max normalization for the score (ASEAN Centre for Energy 2016)

Country	Renewable Energy Diversity	Renewable Energy Score
Brunei	1	0
Cambodia	2	0.2
Indonesia	5	0.8
Laos	3	0.4
Malaysia	4	0.6
Myanmar	2	0.2
Philippines	5	0.8
Singapore	2	0.2
Thailand	6	1
Vietnam	2	0.2
ASEAN Average	3.2	0.44

Overall grid flexibility score and radar charts

Using the normalized scores from each indicator, I found the average grid flexibility score for each nation. This resulted in a ranking order of the ten ASEAN nations (Table 10). The ASEAN nations are categorized by its performance. I found that Philippines and Thailand have the most flexible grid. From the normalized score for each indicator, the radar charts for each nation show distinctive patterns across ASEAN (Figure 2). It shows the clear tradeoffs in terms of indicators that countries have focused upon and indicators that countries need to address for a more flexible grid. These clustering patterns are discussed in the analysis section.

Table 10: Results of grid flexibility analysis with a column indicating the GDP per capita by country (The World Bank 2016).

Rank	Country	Grid Reliability	Electricity Market Access	Load Profile Ramp	Forecasting	Natural Gas Electricity Generation	Renewable Energy Diversity	Overall Grid Flexibility Score	GDP per Capita (USD)
1	Philippines	0.93	0.00	0.82	1	0.23	0.80	0.63	2, 951.10
2	Thailand	0.98	0.79	0.00	0	0.72	1.00	0.58	5, 910.60
3	Singapore	1.00	0.09	0.91	0	0.96	0.20	0.53	52, 962.50
4	Brunei	0.98	0.04	1.00	0	1.00	0.00	0.50	26, 939.40
5	Malaysia	0.99	0.25	0.70	0	0.47	0.60	0.50	9, 508.20
6	Laos	0.51	1.00	1.00	0	0.00	0.40	0.49	2, 338.70
7	Indonesia	0.95	0.04	0.70	0	0.25	0.80	0.46	3, 570.30
8	Vietnam	0.71	0.28	0.51	0	0.34	0.20	0.34	2, 170.60
9	Myanmar	0.00	0.00	0.94	0	0.39	0.20	0.26	1, 195.50
10	Cambodia	0.00	0.12	0.96	0	0.00	0.20	0.21	1, 269.90

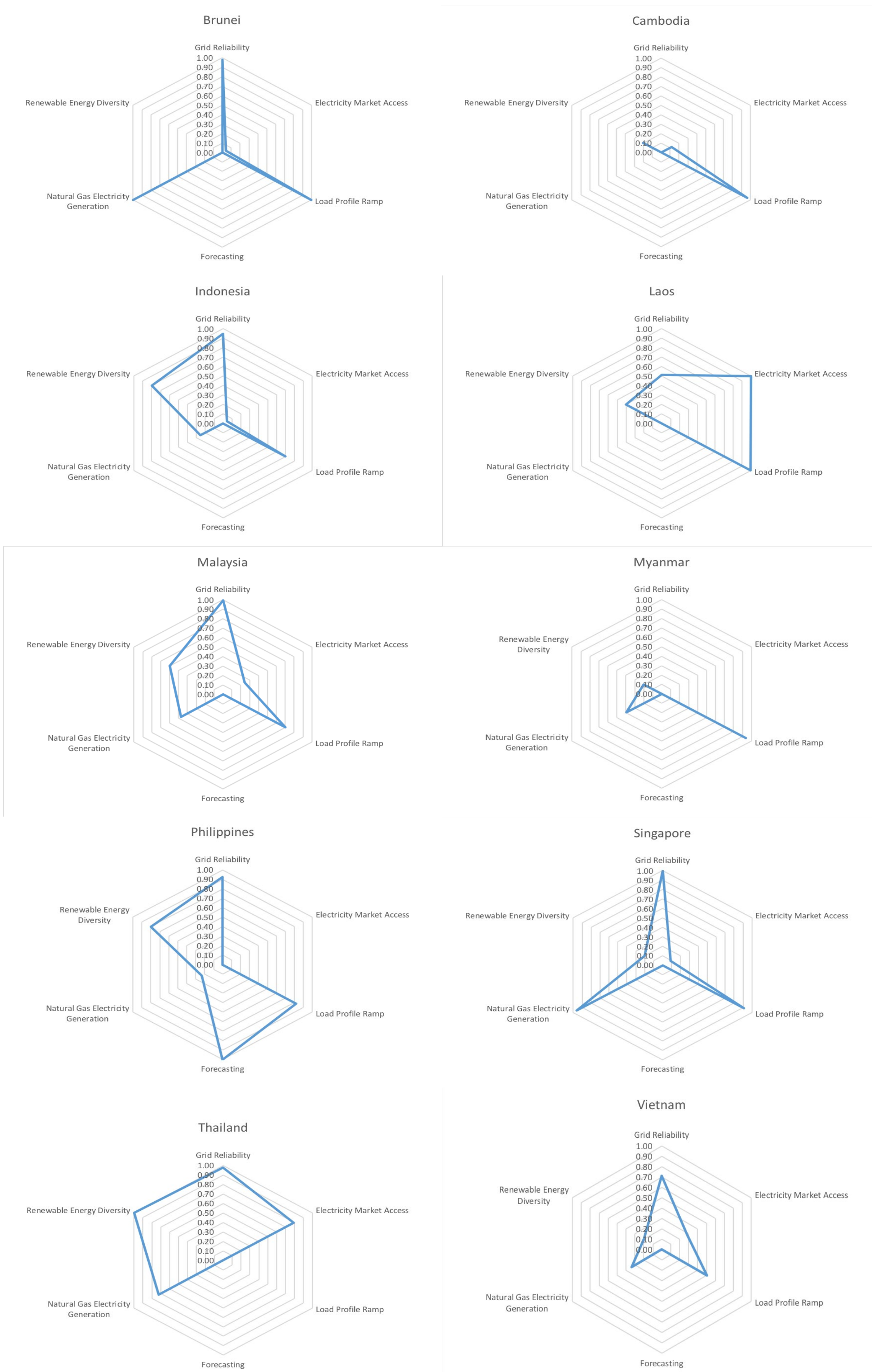

Figure 2: Radar charts for each nation based on the results shown in Table 10.

ANALYSIS

As ASEAN pursues its goal of 23% of electricity generation by renewable energy, the grid flexibility analysis shows that Philippines and Thailand are the most prepared for higher amounts of grid integrated renewable energy sources. Most nations have ambitious targets for integrating renewable energy and will need to be more prepared with a flexible grid to accommodate achieve these goals. ASEAN nations' grid flexibility can accommodate the current grid integrated renewable energy. However, most nations will need to address the absence of wind and solar forecasting practices and steep ramps in load profiles. Both issues result in a less flexible grid. The analysis summarizes the clustering trends found in terms of each country's relative preparedness by the factors studied, and not a justification if one country is truly prepared. Other trends from the data analysis are also described to provide supporting analysis of various ASEAN nations' strengths and challenges.

Performance by country

From the overall grid flexibility score, the ASEAN nations are not well prepared for an increase in renewable grid integration. Philippines has the highest score at 0.63, however it means that even the most prepared nation has room for improvement in the factors studied to achieve a higher score closer to 1. A score of 1 would indicate that the nation performs the best across all factors relative to the other ASEAN nations. The ASEAN nations' preparedness for higher renewable energy grid integration can be grouped into three distinctive groups: better prepared nations, moderately prepared nations, and least prepared nations. Using the average grid flexibility score of six indicators, this clustering trend is evident, which indicates the relative grid flexibility amongst the ten nations as a measure of preparedness (Table 10).

Better prepared nations cluster

The better prepared nations cluster group includes Philippines and Thailand. From the grid flexibility analysis, Philippines has the most flexible grid and is the most prepared ASEAN nation for more renewable energy grid integration. One strength of Philippines' grid operation is forecasting practices, which puts it at an advantage compared to other nations, due to the benefits from predicting electricity generation. Philippines and Thailand are the only two ASEAN nations that perform well across four out of the six indicators. Both currently have a diverse portfolio of renewable energy sources integrated and balanced with a high percentage of natural gas power plants, which increases the grid flexibility (Papaefthymiou et al. 2014, Gonzalez-Salazar et al. 2018). Other studies have shown that Philippines has the potential to achieve 30% and 50% renewable energy within its power system (Barrows et al. 2018). Philippines and Thailand share similar characteristics to other regions with high amount of grid integrated renewable energy. For example, a modeling study on California indicates the diverse portfolio used in a flexible grid scenario to meet higher demand hours (Brinkman et al. 2016). This highlights that Philippines and Thailand have the right practices and grid characteristics, placing it at a higher ranking relative to other ASEAN nations.

Philippines and Thailand have very different patterns in the radar chart, thus indicating separate focuses needed for improving its grid flexibility (Figure 2). The main challenge for Philippines is access to electricity markets. Due to its geographical location and archipelago, Philippines does not currently have access through interconnections and thus resulting in the lowest score for electricity market access variable (Andrews-Speed 2016). In comparison, Thailand needs to reduce its steep ramp seen in its load profile. The steep ramp represents an inflexible grid due to the large increase in electricity demand over a short period of time. It suggests a challenge in meeting future demands. Philippines and Thailand will need to address its respective grid flexibility weaknesses in anticipation for more renewable energy grid integration to achieve its country and ASEAN targets.

Moderately prepared nations cluster

Brunei, Indonesia, Laos, Malaysia, and Singapore are moderately prepared nations. With grid flexibility scores ranging from 0.46 to 0.53, these nations either score moderately well across a few indicators or only score very high for two to three indicators. Moderately prepared nations are characterized by high grid reliability, moderate ramps in its load profile, and little access to neighboring electricity markets. With these characteristics, the moderately prepared nations need to increase grid flexibility by improving electricity market access and diversifying renewable energy sources. Interestingly, Laos has a very different radar chart compared to other nations in this group and yet scores well on average for grid flexibility. This is likely due to Laos' high amount of access to neighboring electricity markets through various interconnections and agreements (Andrews-Speed 2016). It is important to note that Laos is an exporter whereas other nations in the same cluster have a variation of electricity trade available. This can be an issue for Laos as it means that Laos is unable to import electricity during higher demand periods in the future — given the assumption of integrating more variable renewable energy, which affects the predictability of electricity generation.

Least prepared nations cluster

The least prepared nations in ASEAN are Cambodia, Myanmar, and Vietnam. The three countries only perform very well on one grid flexibility indicator: electricity load profile ramp for Cambodia and Myanmar, and grid flexibility for Vietnam. Although Cambodia and Myanmar have more similar patterns in their radar chart than when compared to Vietnam, Vietnam is part of the same cluster group due to the average score calculated. When compared to other ASEAN nations, these three countries do not perform well in the studied indicators. Trends include low renewable energy diversity, low grid reliability, and little to no access of electricity markets. Cambodia and Myanmar have the highest scores for electricity load profile ramp, which indicates a slow demand growth during the peak demand times. This means that Cambodia and Myanmar have the advantage of meeting systems demand during peak demands compared to other nations. Aligning with the results for electricity market access, Myanmar has lower amount of electricity exchanges in the Greater Mekong Subregion when compared to Vietnam and Cambodia (Asian Development Bank 2012).

Although Cambodia, Myanmar and Vietnam are the least prepared, it is important to note that these countries are only the least prepared given the current infrastructure. The lack of prior investment in infrastructure may make it easier to accommodate distributed renewable energy or develop grid infrastructure with the intent to incorporate more renewable energy. These countries have the largest potential to incorporate renewable energy easily than other countries with extensive grid infrastructure embedded upon fossil fuels. Additionally, these countries could aid other ASEAN countries balance surplus and deficit generation through electricity trade.

GDP per capita and cluster groups

From the grid flexibility analysis and cluster group trends, it suggests that GDP per capita, a measurement of financial resource available, may not have an important role in determining which countries are the most prepared from a grid flexibility perspective. This does not support the initial hypothesis: certain countries with more financial resources and stronger renewable energy policies will be better prepared for a future with more grid integrated renewable energy. Within the better prepared nation cluster group, both Philippines and Thailand have a moderate level of GDP per capita when compared to other nations in ASEAN but are the most prepared countries in ASEAN (Table 10). However, the countries in the least prepared cluster group align with the lowest GDP per capita countries in ASEAN (The World Bank 2016). This suggests that GDP per capita may have a greater influence on a country's grid flexibility for countries with less financial resources. Other factors could also affect a country's grid flexibility such as the country's rigor in pursuing a future with more renewable energy.

Trends in ASEAN: Implications for the future

Strengths of ASEAN nations and region

Although the grid flexibility analysis shows that most ASEAN nations are not prepared for more renewable energy grid integration, there are some positive aspects in the results. ASEAN as a region has high grid reliability. This suggests that the countries value grid reliability and there is an intrinsic amount of flexibility within the nation's grid system. For example, Philippines has the highest and most diverse renewable energy integrated to its grid at 15% of electricity generation by renewable energy whilst maintaining a high grid reliability score. This means that the grid supports the current levels of integrated renewable energy. The increase in grid integrated renewable energy often affects the grid stability, thus the current grid reliability is a good indicator for how well a nation is integrating its current renewable energy sources (Cochran 2015). The grid reliability results emphasize that ASEAN countries are currently able to support the amount of renewable energy integrated to its grid.

Another strength is the initiative for establishing an electricity market through the ASEAN Power Grid. From the results of electricity market access, the quantified amounts of current electricity exchanges ability in the region suggests the ability for the ASEAN nations to balance deficit and surplus generation. Although only bilateral agreements currently exist for trade between two neighboring countries, access to regional electricity markets will be beneficial in improving grid flexibility (United Nations 2006, Matsuo et al. 2015). Laos, Malaysia and Thailand recently signed ASEAN's first initiative for multilateral trade in the future (Ali 2017). This suggests a step forward in the direction of creating the regional electricity market beyond agreements for neighboring nations only. The regional electricity trade characteristic is similar to European's regional grid interconnection for electricity trade; notable countries in Europe, such as Denmark and Portugal, have more 30% of renewable energy integrated into their grid system (Cochran et al. 2012, Martinot 2016). Europe benefits from the larger pool of resource access through a regionally interconnected grid smoothens the individual nation's deficit and surplus generation through electricity power exchanges across the region (Huber et al. 2014, Fraunhofer IWES 2015). Although ASEAN is years away from a completed ASEAN Power Grid, the initiative and current levels of electricity exchanges suggest an optimistic future for individual nations to improve its grid flexibility through electricity market access indicator.

Challenges for ASEAN

With the current level of grid flexibility, there are various challenges that ASEAN will face in terms of preparedness for higher renewable energy grid integration. Some results from the grid flexibility analysis indicate potential issues with meeting future demands by renewable energy.

Challenge 1: Aggregated increase in electricity demand. All ASEAN nations have maintained higher electricity demand between 10am and 8pm, and demand increase at 6am to 10 am, which is represented by the ramp slope (Figure 1). These two trends suggest challenges with meeting demands by electricity trade. In an ideal balancing scheme, nations would complement each other in terms of periods of supply and demand. This means that a period of high demand by country X can be balanced out by the period of low demand by country Y through exporting the unused electricity generation to country X. For example, Thailand's high demand could be balanced by

Laos' low demand. However, ASEAN's trend with all nations sustaining high demand creates difficulties for electricity trade to occur unless a country consistently has a surplus generation available for export. Aggregated increase in demands and sustained periods of high electricity demand across all countries means that ASEAN currently will not benefit from an overall smoothing effect seen in Europe through electricity trade (Fraunhofer IWES 2015).

Another concern with the load profile of ASEAN nations is increase in renewable energy will intensify the ramp and increase variability during the day (Huber et al. 2014). An example of the renewable energy effect on the daily load profile is the "duck curve" in California's load profile, a state with 30% of electricity sale from renewable energy sources (California Energy Commission 2017). It describes the intensified increase in electricity demand after sunset due to the sudden decrease in solar electricity generation (Denholm et al. 2015). Although none of the ASEAN nations experience such changes in the load profile, it is a concern for the future given ASEAN's pursuit and target for integrating more renewable energy sources. From the grid flexibility analysis, Thailand has the steepest ramp rate amongst all ASEAN nations. A steeper ramp rate now means it is an inflexible grid because the system needs to meet increasing demands over a short period of time, which it may not have the right resources for. It can be even more challenging to meet demands in the future with the unexpected fluctuations of electricity generation by renewable energy. Despite its steep ramp, Thailand is in a better position that other nations due to the amount of electricity exchanges available and its access to neighboring electricity markets. However, this will be an issue for Vietnam, which is seen to have a moderate ramp score but low electricity market access score. These potential issues with ASEAN's aggregated load profiles and ramp must be considered in future planning and grid operations by ASEAN nations.

To address this challenge, ASEAN should consider the role of grid energy storage given the declining trend in battery cost (Eller and Gauntlett 2017, Kittner et al. 2017). This technology can reduce the ramp steepness in load profiles through load shifting by either storing surplus electricity generated or supplying power when electricity demands increase (Dunn et al. 2011). Additionally, it complements the intermittency from solar and wind generation. ASEAN countries with a low score in proportion of electricity generation by natural gas can potentially adopt grid energy storage instead of expanding transmission systems. In the long term, battery energy storage could improve grid flexibility.

Challenge 2: Forecasting practice. All ASEAN nations, with Philippines as an exception, lack forecasting practices for both solar and wind power, which is a concern for meeting electricity demands. Philippines has implemented a wind and solar forecasting system along with research into next day wind forecasting by Ateneo (NGCP n.d., Barrows et al. 2018). Forecasting is an ideal practice for grid flexibility (Cochran et al. 2012, Aggarwal and Orvis 2016, Martinot 2016). Location specific wind or solar generation can be estimated in advance through using weather data and numerical weather prediction models (GIZ 2015). Given the nature of procuring electricity generation, grid operators need to schedule the generation portfolio a day before the actual generation time. Various regions or countries with high levels of grid integrated renewable energy, such as Denmark, use forecasting system (Cochran et al. 2012). Additionally, modeling studies have shown forecasting systems benefits. Day ahead wind forecasting systems can result in cost reduction of 4 billion USD and day ahead solar forecasting can result in cost reduction by 13.2 million USD (Bird and Lew 2012, Brancucci Martinez-Anido et al. 2016). In addition to the cost benefits, using advanced forecasting system means feasibility for more electricity generation by renewable energy. It accounts for the potential proportion of electricity generation by renewable energy. Thus, effectively reducing the risks for curtailment situations, a shutdown of certain generation plants due to over generation, and maintains grid reliability. Evidently, forecasting practices are extremely important for the ASEAN nations that have an intent in increasing the amount of wind power integrated to the grid. The absence of forecasting practices may be feasible now but given the renewable energy targets and the benefit in planning for the future, ASEAN nations will need to address their practices in preparation for more grid integrated renewable energy.

Limitations and Future Directions

My analysis of grid flexibility for the ten nations in ASEAN summarizes the current performance in context of the renewable energy targets set by each nation and the region. The analysis remains limited to grid integrated renewable energy sources and does not account for the growing potential and development for micro and mini grids for sustainable development in regions without access to electricity. Therefore, it does not consider the possibility that Myanmar, Cambodia, and Vietnam may be more poised to integrate decentralized renewables at a more rapid pace in the future, if investment enables this type of deployment. Although the data found were from credible sources, such as statistic banks, government departments, international organizations, and research institutes, there are inherent issues with latest data availability and data formats used by individual nations. For example, Myanmar does not document grid reliability metrics used by most grid operators and energy suppliers (SAIDI and SAIFI). This makes it difficult to compare across different countries, even though reliability presents most critical challenges to stable power grid and operational efficiency. Additionally, this study is specific to ASEAN and the variables were chosen based upon the available data. Thus, the method can be adapted to other regions, but the results for this particular region are mostly useful when considering ASEAN affairs.

For future research, grid flexibility analysis can be done specifically for each country in cooperation with utility operators and governing ministries as a form of technical assistance. Direct communication with critical stakeholder to understand grid operations will be beneficial in future studies. The purpose is to highlight grid flexibility needs in the pursuit of more renewable energy to policymakers. Other future possibilities include specifically modeling systems under different renewable energy penetration scenarios.

Conclusion

As ASEAN continues to pursue its renewable energy targets, all member nations will need to consider increasing its current grid flexibility to be adequately prepared for future scenarios with more renewable energy integrated to the electrical grid. The radar charts indicate the strengths and weaknesses of each country's grid operation; a comparison across all countries show that no countries perform extremely well across all indicators studied. My method highlights specific priorities for each country, which are crucial in guiding governments to support renewable energy. For example, Thailand's Ministry of Energy recent change in its support for renewable energy does not reflect its potential and position as a better prepared nation for renewable energy found in my study (Tongsopit 2018). Additionally, as discussed, nations in the least prepared cluster also have the potential to integrate renewable energy, given if governments address the weakness and investments are made. Each country is unique and different pathways could be pursued with renewable energy, such as decentralized renewable energy or continued focus on improving grid flexibility in the central system. Investments will be important in overcoming integration challenges in each member nations' existing grid system.

My study also indicates the importance of regional cooperation in addressing ASEAN's grid flexibility and renewable energy challenges. The identified operational barriers, such as aggregated increase in electricity, will require regional cooperation to solve. As one of the first studies to quantify and detail a load profile and calculate worst-case ramp rate for each member nation, these results can be used for future studies on the interconnected regional grid. Addressing this main concern through regional cooperation and electricity trade market, ASEAN will need to focus on more detailed studies in grid operations and renewable energy grid integration economic impacts, whether by individual nations or as a region. ASEAN has the technical potential to improve grid flexibility in anticipation for more renewable energy integrated to the grid. Overcoming the barriers and addressing priorities will aid ASEAN in achieving its renewable energy targets and transition to a cleaner future.

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APPENDIX A: Average Load Profiles by Country

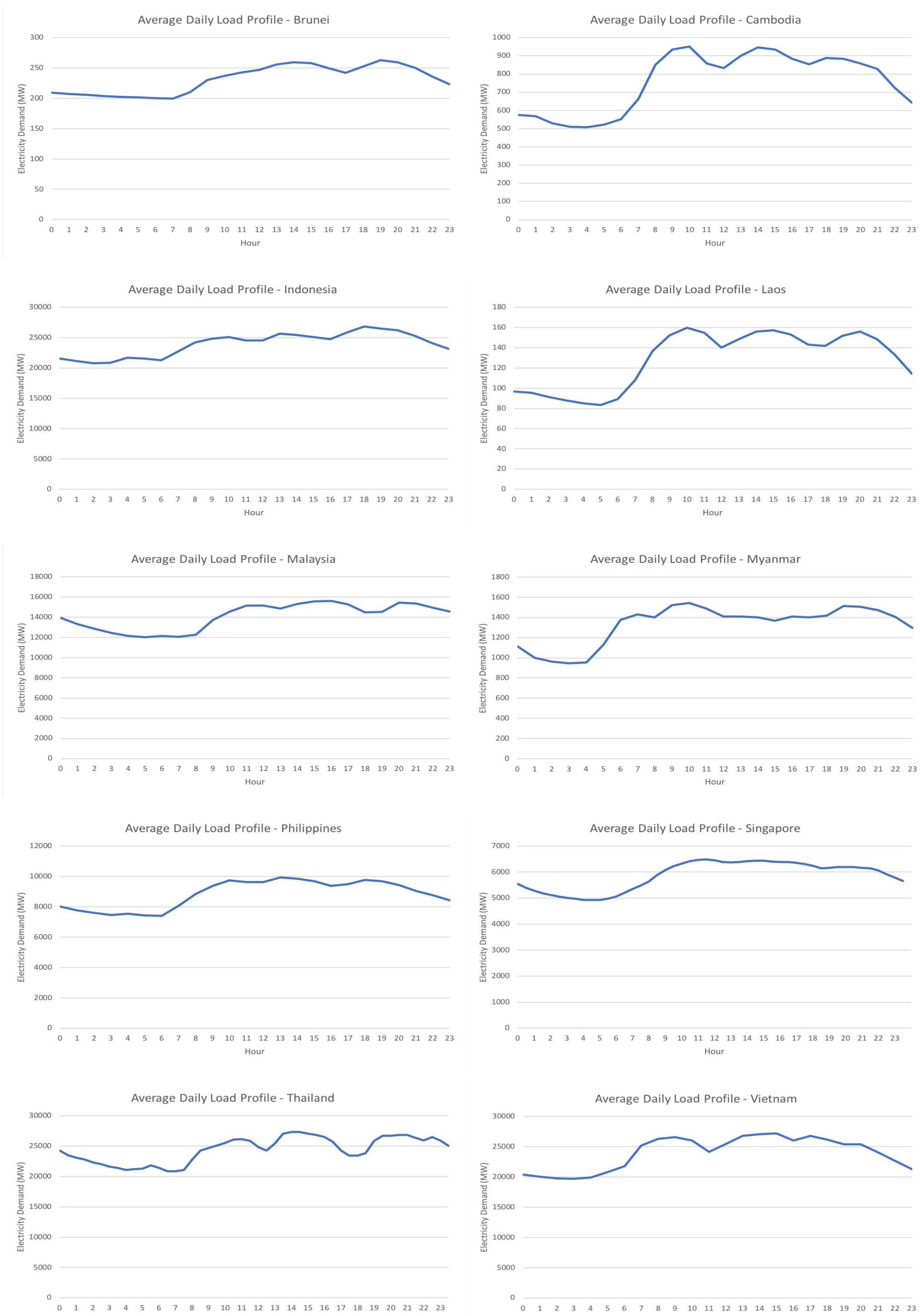

Figure A1: Average daily load profile by country (ERIA 2014, Japan International Cooperation Agency 2014, Electricite Du Cambodge 2015, IEA 2016c, Energy Market Authority of Singapore 2017, Suruhanjaya Tenaga 2017, Wholesale Electricity Spot Market 2017).

APPENDIX B: Forecasting Indicator Results

Table 11: Results for forecasting score in ASEAN.

Country	Forecasting Score
Brunei	0
Cambodia	0
Indonesia	0
Laos	0
Malaysia	0
Myanmar	0
Philippines	1
Singapore	0
Thailand	0
Vietnam	0
ASEAN Average	0.1