Report on ASEAN Renewable Energy Grid Integration Review

One Community
For Sustainable
Energy

Report on ASEAN Renewable Energy Grid Integration **Review**

9 789798 978494

Editors:
- ASEAN Centre for Energy (ACE)
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
- Energynautics GmbH

Published by:
- ASEAN Centre for Energy (ACE)
- Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

ACE Building, 6th floor
Complex Directorate General of Electricity
Jl. HR. Rasuna Said kav.7-8 Jakarta, Indonesia
Tel: (62-21) 527 8027 | Fax: (62-21) 529 6382

www.agep.aseanenergy.org
www.facebook.com/sustainableenergyforasean

April 2019

Credit: GIZ

Acknowledgment

The Report on ASEAN Renewable Energy Grid Integration Review was prepared under the overall guidance of Christopher G. Zamora, Acting Executive Director of ACE, Ir. Dr. Sanjayan Velautham and Maria-José Poddey, Principal Advisor for AGEP, GIZ. The Report development was managed by Rizky Fauzianto (GIZ), Septia Buntara (ACE), Yudiandra Yuwono (ACE) and Melati Wulandari (GIZ).

The Report was developed with the assistance of Dr. Thomas Ackermann and Dr. Eckehard Troester, (Energynautics GmbH) as the consultants.

Valuable review and feedback were provided by ACE colleagues.

The report has benefited from input by representatives from power utilities and regulatory bodies in eight ASEAN Member States, i.e. Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Singapore, Thailand, and Vietnam, that participated in the Third ASEAN Regional Renewable Energy Grid Integration Training held from 27 February – 01 March 2019 in Kuala Lumpur. This training is a follow-up from the first one held in Jakarta on 20-21 March 2018 and second training held in Bangkok on13-15 August 2018. Their comments and suggestions were of great value and have helped shape the final report.

Special thanks and appreciation are extended to the ASEAN Energy Regulatory Network (AERN), Head of ASEAN Power Utilities/Authorities (HAPUA) and Tenaga Nasional Berhad (TNB).

Disclaimer

Foreword

As highlighted in the Joint Ministerial Statement of the 36th ASEAN Ministers on Energy Meeting (AMEM) held in Singapore in October 2018, ASEAN is on track to achieve the collective energy targets by 2020 towards a secure, accessible, affordable and sustainable energy future. This is reflected by the overall positive progress in the implementation of the ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025 Phase 1: 2016-2020. During the last AMEM, the AMS looked forward to continue the effort with the development of Phase 2, that set to achieve the Renewable Energy (RE) component to 23% by 2025 in the ASEAN Total Primary Energy Supply (TPES) and widening multilateral electricity trade in the ASEAN Power Grid (APG). For the region to achieve the target, the share of RE in power generation should reach around 42% (165 GW), according to the 5th ASEAN Energy Outlook.

In order to meet the APAEC target and widen the multilateral electricity trade, ASEAN has highlighted the need for a continued strong cooperation within each AMS. One of the regional cooperations on the electricity interconnecting arrangements has been established through the multilateral electricity trade among Lao PDR, Thailand, and Malaysia, which commenced in January 2018. In addition, the AMS had also requested Heads of ASEAN Power Utilities/Authorities (HAPUA) to synergise the studies on the APG, with considerations to integrate RE into power grid planning. The region believes that the initiative should be enlarged to more AMS so it can assist to boast energy investments and markets at the regional level.

To support the plan and to help answering the challenges of RE grid integration in AMS, the ASEAN-German Energy Programme (AGEP) - a jointly implemented project by ASEAN Centre for Energy (ACE) and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ) – published a report that elaborates the different characteristicsof Variable Renewable Energy (VRE) grid integration in ASEAN.. The report shows that most of AMS are currently positioned in early stage of VRE grid integration and only Thailand is one step further in VRE grid integration in the region. To achieve the regional target on a grid technical level, three key solutions are required: grid code harmonization, RE forecast for system integration and more support on interconnection aspect.

With that, ACE and GIZ are pleased to present the report on ASEAN RE Grid Integration Review. We trust that this report would be useful to all stakeholders, especially the policy makers, utilities, independent power producers, and grid operators in understanding power system in ASEAN. We hope that this report could be used as a reference to support grid code harmonization in the region and widen ASEAN multilateral electricity trade. We believe this report can serve as one of starting bases to examine market mechanisms, interconnection infrastructure and commercial arrangements which would enable further joint activities on APG and grid integration of RE particularly in reaching the APAEC target.

Maria-José Poddey
Principle Advisor for AGEP
GIZ

Christopher G. Zamora
Acting Executive Director
ASEAN Centre for Energy

Table of Contents

List of Abbreviations

AC	Alternating Current
ACE	ASEAN Centre for Energy
ACER	Agency for the Cooperation of Energy Regulators
AERN	ASEAN Energy Regulatory Network
AEMI	ASEAN Energy Market Integration
AFTA	ASEAN Free Trade Area
AGC	Automatic Generator Control
AGEP	ASEAN-German Energy Programme
AMEM	ASEAN Ministers on Energy Meeting
AMS	ASEAN Member States
ASEAN	Association of Southeast Asian Nations
APAEC	ASEAN Plan of Action for Energy Cooperation
APG	ASEAN Power Grid
BMZ	German Federal Ministry for Economic Cooperation and Development
COD	Commercial Operation Date
CRIE	Comisión Régional de Interconexión Eléctrica
DTA	Double Taxation Agreement
ENTSO-E	European Network of Transmission System Operators for Electricity
ESI	Electricity Supply Industry
ERIA	Economic Research Institute for ASEAN and East Asia
EU	European Union
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
FACTS	Flexible AC Transmission Systems
HAPUA	Head of ASEAN Power Utilities/Authorities
IEA	International Energy Agency
IPP	Independent Power Producers
NORDEL	Association of Nordic Electric System Operators
NREL	National Renewable Energy Laboratory
NWP	Numerical Weather Prediction
PEA	Thai Provincial Electrical Authority
PPA	Power Purchase Agreement
PV	Photovoltaic
RE	Renewable Energy
RMS	Root-Mean-Square
SCADA	Supervisory Control and Data Acquisition
SO	System Operator
TAGP	Trans-ASEAN Gas Pipeline
TNB	Tenaga Nasional Berhad
TPES	Total Primary Energy Supply
TSOs	Transmission System Operators
VRE	Variable Renewable Energy

List of Measurement

GW	Giga Watt
Hz	Hertz
kV	Kilo Volt
kW	Kilo Watt
LV	Low Voltage
Ms	Milli Second
MW	Mega Watt
PU	Per Unit (Nominal Voltage)
V	Volt

Credit: DoE

1 Introduction

1.1 Background and Objective

A predominantly rapid demand growth and expansion of access to electricity is observed in the Association of Southeast Asian Nations (ASEAN) region. Overall, a 60% demand growth was observed in the past 15 years and this trend is expected to continue, with installed power capacity rising from 240 GW in 2017 to 565 GW in 2040 in International Energy Agency's (IEA) main projected scenario for ASEAN. A growing demand represents the opportunity to invest in renewable energy, and among these, Variable Renewable Energy (VRE) is expected to account for nearly 40% of installed capacity in 2040 in ASEAN [1].

The ASEAN Plan of Action for Energy Cooperation (APAEC) 2016-2025, the regional guiding document, envisages a target of 23 percent of renewable energy (RE) share in total primary energy supply (TPES) by 2025 and an expansion of multilateral electricity trade in the region. To achieve the target on a technical level in the grid integration point of view, ASEAN needs a continued strong cooperation among the ASEAN Member States (AMS) on regional interconnection, synergise the studies on the ASEAN Power Grid (APG) with considerations to integrate RE into power grid planning, stronger grid codes harmonisation among AMS, and implement RE forecast for system integration.

To support the overall target, the 3rd ASEAN Regional RE Grid Integration Training was held in Kuala Lumpur from 27 February – 01 March 2019, as the last of a three-series training. The aim of the third training was to deepen the knowledge gained during the first training and second training on renewable grid integration and to update the trainees on the comprehensive concept of the impacts of variable renewable energy (VRE) to the grid stability as well as to discuss how to apply stability assessment during RE integration into the grid in ASEAN region.

1.2 Report Scope and Purpose

Within the scope of the aforementioned ASEAN Regional RE Grid Integration Training and, with the ultimate goal of supporting the increase of the percentage of RE share in TPES of AMS by 2025, this report identifies the main challenges of the current VRE integration phase observed in AMS and proposes solutions to overcome such challenges and move towards further VRE integration.

The expected increase in VRE deployment will require an upgrade of public policy and regulatory strategies, power system infrastructure and operational practice, as well as adaptations to emerging investment frameworks and adaptations of grid codes. Three main solutions are discussed in this report. The first solution is on grid code harmonisation between AMS. The second is about the implementation of a centralised VRE forecasting system to better balance increasing VRE shares that become noticeable by the system operators. Last, the need for further power system interconnections between AMS to allow further use of VRE resources in the region, enable reserve sharing and dispatch co-optimisation, thus decreasing electricity costs. The benefits and future needs for the establishment of a multi-lateral electricity trading and power market with increased cross-border interconnections are also discussed.

The challenges encountered in each proposed solution are discussed and recommendations are given to overcome them.

2 | Overview of Renewable Energy Status and Phases of Renewable Energy Grid Integration in the ASEAN Member States

2.1 Overview of Renewable Energy Status in ASEAN

2.1.1 Energy Mix

Renewable energy (RE) potential is abundant and distributed among the ASEAN Member States (AMS). However, apart from biomass and hydro, other sources of renewable energy represent less than 4% of the total energy demand (as shown in Figure 1). Whilst hydropower has grown rapidly, especially in Cambodia, Lao PDR and Myanmar (with ample resources still available and unused), non-hydro RE have had a limited role in the ASEAN generation up to present.

Many countries have plans to speed up the deployment of wind and solar power to address problems with local pollution and emissions. In IEA's main projected scenario for ASEAN, installed power capacity rises from 240 GW in 2017 to 565 GW in 2040, with renewable energy expected to account for nearly 40% of the installed capacity in 2040, with more than 52 GW of solar PV and 22 GW of wind power expected to be installed among AMS [1].

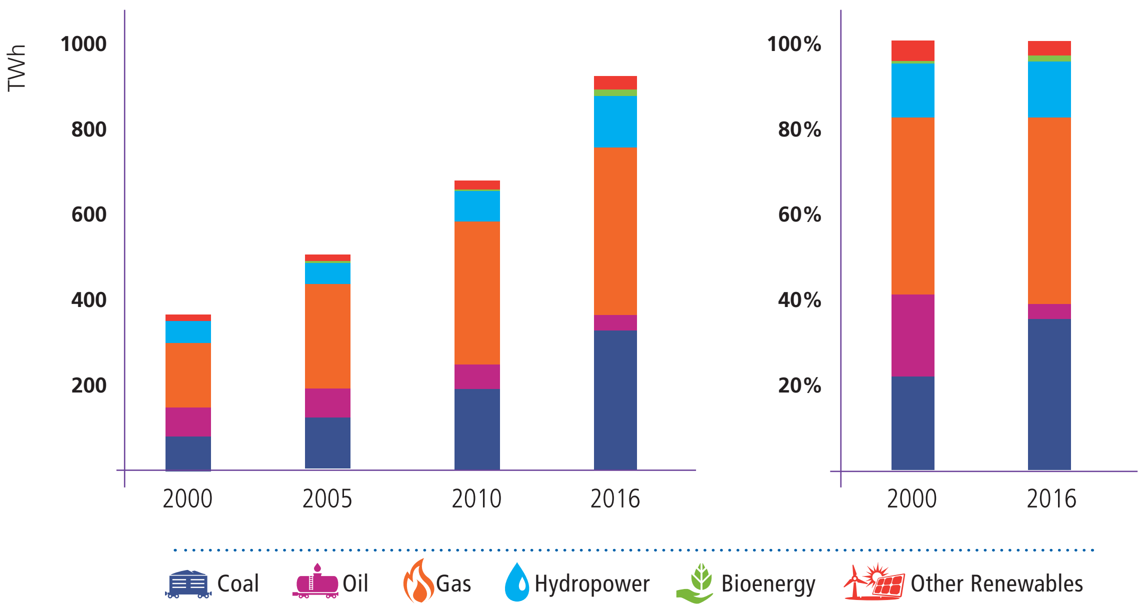


Figure 1: Power Generation Mix in Southeast Asia. Source: [1].

The decreasing cost of VRE technologies, which consist only of wind power and solar photovoltaic (PV), represents an opportunity to meet the growing demand with less emissions and lower generation costs. Indonesia, Malaysia, the Philippines, Thailand, and Vietnam have already introduced feed-in tariffs to incentivise investments in RE. Additionally, local VRE manufacturing industries are growing. Malaysia is becoming the world's third-largest producer of PC cells, while in Thailand, large investments on solar manufacturing industry, for both domestic and export markets was recently announced [1].

2.1.2 Power Sector Structure and Renewable Energy Grid Integration

The majority of ASEAN countries (Cambodia, Indonesia, Lao PDR, Malaysia, Singapore, Thailand and Vietnam) have vertically integrated utilities which allow for the most basic level of competition in the system, corresponding to the participation of Independent Power Producers (IPP), which enter into Power Purchase Agreements (PPAs) with utilities to supply generation at an agreed price[1]. This model has been effective in contributing to RE integration, as it allows to overcome investment shortages and inefficiencies that vertically integrated systems may possess, by attracting privately owned and low-cost renewable energy projects [2].

Brunei Darussalam and Myanmar are exceptions. Although they have a vertically integrated utilities, these correspond to regulated monopolies in which the participation of IPPs is not allowed. On the other hand, the Philippines has the highest private-sector participation in the electricity sector among the ASEAN countries, with a wholesale market and competition for retail customers among suppliers. Countries worldwide are increasingly evolving from vertically integrated models to private-sector participation, passing by model stages of single-buyer, unbundled, wholesale market and retail competition.[2]

Increasing private-sector participation in electricity markets allows for the reduction of electricity costs and further VRE integration. Therefore, studies should be conducted on how to restructure the power sectors to let in more competition, aimed to increasingly attract privately-owned and low-cost renewable energy projects. A rise in private-sector participation in the electricity market requires an adaptation to the market, which can be performed gradually or more aggressively. IEA stated, as an example in [2], that Mexico had a rapid market modification, moving within five years from a vertically-integrated state-owned power market model with few IPPs to a deregulated wholesale market.

2.1.3 Electrification and Opportunities for Variable Renewable Energy Integration

Despite the growing electrification rate in ASEAN (rising 28% points in 17 years, reaching 90% in 2017), many people still lack access to electricity (an estimated 65 million people out of nearly 640 million). Of these, 95% are concentrated in Cambodia, Indonesia, Myanmar and the Philippines [1]. The large number of island communities increases the challenge of extending grid connections. Nevertheless, VRE-diesel hybrid systems can represent new opportunities to achieve higher electrification rates for island systems.

Mini and micro-grids that rely on distributed generation may present a faster and less expensive alternative solution to transmission grid investments to expand electricity access. In scenarios investigated by IEA, Southeast Asia succeeds in achieving universal electricity access by early-2030s (as shown in Figure 2), through the deployment of a variety of tools, with mini-grid and off grid technologies accounting for more than half of additional access-related demand [1].

[1] Also known as the "single-buyer" model for the electricity sector ownership.

[2] Nevertheless, as stated by IEA in [2], moving towards the highest private sector participation model (corresponding currently to wholesale market with retail competition) is not necessarily considered as a natural evolution of power systems. Some countries are considering removing the retail competition or returning to re-regulation.

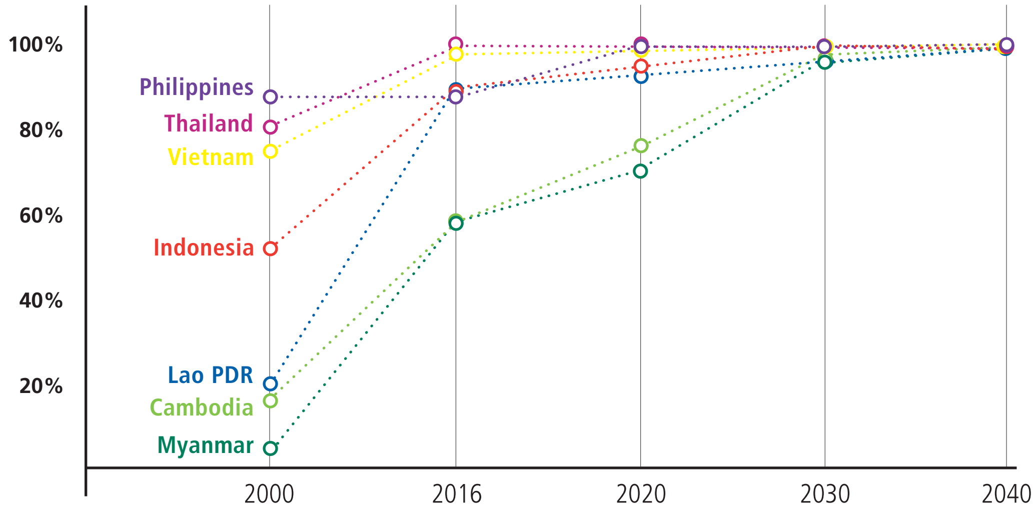


Figure 2: Electricity Access Rates in Southeast Asia (Historic and Forecasted in IEA's Scenarios). Source: [1].

2.2 Characterisation of Variable Renewable Energy Grid Integration Phases

Moving towards larger shares or VRE integration requires identifying each country's VRE integration status and prioritising its corresponding grid integration tasks in order to accelerate its VRE deployment. Increasing shares of VRE capacity have different impacts on the operation of power systems. IEA has defined, in [3], six phases of VRE integration, which are summarised in Table 1 and introduced in the remainder of this chapter. International experience has shown that the share of VRE generation is system-specific at each phase entered.

Table 1: Phases of Variable Renewable Energy Integration. Adapted from [3].

Phase	Description
1	VRE capacity is not relevant at the all-system level
2	VRE capacity becomes noticeable to the system operator
3	Flexibility becomes relevant with greater swings in the supply/demand balance
4	Stability becomes relevant. VRE output can cover most of demand at certain times
5	Structural surpluses emerge; electrification of other sectors becomes relevant
6	Bridging seasonal deficit periods and supplying non-electricity applications; seasonal storage and synthetic fuels

2.2.1 Phase One: Variable Renewable Energy Capacity is not Relevant at the All-System Level

In Phase One of VRE integration, VRE capacity has no relevant impact on the system as it is much smaller than the capacity of the remaining power plants. The VRE variable is unnoticed by the System Operator (SO) during this phase. Existing impacts occur locally, at and/or near the VRE point of connection.

Although the impacts are local, existing grid codes should include considerations for the connection of VRE plants.

2.2.2 **Phase Two:** Variable Renewable Energy Capacity Becomes Noticeable to the System Operator

In Phase Two, the impact of installed VRE capacity becomes noticeable to SOs. For example, a lower-than-expected-demand will be observed by SO when VRE generation meets part of the demand and is not directly metered nor visible to SO. Therefore, the corresponding demand met by VRE is not being directly accounted for as part of the total demand. The reduced demand is named net demand, obtained by subtracting the VRE output from the power demand. Additionally, grid congestions may occur, especially in areas where the VRE deployment is rapidly increasing.

In this phase, simple modifications are recommended for operational practices. These include establishing a forecasting system for the VRE production in order to achieve a cost-effective balancing of VRE variability using flexible power plants. However, in the absence of a forecasting system, reliability can still be achieved at higher costs.

2.2.3 **Phase Three:** Flexibility Becomes Relevant

In Phase Three, installed VRE and its variability would impact not only the overall system operation but also other power plants. This will require a flexible system to balance supply and demand when generation becomes increasingly variable and uncertain. The system flexibility includes more dynamic operation of existing power plants and, in Phase Three, VRE forecasts become essential for the system operation.

Grid impacts, observed in Phase Three, include significant changes to power flow patterns across the grid, and are driven by weather conditions and corresponding VRE production. Reverse flows from medium and low-voltage up to the transmission level will occur, which will require coordination between distribution and transmission SO.

In this phase, interconnecting power systems and combining the operation of adjacent balancing areas will aggregate and smooth VRE output over a larger region. Such interconnection and combined operation of balancing areas enable sharing of reserves and consequently reduce corresponding costs.

2.2.4 **Phase Four:** Stability Becomes Relevant

In Phase Four, scenarios in which VRE can cover most or all the power demand are observed, especially when a high VRE in-feed to the grid occurs in combination with a low demand.

In this phase, issues may arise regarding the system's stability. The high VRE production displaces conventional synchronous machines, reduces system available inertia and increases the challenge of maintaining a stable system operation immediately after the occurrence of disturbances.

Therefore, measures to increase the stability of system are a priority in Phase Four. Such measures include requesting the provision of essential reliability services from VRE plants, including participation in frequency and voltage regulation, both during normal- as well as during fault operations.

2.2.5 Phase Five: Structural Surplus of Variable Renewable Energy generation

In Phase Five, scenarios with a surplus of VRE generation are observed, which result in large-scale curtailment of VRE. The electrification of other end-use sectors, such as transport and heating, represents a potential solution to reduce the restriction and allow further expansion of VRE.

2.2.6 Phase Six: Structural Energy Deficit Periods

In Phase Six, existing system flexibilities, such as demand-side management and electricity storage, may be insufficient to cover for long periods of supply shortage (such as longer moments with insufficient wind production), leading to energy deficit. Cost-effective large-scale storage solutions can be sought to cover for these seasonal occasional imbalances between supply and load in a VRE-dominated generation system.

Credit: GIZ

2.3 ASEAN Status of Variable Renewable Energy Grid Integration

Most ASEAN Member States are currently in the Phase One of VRE integration, because VRE output only represents a small percentage of the demand and is not noticeable by SO. VRE shares in Southeast Asia correspond to less than 4%, as shown in Figure 1. This is similar to shares observed internationally for countries in Phase One (approximately 2% to 3%) [3].

Among AMS, Thailand is the most advanced in VRE integration and currently nearing Phase Two [4]. The annual energy penetration of VRE in Thailand is around 4%, and VRE generation is becoming noticeable to SOs [4]. The introduction of feed-in tariffs in Thailand has contributed to incentivising investment in RE, with solar PV capacity more than tripling between 2013 and 2016, reaching 2.8 GW [1]. Thailand currently accounts for most of the region's installed solar PV capacity.

However, although most AMS are currently on Phase One, they have RE integration targets which together lead to an increased deployment of RE expected to reach nearly 40% of installed capacity by 2040 in IEA's outlook scenario [1]. With Phase Two approaching, this chapter will focus on the initial two phases by looking into detailed challenges encountered, as well as recommended tasks to overcome them. Overcoming the challenges of each phase will allow the transition to higher shares of VRE and therefore to the next VRE integration phase.

2.3.1 Challenges of Phase One

As introduced in Section 2.1, the impact of VRE is unnoticed by SO in this phase because their output only represents a small percentage of the demand. At this stage, VRE grid integration challenges are limited to local impacts. In Figure 3, the main tasks to ensure a successful integration of the first shares of VRE into a power system are shown.

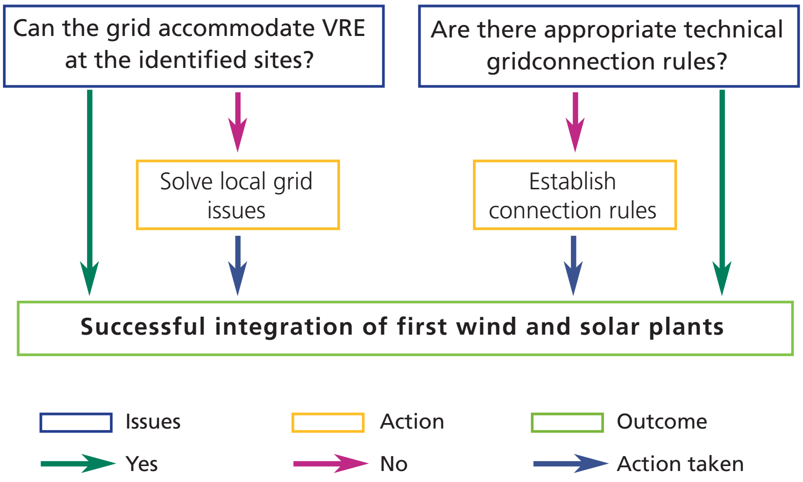


Figure 3: Phase One: Variable Renewable Energy Grid Integration Challenges and Approaches Source: [3]

Before the integration of VRE to the grid, an assessment of the local grid's available capacity is required to ensure that the grid can accommodate the planned VRE with no negative effects on the quality and reliability of the local supply. Larger plants will connect at a high voltage level and a mechanism is usually already in place to determine the local grid impacts of such projects as well as their mitigation measures. In [3], IEA recommends that the grid impact assessment is performed by a neutral party, with no interest in either generation or grid asset ownership, to avoid bias from either the project developer or grid company.

The second issue shown in Figure 3 is the requirement of appropriate connection rules for VRE. At this stage, a full grid code is not required. Excessive requirements will increase plant costs and might slow the VRE deployment. However, sufficient requirements of state-of-the-art capabilities from the VRE plants should exist in order to meet mandatory SO requirements and minimally ensure that the VRE plants do not negatively impact the local quality and reliability of the electricity supply.

2.3.2 Challenges of Phase Two

As introduced in Section 2.1, this phase is characterised by a noticeable impact of VRE on other generators as well as on the system, the latter can be observed by the relevant difference obtained between load and net load curves.

In this phase, a gradual update to the system operation is sufficient to ensure reliability. The Phase Two-specific challenges are shown in Figure 4, along with the recommended approaches to solve them.

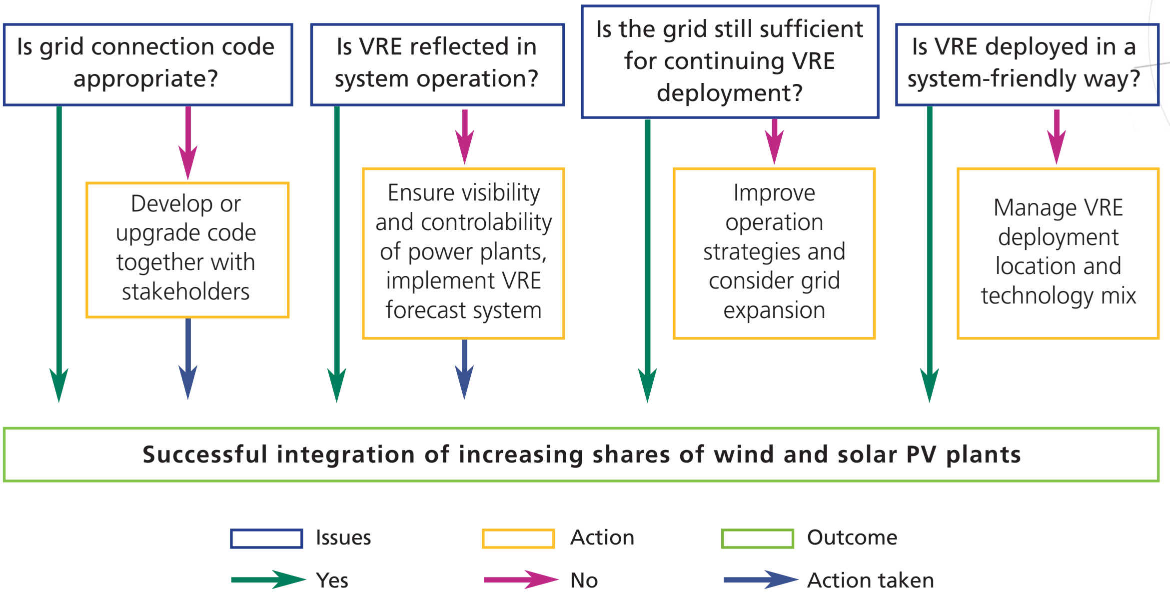


Figure 4: Phase Two: Variable Renewable Energy Grid Integration Challenges and Approaches. Source: [3]

With a noticeable impact of VRE in the system, having appropriate technical requirements for grid connection, as recommended in Phase One, becomes essential in Phase Two and beyond. In addition to specifying requirements, verifying whether such requirements are being met is equally important.

In Phase Two, VRE output starts to be noticeable to the SO and therefore it becomes important to familiarise operators with VRE technologies and their impacts. More information about the operation of this added technology to the system will reduce concerns about its variability and uncertainty, and consequently reduce unnecessary curtailment [3].

Visibility and controllability of VRE are required for an efficient management of system operation in Phase Three. Visibility refers to the ability of SO to assess the current and future state of the system based on available information. Controllability signifies to the ability of SO to control the system based on such information and available technology. These will be further elaborated below.

Visibility:

Information is made available to SO to ensure system visibility consists of static and operational data. Static data refers to plant parameters, such as rated power, hub height for wind turbines, ramp rates, and minimum operating levels, among others. Operational data refers to real-time communication of plant data, including plant output, typically collected by a Supervisory Control and Data Acquisition (SCADA) system. Sufficient visibility to SO can be achieved through real-time monitoring of selected VRE plants, as it is not cost-efficient to perform real-time monitoring of all plants. From real-time data of a selection of representative plants, SO can estimate the data for the remaining plants. Additionally, SO should be fully aware of the capabilities of the conventional power plants and be capable of monitoring their operating state in order to enable their dispatch in response to weather patterns and VRE plants' behaviour.

A necessary key information for SO's visibility is a forecast of the VRE production. With such forecast, a more efficient plant scheduling as well as management of interconnections and operating reserves can be achieved, thereby reducing the system costs. Additionally, higher controllability can be achieved when SO can control plants closer to real-time operation. A forecast system is therefore essential for VRE integration and will be discussed in Chapter 3.

Controllability:

Increasing shares of VRE in systems require higher controllability from SO to maintain security of supply. Therefore, it is recommended that systems, which still communicate between the SO and power plant operators by phone, upgrade their control capabilities to an Automatic Generator Control (AGC).

The required SO control over VRE plants also increases in this phase and VRE plants must respond to SO's signals (directly or intermediated by plant operators) and adapt their outputs accordingly. Curtailment may be needed during contingencies and this reinforces the need for controllability of VRE plants. In addition to curtailment, SO may choose to control the change of VRE plants' output at a certain rate (MW per minute).

With increasing VRE, issues on grid hosting capability (third challenge shown in Figure 4) may arise in Phase Two that require grid modifications. The common issues that have been identified by IEA in [3] are listed as:

- Newly built VRE plants being unable to connect to the grid due to delays in building new transmission lines. Therefore, a synchronisation between the VRE deployment and new transmission lines is necessary.

- Congestions in lines. These occur when electricity is not able to reach consumers on the other side of a line due to being close to its thermal limit. Congestion results in the curtailment of outputs of power plants on one side and the ramping up of output of power plants on the other side of the congested line. Reinforcements (for example uprating lines) are necessary to solve severe congestions, making the best use of existing infrastructure can reduce the need for them. This includes spatially distributing VRE in the grid as well as identifying the grid's weak spots in advance and strengthening them with methods such as Dynamic Line Rating, Flexible AC Transmission Systems (FACTS) and line repowering (replacing the conductors with ones that function at higher temperatures).

- Reverse power flows in the low and medium voltage grid. These occur when the production of electricity in the distribution grid exceeds consumption. It can be observed for example, around midday in networks with a high feed-in from rooftop PV. Although most distribution grids can support two-way power flows, operational changes may be required, such as increasing the need for re-dispatch and congestion management.

The last integration challenge identified in Figure 4 corresponds to the adaptations that can be done from VRE's side in order to accommodate them to the existing system. For example, placing VRE in a "second-best" renewable potential area to avoid grid reinforcements might represent a higher cost-benefit solution. Additionally, geographically distributing VRE capacity would be a better use of the existing grid before reinforcements are necessary. It would reduce the variability of the aggregated VRE output which may consequently reduce reserves required to cover VRE's sudden variations. Such decisions must be based on a cost-benefit analysis of each scenario.

Credit: GIZ

3 | Solutions for Large Renewable Energy Capacity Grid Integration in ASEAN Member States

A large-scale RE capacity grid integration requires the combination of innovative technologies with adaptations to markets structure and operations, as well as adaptations to system planning and infrastructure. Innovative technologies can increase system flexibility and reliability which are required to achieve a large capacity integration of RE to the grid. However, this integration to the system needs improved market frameworks, system operations, and support by regulatory measures. A cost-effective system transformation to include large shares of RE also requires adapting power system planning strategies to prepare for such integration.

In Chapter 2, most AMS were identified as currently being on Phase One of VRE integration. Thailand is approaching Phase Two. The main challenges of Phases One and Two for larger RE capacity grid integration have also been discussed in the previous chapter. In Chapter 3, three critical solutions to address challenges encountered by AMS in these phases will be presented. These solutions, ultimately focused on increasing flexibility on system operation, correspond to: grid code harmonisation, improved renewable energy forecast system and increased interconnections between ASEAN countries.

The proposed solutions, discussed in Sections 3.1, 3.2 and 3.3, are part of a wider set of recommendations to ensure the smoothest and most cost-effective deployment of VRE. Specific recommendations for Phase One also include [3]:

- VRE system integration should be treated gradually, with a continuing adaptation of the system according to the challenges encountered as VRE shares grow;
- Misinformation regarding VRE integration may slow down its deployment, therefore issues should be discussed, and international experience can serve as a basis for clarification;
- A neutral and technically competent body should be assigned. This body shall be responsible for performing assessments of the feasibility of grid connections as well as of the necessity of potential grid reinforcements (versus alternative solutions);
- International experience and state-of-the-art industry standards should be used as basis and from the start of the activity to establish the technical requirements. The latter should be modified to meet the local needs as well as the current share of VRE and, as this share increases, should be adjusted accordingly.

Recommendations for Phase Two include [3]:

- Establishment of an appropriate grid code, by rewriting or revising the existing code to accommodate the connection of VRE systems. State-of-the-art international grid codes should be (continuously) consulted as reference, as this will save time in dealing with issues that have already been identified previously elsewhere. With increasing VRE shares, the grid code should be continuously monitored and revised to meet the power systems' needs. Compliance to the grid code should also be verified;
- Power plant operation should be adapted to include VRE:
    - o In order to have adequate system visibility, SO must require and obtain real-time monitoring data from conventional power plants as well as from a sufficient number of VRE plants (using statistical methods to estimate the production forecast of remaining smaller plants);

- A forecasting system must be implemented in Phase Two and be considered when determining the power plant scheduling and dispatch;
- System operation planning as well as control of power plants should be closer to real-time to better compensate VRE variability;

- The grid hosting capacity must be analysed and managed. When new transmission lines are required, these lines must be built in synchronisation with the VRE deployment. Alternative cheaper solutions to grid reinforcements should be analysed in anticipation of congestion. Additionally, by already looking into the future expansion of VRE during grid planning may give additional insights into trade-offs between connecting VRE close to loads and placing these further where higher renewable resources might be available and future VRE plants are expected to be installed;

- Geographically distributing VRE onto the grid to make use of available grid hosting capacity should be assessed. There may already exist incentives/measures that (intentionally or not) favour the deployment of VRE in certain areas and these must be identified and analysed as the share of VRE increases. Creating locational grid charges can steer the deployment of VRE to specific locations.

3.1 Grid Code Harmonisation

Grid codes provide basic design criteria and operational rules and responsibilities to be followed by the generating stations, transmission utilities, and distribution utilities. The technical requirements for VRE connection should be included in grid codes even if the installed VRE has no relevant impact on all-system level (observed in Phase One of VRE integration). As VRE capacity increases, the provision of system services from VRE power plants can be gradually requested in grid codes and VRE reduce integration challenges.

There are many rules and criteria in every grid code dealing with generation, transmission, distribution, protection, metering, maintenance, buying and selling of power, ancillary services, etc. Cross-border power trade is expected to increase and thereby additional cross-border power transmission system interconnections are anticipated to be built. It is therefore important that the power grids of each ASEAN member country are integrated through a harmonised coordination of grid codes for a smooth, optimal, secure and reliable power system operation.

By harmonising grid code requirements for the VRE integration among AMS and directing these requirements to meet the challenges of their corresponding VRE integration phase, higher efficiency can be achieved in the VRE grid integration. Similar requirements in countries offset the low individual market power and can consequently it would be easier to force new developments on the manufacturers' side. System operators, especially those who have not yet developed requirements, will also benefit from such harmonisation strategy, as bundling of resources allows for faster learning and reduces the cost imposed by the code development process in each individual country.

In order to achieve the harmonisation of grid codes within ASEAN, it is recommended to create a working group which consists of VRE technology manufacturers, engineering companies, plant operators, service providers and certification bodies. A template can be initially created that contains common definition, parameters and units. The second stage consists of adapting existing grid code parameters of each country to the said template. The proposed grid code must go through several rounds of revisions. In most cases, the approval from the regulatory agency is necessary as a last step before the grid code can enter into force.

International harmonisation efforts have already been made and lessons learnt from these efforts can be used by AMS to develop their own harmonisation exercise. International examples include: the European Network of Transmission System Operators for Electricity (ENTSO-E) harmonisation experience through the creation of Network Codes; the Association of Nordic Electric System Operators (NORDEL), with the publication of the Nordic Grid Code in 2007; the technical criteria established by the Comisión Régional de Interconexión Eléctrica (CRIE) that directly impacts grid code requirements in the member countries of the Central American interconnected system; The European Wind Power Association, with the publication of a generic grid code document in 2009 which attempted to define the scope of a grid code for wind power, and their subsequent involvement in the development of the EU Network Codes.

3.1.1 European Network of Transmission System Operators for Electricity Grid Code Harmonisation Experience

The European Network of Transmission System Operators for Electricity (ENTSO-E), with guidance from the Agency for the Cooperation of Energy Regulators (ACER), has drafted Network Codes in which a set of rules have been defined to "facilitate the harmonisation, integration and efficiency of the European electricity market. Each network code is an integral part of the drive towards completion of the internal energy market and achieving the European Union's (EU) 20-20-20 energy objectives"[3].

The Network Codes represent the first large scale attempt at harmonising international grid codes, with the target of ensuring a coherent regulatory framework for power system operations in all EU member countries. The Codes are a framework that defines the structure and content of grid code documents, and the rights and responsibilities of stakeholders. The EU member countries have their own grid codes, however, they use the Network Codes as a reference to which they must harmonise with within three years.

The Connection and Operations code specify which requirements for generators must be included in the grid code, but specific technical parameters are the responsibility of each individual transmission system operator (TSO). The Codes also directly govern issues that require inter-TSO cooperation, such as frequency control, contingency events and allocation of interconnector capacity. The structures, communication pathways and necessary bilateral agreements are defined, but the final execution is up to the individual member country and their TSO.

3.1.2 Lessons Learnt for the ASEAN Member States[4]

As identified in a previous report "Grid Code Comparison for Indonesia, Malaysia and Thailand" prepared for ASEAN, there is no regional/international grid code in the ASEAN region. Each AMS and power utility develop grid codes and interconnection standards within their domain. Seven AMS (Cambodia, Indonesia, Malaysia, the Philippines, Singapore, Thailand and Vietnam) were identified as having already developed grid codes and/or interconnection standards. For Brunei Darussalam, Lao PDR and Myanmar, there are indications that such documents exist as internal documents (unpublished) and are used on a case-by-case basis for bilateral negotiations between utility and applicants for connection. Therefore, a harmonisation strategy is recommended for AMS, as bundling of resources will allow faster learning and reduce the cost of the code development process in each country.

[3] https://electricity.network-codes.eu/network_codes/

[4] As concluded in the report "Grid Code Comparison for Indonesia, Malaysia and Thailand" prepared for ASEAN.

Currently, the regulatory environment for RE in the ASEAN countries in general, and in Indonesia, Malaysia and Thailand in particular, is made up of a variety of different documents, making it a challenge for developers to navigate. All power system stakeholders would profit from a harmonisation of grid code documents, but the process needs to start within each country. Thailand, largely a single synchronous system, possesses a consistent grid code framework. The codes in Indonesia and Malaysia are splintered into a multitude of different documents for different operators (Malaysia) and different synchronous systems (both). As a first step towards better code applicability, these documents should be streamlined into a single national framework.

Most of the power utilities in ASEAN are state owned with single buyer market environment. The power utilities are responsible for grid code development with or without supervision of regulator depending on the legislation of each Member State. Grid codes are developed based purely on practical experience and reflect the current grid conditions. Thus, the code of the Thai Provincial Electrical Authority (PEA) is the most advanced code among AMS, since PEA is already connected a significant share of renewable generation to their network in the past decade. Other Member States and operators lag far behind. Communication between different utilities, sharing of experiences, analysing international experience and good practice and developing grid codes with a look into the future should be highly encourage, although they are a new concept to most operators. As there is a dire need for revisions in most grid code documents in the region, it is recommended to set up an ASEAN grid code committee, involving power utilities, operators and regulators within ASEAN, as a platform to share experience and knowledge on the initiation of grid codes harmonisation.

A special case that deserves additional attention is grid codes for small isolated power systems. Many countries in ASEAN, in particular Indonesia and the Philippines, are island nations with a multitude of mini-grids mainly powered by diesel gensets. With the high cost of electricity from diesel generation, these grids will profit from cheap renewable generation first, but also impose a set of unique integration challenges. While some high-VRE islands have existed for at least 20 years, most of them were pilot installations that came with high effort and cost. The large-scale development of high-VRE island systems is just starting out, and the ASEAN region, with its many islands, may be the forefront of this development. It is therefore highly recommended to set up an international body or enhance the existing association/organisation in the region in dealing with mini-grid integration issues. This body should also develop a grid code framework for small island systems.

3.2 Renewable Energy Forecast for System Integration

As identified in Chapter 2, installing/improving VRE forecast systems can better match VRE output to power demand and reduce system reserves (and associated costs) necessary to cover for higher generation uncertainty. While a forecast system was only set as a recommendation in Phase Two of VRE integration, it is an essential part of the system operation during Phase Three of VRE integration.

Real-time data of VRE plants provide SO with visibility of the current plant behaviour and allows for "persistence forecasting". This corresponds to a prediction of the plant's behaviour up to twenty or thirty minutes ahead [3] based on the assumption that current generation levels will not change in the very near future [5]. In order to obtain a VRE output forecast suitable for use in the day-ahead and intra-day planning of dispatchable power plants, a forecasting system for a larger time horizon must be in place. By integrating VRE forecasts into system operations, SO can anticipate the up- and down-ramps in VRE generation and cost-effectively balance load and generation in the day-ahead and intra-day scheduling, reduce fuel costs, improve system reliability and minimise the curtailment of VRE plants [5].

3.2.1 Forecasting Methods

Different methods exist for the forecast of VRE output, categorised into two main types: physical methods and statistical methods. The former is based on measured data inputs to Numerical Weather Prediction (NWP) models in order to create terrain-specific weather conditions which can be converted into energy production estimates. Data inputs include temperature, pressure, surface roughness and obstacles. The latter is based on historic (at least six months of data is recommended [3]) and real-time generation output data in order to statistically correct results obtained from NWP models. In general, forecasts are more accurate closer to real-time.

3.2.2 Wind and Solar Forecasting Differences

While wind energy forecasting methods are already widely implemented in power systems with medium to high levels of wind power generation, such as Denmark and Ireland, yet, solar power forecasting is still quite recent [5]. Both forecast methods are based on NWP models, however solar forecast can also make use of sky imagers and satellite imaging to track and predict cloud formations.

Distributed solar PV forecasting is more challenging to produce because real-time meter data (as well as data on location, hardware information and panel orientation) becomes excessive to gather and process for all connected distributed PV systems. Therefore, it is common practice to scale up forecast of a sample of such PV systems as a cost-effective solution for regional PV forecast [5].

3.2.3 Centralised Versus Decentralised Forecasts

Centralised and decentralised forecasting strategies for the administration of VRE forecast can be chosen. In a centralised VRE forecasting system, SO will administer a centralised forecast that provides system-wide forecasts for all generators. In a decentralised forecast system, individual plant operators are responsible for providing plant-level information to the SO.

3.2.4 Recommendations in Literature

A centralised forecast has been recommended in [3] and [5]. The advantages include consistency in results, due to uniformity of the methodology applied, as well as reduced financial burden for VRE plants to produce and submit individual forecasts to the SO [5]. When appropriate, the SO can request plant-level forecast data from individual VRE power plants to incentivise high forecast accuracy by combining different forecast results and methods [3].

Additionally, as mentioned in Chapter 2, it is not cost-efficient to perform real-time monitoring of all plants. Therefore, data from selected plants can be used to scale-up forecasted VRE power production system-wide based on statistical analysis of historic power production. Performing a system-wide scale forecast of VRE production reduces the Root-Mean-Square (RMS) error of the forecasted output compared to single plant forecasts [3].

The forecast system can be procured by SO from third party vendors or meteorological research institutions, or developed in-house. In either case, requirements for standardisation and certification for forecast data must be in place. Additionally, training is required for control centre staff on how to interpret and integrate forecast VRE data into dispatch decisions.

3.3 Interconnection Aspects

Increasing cooperation and interconnections between power systems of AMS will facilitate VRE integration. By designing a joint system operation, reserve sharing, and dispatch co-optimisation can be enabled to reduce the system costs, in addition to aggregating and smoothing VRE output over a larger region.

Interconnecting balancing areas with transmission lines allows for the aggregation of VRE output over larger areas and therefore reduces the overall variability of VRE production. This would reduce the local active balancing performed by other generators as well as the requirements on storage and demand response. Interconnections can avoid situations in which neighbouring balancing areas have complementary needs, for example, when one area activates upward reserves whereas another area activates downward reserves. The creation of such interconnections across balancing borders can follow onto the establishment of a common balancing market, requiring negotiated interchange agreements.

Furthermore, interconnections between AMS may economically justify the development of new RE plants, such as large hydropower plants, in countries and regions where the local demand does not justify such investments. Additionally, the variability of VRE in countries with stronger VRE potential could be better managed by further interconnecting such countries with those that have strong hydro resources. For example, Vietnam's strong wind potential could be balanced with Lao PDR's hydro resources [1].

3.3.1 Overview of Current Interconnection Status in ASEAN

ASEAN has already identified the need for increasing cooperation and interconnections between its member countries decades ago. In 1997, AMS agreed to develop the ASEAN Power Grid (APG), with goals which include increasing energy security by connecting countries with surplus power to those with a deficit and optimising resource sharing between countries so that peaking plants are used communally. The Head of ASEAN Power Utilities/Authorities (HAPUA), which is responsible for APG, is already collaborating with international organisations such as ACE, ASEAN Energy Market Integration (AEMI), Economic Research Institute for ASEAN and East Asia (ERIA), and IEA. HAPUA has five working groups: Generation & Renewable Energy, Transmission/ASEAN Power Grid, Distribution & Power Reliability and Quality, Policy & Commercial Development, and Human Resources.[5]

There are currently nine cross-border interconnections with a combined capacity of 5200 MW (shown in Figure 5). Additionally, there are 6 planned projects for 3300 MW (commercial operation date (COD) 2018/2021) and future planned expansions for 16 more interconnections after 2020 with a total of 23200 MW [6]. Interconnections exist between Cambodia-Vietnam, Indonesia-Malaysia, Lao PDR-Vietnam, Malaysia-Singapore, and Malaysia-Thailand . A model for power exchange between Lao PDR, Malaysia and Thailand was outlined and signed in 2017 at the 35th AMEM [7], to allow Malaysia to import 100MW from Lao PDR, wheeled through Thailand's interconnections.

[5] http://hapua.org/main/hapua/hapua-structures/

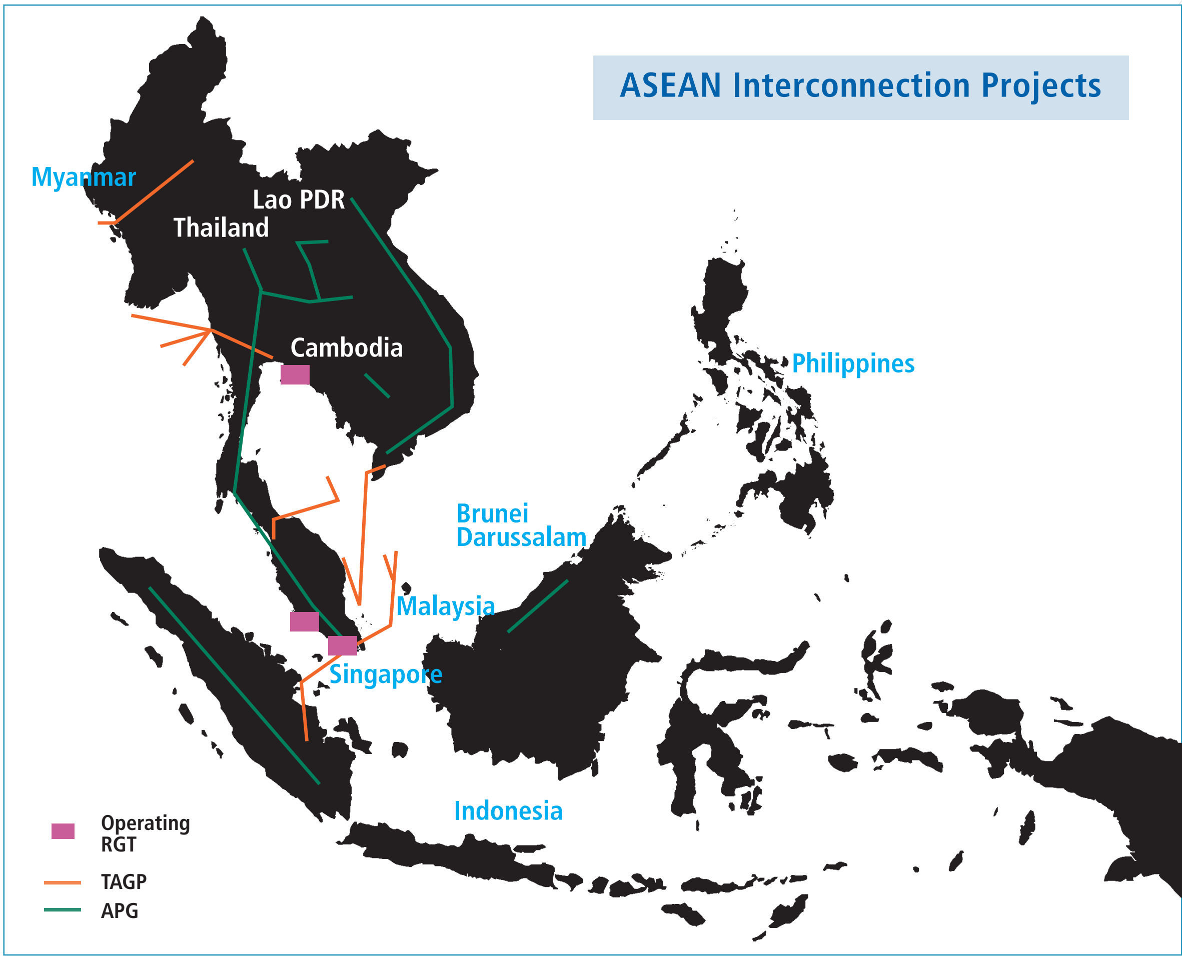


Figure 5: ASEAN Interconnection Projects (ASEAN Power Grid and Trans-ASEAN Gas Pipeline) as of 2017.
Source:[7].

HAPUA has identified three priority regions for increasing interconnections within ASEAN: northern (Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam), southern (Indonesia, Peninsular Malaysia and Singapore) and eastern (Brunei Darussalam, Indonesian Borneo, Malaysian Borneo, and the Philippines) regions. Nevertheless, a solid plan to achieve increased interconnections in these areas has not yet been established [1].

Interconnections have been built exclusively on bilateral agreements, mostly between utilities, in which they jointly build the infrastructure and develop the operating plan. Examples of such bilateral exchanges include an exchange between Malaysia and Singapore, in which no price is associated with the power exchange and power flows are netted to zero over time; and between Lao PDR and Thailand in which Thailand has imported hydropower from Lao PDR's IPP located close to the border. Although some bilateral agreements exist between AMS, little progress has been made on the establishment of a multi-lateral electricity trading and power market. A task force has been created to conduct a feasibility study for a pilot multilateral trade arrangement with selected ASEAN Member States (potentially Laos, Malaysia and Thailand, which already have bilateral agreements) [1].

3.3.2 Lessons Learnt for the ASEAN Member States

Although cross-border interconnections exist and future interconnections are planned, as shown in Section 3.3.1, the interconnection has been a challenge in the region for the last two decades. The main national impediments to increase interconnections and power trades in the ASEAN region were identified in [6] as:

- Different national policies within ASEAN Member States;
- Countries' desire for self-sufficiency before allowing interconnections;
- Countries' concern about restructuring the Electricity Supply Industry (ESI) under a Multilateral Electricity Trading.

Challenges of restructuring ESI and moving from a few bilateral power exchange agreements towards multi-lateral electricity trading have also been identified by [6] and [7], and include:

- Lack of harmonised operational and regulatory framework, and tariff structure between countries. This includes different licensing regimes, absence of free flow of funds and of Double Taxation Agreements (DTAs) within the countries;
- Confidentiality of national-level information, contracts and other documents;
- Lack of existing mechanisms for power wheeling[6], pool rules, power bidding, regulatory framework and ensuring system reliability and security;
- Absence of interest from investors, and cost recovery and guarantee framework for regional power cooperation.

AMS' openness to trade and pre-commitment to free-trading are critical in establishing a power pool[7]. International experience shows that, in 5 out of 6 major power pools (in Africa, America, and Europe), free trade agreements already existed between participating countries prior to the establishment of a successful power pool.

Regarding the physical structure (transmission capacity) of the interconnections, multilateral agencies can have an important role of conducting the feasibility study for such interconnections as well as facilitating the infrastructural expansion and power pool design.

Multilateral electricity trading requires strong, efficient and independent institutions to regulate and oversee the power pool as well as sanction participants. The better the power pool market is designed, the less cross-border enforcement actions will be needed. It has also been identified in [1] that regional institutions need to be strengthened in ASEAN. HAPUA has limited number of staff, resources and influence on regulations for the given broad task of supporting APG and multilateral electricity trade pilot projects. Additionally, the ASEAN Energy Regulators Network (AERN) also lacks mandate and staff. Therefore, IEA recommends in [1] to establish a regulators network secretariat with a mandate to work with national regulators, and harmonise regulations.

[6] "Wheeling" refers to the transfer of electrical power through transmission and distribution lines from one utility's service area to another, with the ultimate goal to move the least-cost power to where it is needed, as defined in http://www.iepa.com/wheeling.asp.

[7] An ASEAN Free Trade Area (AFTA) agreement exists, signed in 1992 and with all ASEAN countries participating by 1999. Nevertheless, it is a work in progress. Inconsistent applications of AFTA measures between AMS have occurred, as the administration of AFTA is handled by the national customs and trade authorities of each AMS, resulting in disagreements between national authorities and further reluctance to share authorities with the other countries.

4 | Summary of Recommendations

At present date, variable renewable energy (VRE) installed capacity still represents a small share of the demand in the ASEAN Member States (AMS), resulting in their current classification as being predominantly in Phase One of VRE integration. With the expected increased deployment of renewables in ASEAN, following AMS's renewable targets and incentivising policies, current challenges encountered in Phase One must be overcome, allowing further VRE integration and consequently to reach Phase Two.

The main challenges encountered in these two phases and solutions to overcome these problems have been discussed, while focusing on three main tasks necessary to enable further VRE integration in the ASEAN region: grid code harmonisation, renewable energy forecast system and the need for increased cross-border interconnections. These solutions will be summarised in this chapter.

In addition to these three main challenges, it was pointed out that increasing private-sector participation in electricity markets allows for the reduction of electricity costs and further VRE integration. VRE can play an important role in increasing electrification, with mini and micro-grids that rely on distributed generation potentially representing a faster and less expensive alternative solution to transmission grid investments, especially in island systems.

4.1 Grid Code Harmonisation

With additional cross-border power transmission system interconnections expected to be built, it is important that the power grids of AMS are integrated through a harmonised coordination of grid codes. This will allow for higher efficiency in VRE grid integration and a smooth, optimal, secure and reliable power system operation.
An ASEAN working group should be set up to:

1. Agree on all definitions used within a grid code, so that all members have the same understanding. These definitions should be used by all national grid codes. The European Network of Transmission System Operators for Electricity (ENTSO-E) definitions can be used as a guideline.
2. Agree on a similar structure/content for the grid codes, using the definitions previously agreed upon. The ENTSO-E definitions and structures can be used as a guideline.
3. Develop a common approach on how to verify grid code compliance. Even though this will be a long-term process, it is important that AMS agree on a common approach. A, regional cooperation in this area will be key to a successful and economic approach towards a common grid code compliance approach. A joined institute to certify grid code compliance is suggested.
4. In the long run, following steps one to three outlined above, a common grid code for the southeast Asian area can be developed. ENTSO-E approach can be used as guideline.

Furthermore, many countries in the ASEAN region are island nations with a multitude of mini-grids mainly powered by diesel generators. It is therefore recommended to enhance the existing association/organisation in the region dealing with mini-grid integration issues and develop a grid code framework for small island systems.

4.2 Renewable Energy Forecast for System Integration

In order to have adequate system visibility, a forecasting system for VRE production is recommended in Phase Two of VRE integration and is essential to be established for system operation during Phase Three. By integrating VRE forecasts into system operations, SO can anticipate the up- and down-ramps in VRE generation and cost-effectively balance load and generation in the day-ahead and intra-day scheduling, reduce fuel costs, improve system reliability and minimise curtailment of VRE plants [5].

An ASEAN working group should be set up to:

1. Review international energy forecasting regulations and approaches.
2. Develop suggestions for forecasting regulations and approaches/standards in the ASEAN region.
3. Jointly implement national and potentially regional forecasting solutions.

4.3 Interconnection Aspects

Increasing cooperation and interconnections between power systems of AMS will facilitate VRE integration. By designing a joint system operation, reserve sharing, and dispatch co-optimisation can be enabled to reduce the system costs, in addition to aggregating and smoothing VRE output over a larger region.

Restructuring the power system and moving towards multilateral electricity trading in ASEAN will require a series of modifications. These alterations include harmonising operational and regulatory framework and tariff structure between countries; creating a competitive power market sector; allowing access to information currently unpublished/confidential; increasing countries' openness to trade and pre-commitment to free-trading; and strengthening regional institutions in ASEAN.

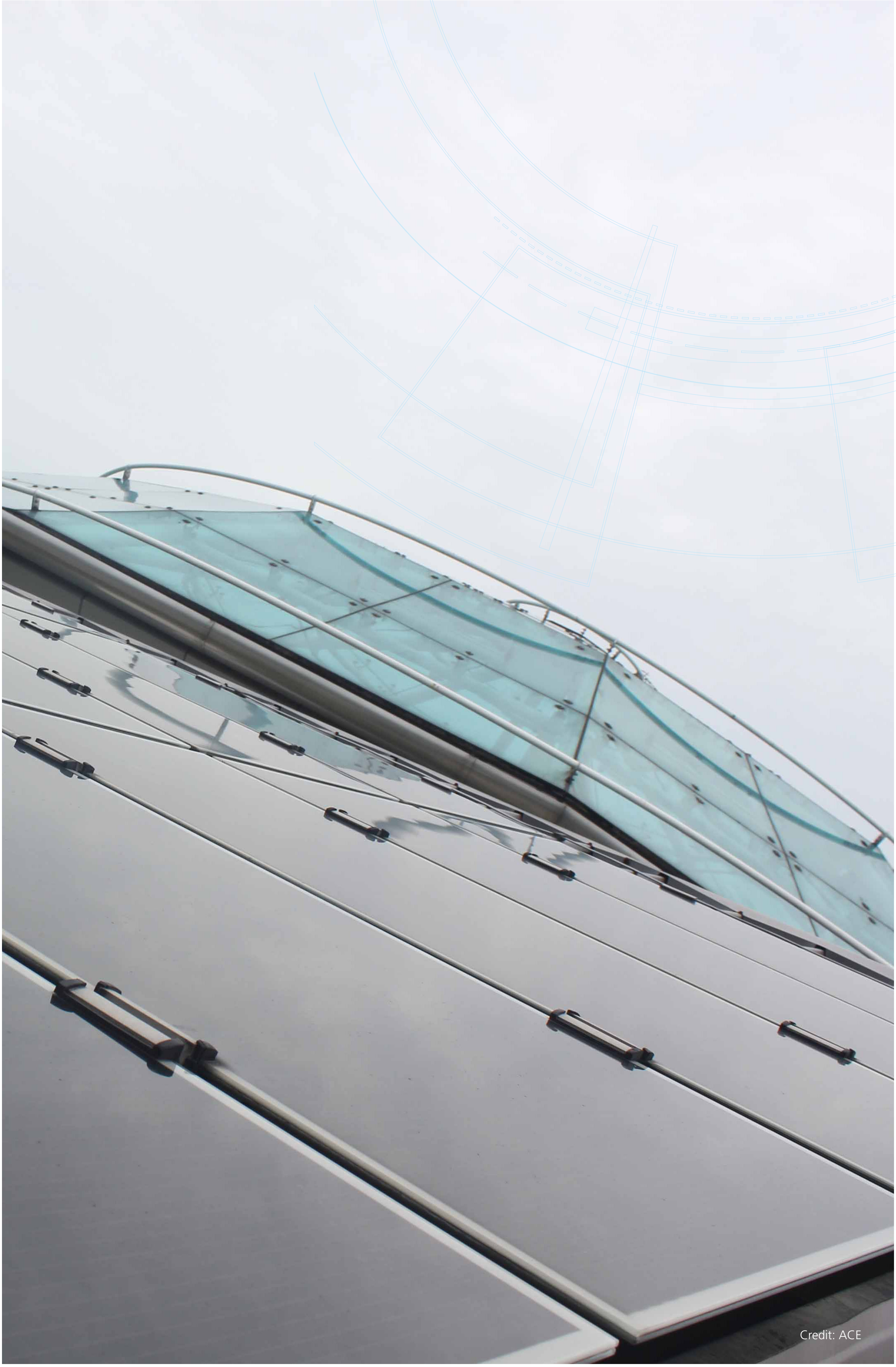
An ASEAN working group should be set up to:

1. Investigate international regulations for trading and operation between different power systems/markets.

2. Develop and update a common simulation model for the ASEAN region and, using this model, develop different 10-year scenarios considering the different national RE targets. Perform the relevant grid studies and economic evaluations for the different scenarios while considering different grid upgrades in order to be able to quantify the economic benefits of interconnections. In this process, consider the lessons learnt from international trading and operation practices.

3. Repeat the grid studies proposed in step 2 every 2-3 years, in order to consider the fast development of renewables. The study results should be published, along with the simulation models, so that international experts can review and comment on the results. The ENTSO-E development of the ten-year network development plan[8] is recommended as a reference for this task.

8 More information can be found in: https://docstore.entsoe.eu/about-entso-e/system-development/ten-year-network-development-plan/Pages/default.aspx


Credit: ACE

References

1. ASEAN Centre for Energy, "Status and Challenges Towards Regional Energy Connectivity." [Online]. Available: http://www.aseanenergy.org/blog/status-and-challenges-towards-regional-energy-connectivity/. [Accessed: 25-Jan-2019

2. Bambang Hermawanto, "ASEAN Power Grid: Route to Multilateral Electricity Trade", 2016.

3. International Energy Agency, "Getting Wind and Sun onto the Grid A Manual for Policy Makers," Int. Energy Agency, p. 64, 2017.

4. International Energy Agency, "Partner Country series - Thailand Grid Renewable Integration Assessment", 2018.

5. International Energy Agency, "Southeast Asia Energy Outlook World Energy Outlook Special Report, IEA International Energy Agency", 2017.

6. International Energy Agency, "Status of Power System Transformation 2017," 2017.

7. National Renewable Energy Laboratory, "Forecasting Wind and Solar Generation: Improving System Operations, Greening the Grid", 2016].

9 789798 978494

SustainableEnergyforASEAN

www.agep.aseanenergy.org
www.aseanenergy.org

This publication is supported by:

AGEP
ASEAN-German Energy Programme

A joint cooperation between:

german cooperation
DEUTSCHE ZUSAMMENARBEIT

Implemented by:
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

ASEAN CENTRE FOR ENERGY
ACE