ASSESSMENT OF PROPOSED TRANSMISSION PROJECTS TO FACILITATE CROSS-BORDER POWER TRADE AMONG LOWER MEKONG COUNTRIES

USAID CLEAN POWER ASIA

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ACRONYMS

AC	Alternating Current
ACE	ASEAN Centre for Energy
ACMECS	Ayeyawady-Chao Phraya-Mekong Cooperation Economic Strategy
ADB	Asian Development Bank
AFD	Agence Française de Développement
AGC	Automatic Generation Control
AEDP	Alternative Energy Development Plan
AIMS	ASEAN Interconnection Master Plan Study
APG	ASEAN Power Grid
ASEAN	Association of Southeast Asian Nations
DC	Direct Current
EAC	Electricity Authority of Cambodia
EdC	Électricité du Cambodge
EDL	Électricité du Laos
EDLT	Électricité du Laos Transmission Company Limited
EGAT	Electricity Generating Authority of Thailand
EHV	Extra High Voltage
EREA	Electricity and Renewable Energy Authority
ESIA	Environmental and Social Impact Assessment
EVN	Electricity Vietnam
GMS	Greater Mekong Subregion
HAPUA	Head of ASEAN Power Utilities/Authorities
HNEI	Hawaii Natural Energy Institute
HV	High Voltage
IEA	International Energy Agency
IPP	Independent Power Producer
IRP	Integrated Resource Planning
JICA	Japan International Cooperation Agency
Lao PDR	Lao People's Democratic Republic

LM	Lower Mekong
LNG	Liquefied Natural Gas
LTM-PIP	Laos-Thailand-Malaysia Power Integration Project
NLDC	National Load Dispatch Center
NREL	National Renewable Energy Laboratory
PDP	Power Development Plan
PEC	Power Electronic Conversion
PPA	Power Purchase Agreement
RPTCC	Greater Mekong Subregion Economic Cooperation Program, Regional Power Trade Coordinating Committee
SREPTS	Specific Requirements of Electric Power Technical Standards
VRE	Variable Renewable Energy

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EXECUTIVE SUMMARY

This report reviews studies on regional power market integration involving the Lower Mekong area. The studies, focused on different groupings of countries and undertaken with different methodologies, all present high priority transmission infrastructure projects that could be implemented that would further a goal of increased market integration. The report summarizes the studies and their findings on a common basis, collates and summarizes information about all existing and proposed cross-border transmission projects in the region, and evaluates proposed projects. A short list is provided of nine projects that may merit further study.

Reports reviewed included the following:

- "ASEAN Interconnection Master Plan Study (AIMS) III". USAID. Phase I (November 2020) and Phase II (December 2020)[1];
- "Greater Mekong Subregion Power Market Development: All Business Cases Including the Integrated GMS Case. Final Report". World Bank. February 2019;
- "Harmonizing Power Systems in the Greater Mekong Subregion: Regional Power Master Plan". ADB. 2020;[2]
- "The Study on Power Network System Master Plan in Lao People's Democratic Republic. Final Report". JICA. February 2020; and,
- "ACMECS Master Plan (2019 – 2023)". 2018.

The studies, most of which are power sector expansion planning exercises, focus on different geographic areas. AIMS III, for instance, covers all ten ASEAN countries, but not China (Yunnan), whereas the next two studies listed focus on the Greater Mekong Subregion (GMS)[3], involving the Lower Mekong countries plus China (Yunnan), but not Malaysia or other ASEAN states. JICA's study focuses on the Lower Mekong countries for modeling purposes, while also addressing proposed connections between Yunnan and Lao PDR as well as between Thailand and Malaysia as part of a regional trading framework also involving Lao PDR (the "LTM-PIP", discussed in section 2.1.3.6). The ACMECS Master Plan, which is not a power sector planning document, but rather a cross-sectoral vision statement by ACMECS, includes a list of priority cross-border transmission projects for its member (Lower Mekong) nations.

Given that there are significant existing and proposed interconnections of Lower Mekong countries with Yunnan, and that most of the studies reviewed include Yunnan (as part of the GMS), the authors decided to include Yunnan as part of the core area of interest for this report. Similarly, given that there are significant existing and planned transmission ties between Thailand and peninsular Malaysia,

[1] A "Revision – 1" version of this document, dated April 21, 2021, was also reviewed after the present report was substantially complete. Updates have been incorporated in the text where appropriate to reflect the updated version.
[2] The study is understood to be in draft form; a final version was not available for review.
[3] The GMS formally includes both Guangxi Zhuang Autonomous Region and Yunnan Provinces, but the studies do not address the former.

given that Malaysia has an existing interconnection with Singapore, and considering as well the LTM-PIP arrangements mentioned above, this report broadens the geographic area of interest to include peninsular Malaysia and Singapore for portions of the analysis.

Reflecting that power sector expansion planning generally involves 10 to 30-year modeling horizons in which projects planned to be completed more than 10 years in the future are mainly hypothetical, this report focuses on the near-to-medium term - assumed to stretch through 2030 - to keep the analysis tractable.

Table 1 summarizes GMS markets. As can be seen, there are three small markets (Cambodia, Myanmar, and Lao PDR) and three much larger markets (Thailand, Vietnam, and Yunnan). System operations and grid control are weak in each of the small markets and strong in each of the large markets. Not included in the table are Peninsular Malaysia and Singapore; Peninsular Malaysia's peak demand is about 19 GW, and Singapore's around 7 GW; grid control is strong in both markets.

Table 1. Summary Information on Regional Markets in the GMS[4]

Item	Cambodia	Myanmar	Lao PDR	Thailand	Vietnam	Yunnan (PRC)
Population, millions	16.5	54.0	7.2	69.6	96.5	48.6
GDP, $ billions	27.1	76.1	18.2	543.5	261.9	347.1
GDP/Capita, $000s	1.6	1.4	2.5	7.8	2.7	7.1
Electrification Rate	91.6%	66.3%	97.9%	100.0%	100.0%	100.0%
System Operations & Grid Control	Weak	Weak	Weak	Strong	Strong	Strong
Peak Demand, MW	1,530	4,493	1,604	32,732	41,332	52,000
Installed Capacity, MW	2,356	5,257	5,506	50,489	57,873	92,455
Capacity Reserve Margin, %	54%	17%	243%	54%	40%	78%

Source: Delphos International

Judging from capacity reserve margins, all markets in the GMS might appear to suffer from excess capacity.[5] In fact, this is only true for Lao PDR, Thailand, and Yunnan. Several points bearing on national supply/demand balances are addressed below.

- Markets where hydro provides the bulk of energy supply in an average hydrological year, referred to as "hydro dominated" or "hydro thermal" markets, require much higher capacity reserve margins than thermal markets to ensure supply during the dry season or droughts.
- In Cambodia and Myanmar, thermal plants are aging and suffer from low availability. Myanmar's gas-fired thermal fleet also faces major gas supply constraints.
- The static values presented do not capture the challenge that Myanmar and Cambodia face of struggling to add capacity quickly enough to meet persistently high demand growth,[6] leaving inefficient high speed rental gas and diesel-fired motors performing the role of marginal supplier in these markets.

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[4] See Table 5 for sources.

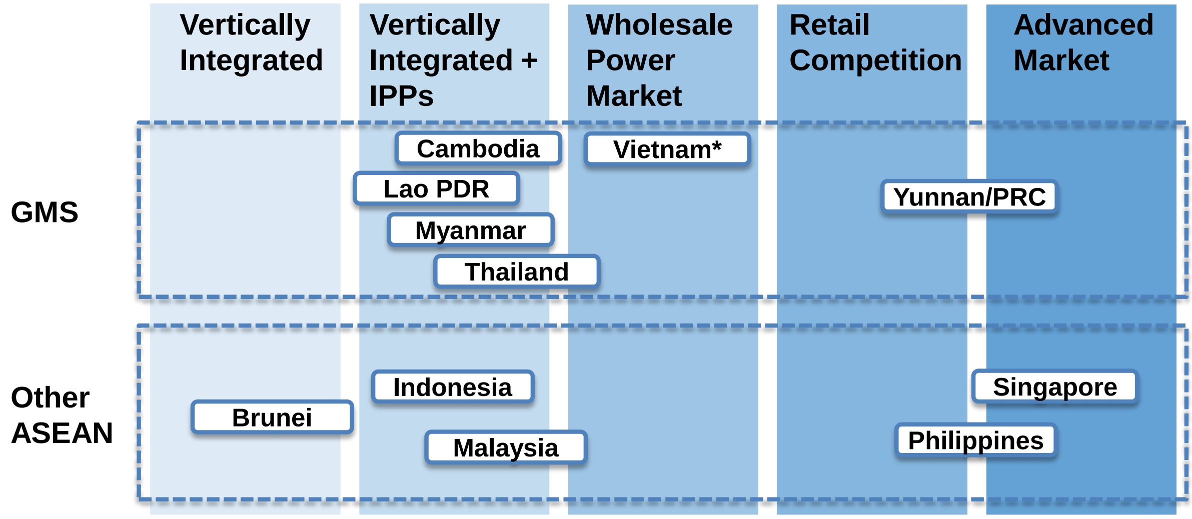
[5] Capacity reserve margin is (capacity minus peak demand)/peak demand. In thermal dominated markets, a capacity reserve margin of 15% is typically considered adequate.

[6] The analysis here and throughout this report uses data, reporting and other sources about planning and market issues that predate the coup in Myanmar. Implicitly, the analysis assumes that there will be a return to the *status quo ante* soon or that the coup itself will not much affect regional integration efforts.

- Yunnan is part of a much larger Chinese grid operated by a major state-owned utility. There is no Yunnan power market *per se*. Nonetheless, the Yunnan portion of the grid is long on supply.
- The electric power values in the table were sourced from the AIMS III study and were not independently validated. For modeling purposes, the AIMS III study attempted to allocate export-dedicated independent power producer (IPP) capacity to the importing market.
- In summary, and taking all these factors into account, Cambodia and especially Myanmar are short of power; Vietnam is a natural market for imported power to support high domestic demand growth; Yunnan and Lao PDR are oversupplied with hydropower; and, Thailand is long on supply, after overinvesting in domestic capacity and purchases from Lao PDR. Peninsular Malaysia and Singapore have an appetite for reasonably priced imports.

Most markets in the area of interest are at a comparatively early stage of restructuring, as shown in Figure 1, which arrays markets on a continuum from the traditional vertically integrated utility structure to advanced markets featuring independent regulators and system operators, wholesale power markets/exchanges where multiple products are transacted on different time horizons, and also involving competition across the entire sectoral value chain.[7]

Figure 1. Market Types in Region



Source: Delphos International
** Vietnam is in the process of implementing a significant market restructuring.*

Existing cross-border interconnections in the region involve a mix of grid-to-grid links and other arrangements, as shown in the simplified, symbolic, and indicative Figure 2 grid topography map and discussed below.[8]

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[7] The figure is intended to help orient the reader as to the relative level of market development; it is not intended to represent a complete taxonomy of regional markets. There are numerous variations on market structure within each of the columns, and there are entire market structural types (such as "single buyer" structures) that could fit between the existing columns and might apply to some of the markets. With respect to "vertical integration", the focus is on the vertical integration by government-controlled entities (even if partially unbundled, such as by corporatization and sale of a minority stake to private investors) across the three main sectoral functions: generation, transmission, and distribution.

[8] See Section 1.2.2 "Different Types of Transmission Connections" for an explanation of connection terminology.

- The map focuses on cross-border connections of 230 kV and above, with lower voltage exceptions highlighted below.
- Grid-to-grid interconnections are limited to Vietnam-Cambodia, and Lao PDR-Thailand-Malaysia-Singapore. The Lao PDR-Thailand grid-to-grid ties are all at 115 kV or below but included in the map given their high aggregate transfer capacity and operational factors. The Thailand to Malaysia link is via HVDC.
- Most cross-border interconnections in the region are of the generator-to-foreign-grid type (also known as "export IPPs"), of which there are over a dozen operating at 230 kV and above. Most of these projects involve generation in Lao PDR for export. In the map, a single link of this type represents one or more such links on the ground. From the perspective of market operation, these projects are in nearly all respects part of, and controlled by, the importing system (as indicated by the color of the circles containing the "G"s).
- There are numerous grid-to-isolated-load connections, mostly operating at voltages below 230 kV. Among the most significant, and shown in the map, is a 110 kV line from Thailand to Tachileik, Myanmar.[9] Others include a 110 kV line from Yunnan to Mongla, Myanmar.
- Some of the ties are "load switchable", wherein there are existing connections to both countries' grids in the load area, and the parties can decide who supplies by disconnecting the load from one grid and reconnecting to the other. Significant connections in this category include the 110/220 kV lines from Yunnan to northern Vietnam, Yunnan to northern Lao PDR (115 kV), and a 115 kV line from Thailand to western Cambodia. The color of the polygon reflects the color of the country providing power to that location currently. When the circuit is closed, load is served by the foreign country and when it is open, it is served by the local country.
- The map shows five synchronous blocks, indicated by color.[10] Cambodia's and Lao PDR's high voltage grids are controlled in large part by Vietnam and Thailand, respectively. (There are nuances: see sections 2.1.2.3 and 2.1.3.3). Peninsular Malaysia and Singapore make the other two-nation synchronized block.[11]
- Much of Myanmar is not covered by the national grid, including broad border swaths from the northwest through the southeast. Notably, much of eastern Shan State and all the Tanintharyi Region are off the national grid. To give a sense of scale, the Tanintharyi Region, with a population of 1.5 million, is larger in area than Denmark and Switzerland, and about the length of Portugal.

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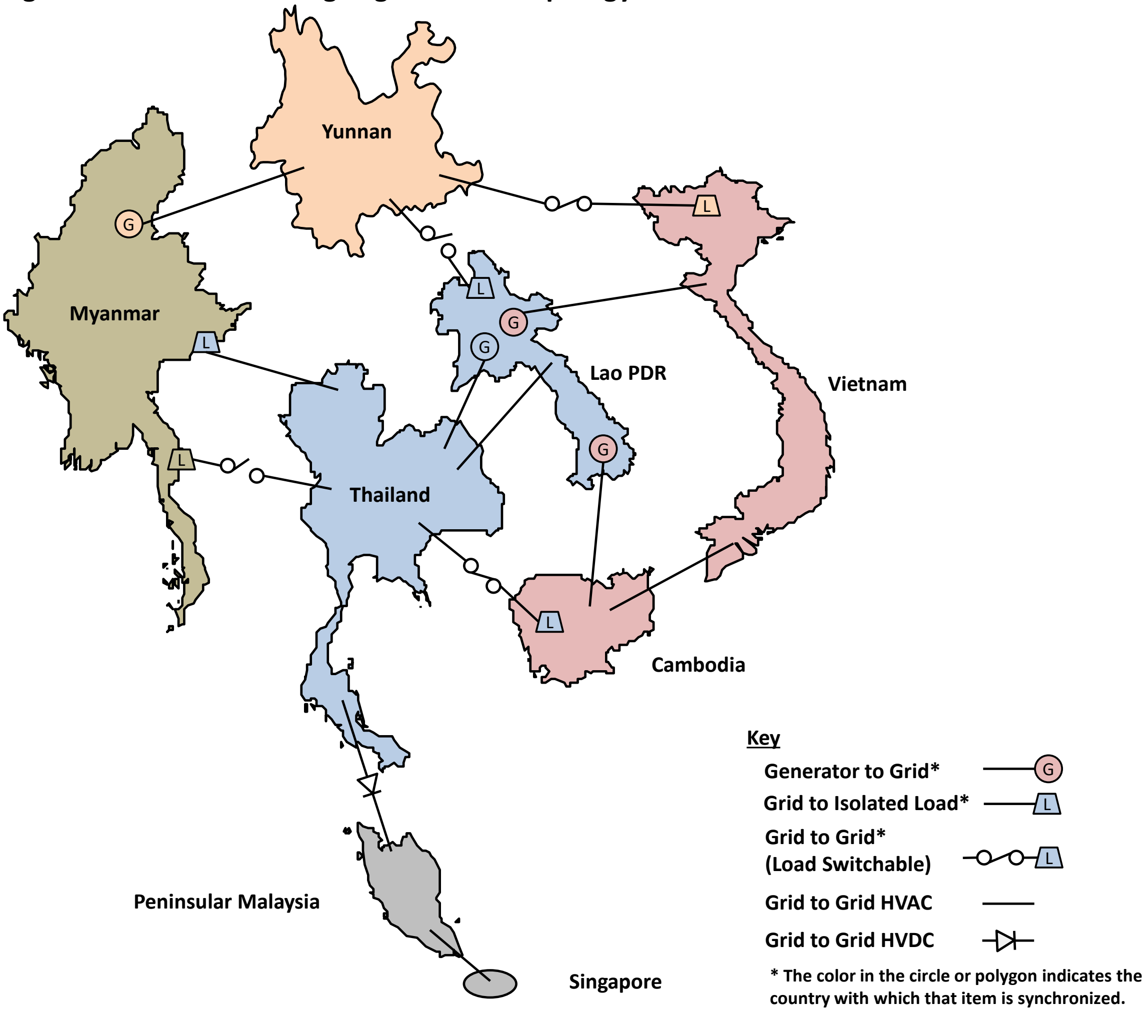
[9] Several sources support the existence of this line, while others that would be expected to document the line (such as Thailand's Power Development Plans) do not.

[10] The main source regarding synchronization is the JICA report (see section 19 in particular). Other sources and facts are confirmatory. For instance, there are numerous 115 kV AC grid-to-grid links between Lao PDR and Thailand; it is difficult to imagine how this would not reflect a synchronous interface; there is only a single line from Thailand to Cambodia and sources imply it is load switchable; there are no known grid-to-grid HV links between Lao PDR and Vietnam or Cambodia; there are HVAC links between Vietnam and Cambodia; and we encountered no sources claiming outright that synchronized areas are any different than we depict.

[11] Synchronous operation of Singapore – Malaysia is assumed based on HVAC interconnection and other factors but has not been directly confirmed.

Figure 2. Indicative Existing Regional Grid Topology



Source: Delphos International[12]

Table 2 highlights the national-level market status and market features that have the most bearing on potential new regional trade through the medium term.

- As discussed earlier, there are three prospective suppliers: Lao PDR, Thailand, and Yunnan. Lao PDR and Thailand have the advantage of incumbency in this respect, given existing trading patterns and geography. Potential buyers in the region are Cambodia, Vietnam, Myanmar, Malaysia, and Singapore. Opportunities for export from Yunnan to Myanmar would seem limited at this point, based on low domestic demand in Myanmar and internal transmission constraints on power transfer from the north (where Yunnan would supply Myanmar) to the main load center, Yangon, in the south. Yunnan may have a more natural export market in Vietnam, though it is believed there are no grid-to-grid projects planned to supplement existing grid-to-grid (load switchable) connections. Thus, Lao PDR and Thailand are well-placed to dominate as suppliers to other markets in the region.

[12] It was not possible to confirm the details of some of the interconnections summarized in this chart, and others in this report. For instance, it is not confirmed that the load served by Thailand in western Cambodia is load switchable. Sources also conflict on the names of connection points and voltages. It is not confirmed that Peninsular Malaysia and Singapore are synchronized.

- The geography of the region, combined with grid control weakness and unenforced or missing grid codes in Cambodia, Lao PDR, and Myanmar, suggests that new high voltage grid-to-grid projects – especially HVAC projects – linking the different synchronized blocks in the GMS would require considerable investments in internal grids, grid control infrastructure and training, grid code improvements, and institutional development.
- Variable Renewable Energy (VRE) projects are playing an increasing role in the GMS, driven by the low levelized cost and fast lead times for solar PV projects. Recent procurements include a 60 MW solar PV project in Cambodia in 2019 (with another 40 MW currently being tendered) and a 1,020 MW solar PV tender in Myanmar in 2020.[13] Wind power is also gaining momentum, in Vietnam especially.

Table 2. Summary of Regional Trade Orientation Factors

Item	Cambodia	Myanmar	Lao PDR	Thailand	Vietnam	Yunnan (PRC)
Approx. Peak, MW	1,530	4,493	1,604	32,732	41,332	52,000
Supply Mix	Hydro dominated	Hydro dominated	Hydro dominated	Gas-fired = 65% + hydro, coal and VRE	Hydro, coal and gas	Hydro dominated
VRE, % Total Capacity	1 - 3%	1 - 3%	1 - 3%	5%	10%	13%
Supply / Demand Balance	Tight	Tight	Excess supply	Excess supply	Tightening	Excess supply
Grid Code	Major gaps; non compliant	Draft version only; gaps for VRE	Major gaps; non compliant	Compliant	Compliant	Compliant
Grid Control	Weak	Weak	Weak	Strong	Strong	Strong
Synchronization Status	with Vietnam	standalone system	with Thailand	with Lao PDR	with Cambodia	standalone system (CSG)*
Stance on Power Trade	Import	Import	Export	Export	Import	Export

Source: Delphos International

** Yunnan province constitutes only a small portion of the area controlled by China Southern Grid (CSG).*

Note: for the "Grid Code" item, countries are judged in terms of being "compliant" with their own grid codes, that is, for example, whether frequency is regularly maintained within the normal control band.

Findings on the studies reviewed are presented below, first for the four core expansion planning studies as a group (not including the ACMECS document) and then individually. (With respect to the core planning studies, comments do not apply to the JICA study unless specifically mentioned. The JICA study was organized around the Lao PDR system and involved much more detailed analysis of that system and its interfaces than the other studies.) After these two sets of findings, a set of cross-border transmission projects are identified as potentially meriting further study.

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[13] Even before the coup in Myanmar, there were questions about the bankability and timelines of the procured projects, but the scale of the procurement itself is an indication of VRE ambitions in Myanmar.

General Findings on the Reviewed Expansion Planning Studies

- Whatever their stated objectives, the studies are by their nature general, conceptual, and directional; they should not be interpreted as identifying specific implementable cross-border projects (though some evaluated projects could turn out to be implementable).
- The formation of an interconnected wide-area transmission network supporting a regional wholesale electricity market is evidently feasible from a technical perspective and the studies indicate that implementing such a market could provide holistic benefit to the region, supporting more economical and secure access to energy, while also supporting entry of renewable energy resources including VREs.
- The studies exhibit built-in limitations and biases common to multinational cross-market power planning studies.
    - The focus ends up being on grid-to-grid links. The statement is less axiomatic than it may at first seem. To be clear, and as discussed above, markets may be linked by other types of connections as well (e.g., load switchable grid-to-grid, and others) which do represent market-to-market trade at the national level. It is certainly true that, all else being equal, grid-to-grid AC interconnections are the most flexible, grid-to-grid links with a DC element being the next most flexible: both allow power transfers in either direction reflecting the full supply mix on the injecting side and all demand on the withdrawing side. All is not equal, however, since grid-to-grid connections involve a much higher level of coordination and trust than other types of connections and are therefore more difficult to achieve. Moreover, in the context of the Lower Mekong, the other types of connections are much more flexible and more conducive to regional trade than may be appreciated, given the supply mix of exporting countries and other factors, as discussed in Section 4.4 "Barriers and Aids to Regional Integration".
    - The focus on grid-to-grid projects in the studies limited consideration of other types of interconnections. None of the studies considered any grid-to-grid (load switchable) project or a grid-to-isolated load project, though there are evidently successful instances of such projects in the region, and there are several potential projects in these categories at a scale that should be of interest as part of any regional planning exercise.
    - With respect to new grid-to-grid projects, often there are costs tied to addressing internal grid inadequacies that would have to be borne for these projects to proceed. The studies assume such costs are borne as a matter of course rather than being considered part of the cost of the projects themselves. Relatedly, the studies assume AC grid-to-grid projects nearly across the board rather than projects involving DC elements.[14] While some of the studies highlight this assumption as being potentially unrealistic, this modeling decision nonetheless may leave an unrealistic impression of

[14] The only exceptions to this rule for modelling within the area of interest are (i) two HVDC links proposed from Yunnan to Thailand and from Yunnan to Vietnam in the GMS Master Plan and the World Bank study, and (ii) a new HVDC link between Peninsular Malaysia and Thailand in the AIMS III study. (There are other new HVDC links as well across other more southerly systems in the AIMS III modelling).

technical viability for the AC projects and at lower cost than would be expected for DC alternatives.

- The models assume that the entire interconnected region is centrally dispatched. When a region is centrally dispatched, the objective is to minimize costs for the region as a whole[15]; frequently, the optimum solution involves exporting a limited resource (hydropower, for instance) without regard for the upward cost pressure on the local market of such exports. There are political economic challenges to such an approach. In most multinational power markets, therefore, there is much national-level interest in the approach taken to dispatch scheduling (particularly for hydropower projects), resulting in less power trade than models indicate is economic.

- Modeling efforts had to contend with data gaps about existing systems that were numerous and significant, lack of accurate information about potential transmission projects, and wholly unrealistic power development plans. Data gaps were especially challenging for the Vietnam, Myanmar and Cambodian systems (some studies had better access to data for one or another country, but all faced similar challenges). The power development plans used as the starting point (in some cases, with adjustments) for "base scenario" analyses were dated and highly optimistic as to the timing of new capacity entry through the medium term; it is not clear in the studies what was done to develop more realistic "scheduled" capacity expansion plans for the region for modeling purposes.[16]
- The studies took a reasonable approach to populating initial lists of candidate transmission projects, relying on previous studies for the region. There was, however, little apparent effort devoted to vetting these projects based on current information or to expanding the candidate list to include other potential projects. The result is like the problem of a restaurant that no one goes to because no one is there: there are transmission projects no one studies because no one has studied them before. Taking such an approach may have reflected a lack of time, budget, and access to relevant information to conduct the sort of research required to populate a more complete transmission project candidate pool. From a modeling perspective, it does not matter much if one assumes a 100 kms 230 kV line from Substation A to Substation B rather than the same line from Substation C to Substation D when the modeling of national systems is highly simplified. When results are intended to be used to evaluate specific projects for potential further study by stakeholders and development partners, this approach is severely limiting, resulting in numerous candidate projects in all the studies that are implausible for one or another reason while excluding new projects that could make sense.[17]

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[15] There are exceptions to this rule; and some models can accommodate such exceptions. However, there was no indication in the studies that anything other than a least-cost regional objective function was specified.

[16] In an expansion planning framework, scheduled new entry refers to projects hard-wired to enter in specific years.

[17] A few examples of implausible candidate projects are: (i) The GMS Master Plan included a 600 kV HVDC line from China through Lao PDR to Thailand by 2023 (unrealistic on timing and economic/political dimensions), two 500 kV HVAC lines from Thailand to Myanmar (Mawlamyine and Yangon area) by 2022 (unrealistic on timing, voltage, and technology), and a 500 kV HVAC line from Lao PDR to China in 2024 (unrealistic on timing, technology, and probably economics). (ii) The World Bank study, in its candidate list of 14 projects, included the above four projects from the GMS, while screening out the Mawlamyine project on the incorrect grounds that the city is not currently on the national grid. (iii) None of the studies, as mentioned in the text, considered potential grid-to-isolated load projects, such as from Thailand to Myanamar's Tanintharyi region, or grid-to-grid (load switchable) projects, an approach that could improve the technical/operational viability of several candidate projects. (iv) Neither the GMS Master Plan nor the World Bank study examined any grid-to-grid connections between Lao PDR and Thailand.

To be clear, the consultant teams producing the studies are not to be faulted for this approach; it is more accurate to point the finger at unrealistic expectations for studies such as these given data, budget, time and access challenges.

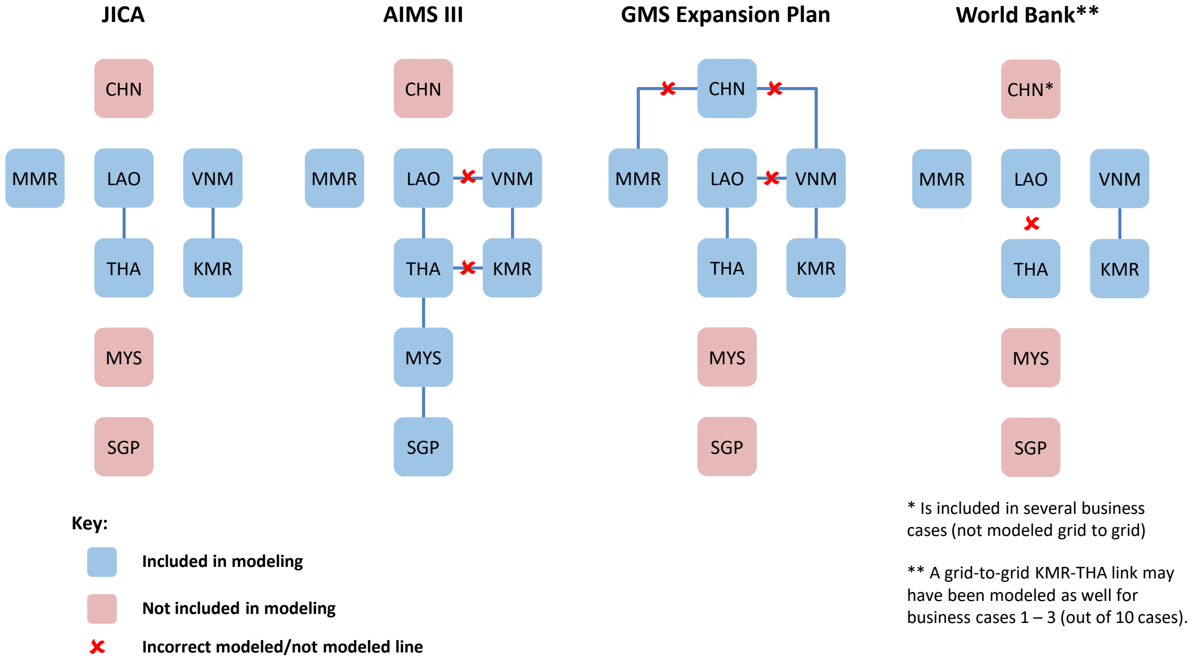
- It appears that the nature of existing cross-border interconnections in the GMS may be inaccurately represented in several of the studies. Figure 3 depicts the existing network configurations in each of the studies, with blue boxes representing core modeled markets. Grid-to-grid links within the core modeled market area that are believed incorrect are denoted by a red "X". To be clear, links are only evaluated within the core modeled area for each study. Note the following:
    - The JICA study is regarded as correct for the GMS markets, reflecting two synchronized zones (Vietnam & Cambodia plus Thailand & Lao PDR) and Myanmar as an isolated system, with no grid-to-grid interconnections across any other interfaces. The study, which was focused on the Lao PDR, did not include Malaysia and Singapore in its explicit grid modeling, though trade under the LTM-PIP was discussed at length.
    - The AIMS III study, which included modeling of all ten ASEAN member states (not all shown here), correctly included Malaysia and Singapore as connected to Thailand and Lao PDR. This is an important advantage over the other studies, considering there is substantial existing trade from the north to the south on this path and much potential for increased trade. While the study incorrectly assumes grid-to-grid links between Vietnam and Lao PDR (200 MW transfer capacity), and between Cambodia and Thailand (120 MW transfer capacity), these errors are expected to have minimal impact, given the low modeled transfer capacity on those interfaces.
    - The GMS Master Plan's market topology included several highly distorting assumed links with large transfer capacities. For instance, it appears that all or most generator-to-grid projects and all HV grid-to-grid (load switchable) were modeled as reflecting grid-to-grid connections, resulting in large cross-border grid-to-grid transfer capacities where none exist: over 1,200 MW for Yunnan-Myanmar; over 900 MW for Yunnan-Lao PDR; and over 700 MW for Lao PDR-Vietnam.[18]
    - The World Bank study specified different configurations in different "business cases". While the study correctly and authoritatively describes the operation of the Lao PDR and Thailand systems in most respects, it appears that in all ten business cases, it was incorrectly assumed there is no Lao PDR - Thailand grid-to-grid connection, which is regarded as potentially highly distorting, given the significant aggregate transfer capacity at 115 kV across that interface.[19] In three of the ten business cases, a grid-to-grid tie may have been incorrectly assumed between Cambodia and Thailand (not shown in the figure). Several business cases include modeling of China. Section 4 of the report correctly describes the regional grid (though with little discussion of the

[18] It should be recalled that the GMS Master Plan documents reviewed were not final. It is evident that the consultant had questions about regional grid topology, as indicated by notes about further analysis being required with "adequate details of the regional network."

[19] Several sources estimate 700 MW transfer capacity on this interface, more than double the transfer capacity on any other interface in the region. The World Bank study notes its focus on HV lines > 115 kV, effectively "defining out" the 115 kV Thailand-Lao PDR lines. The AIMS III study, by contrast, modelled at 230 kV and up, but captured the importance of the lower voltage Thailand-Lao PDR lines by modelling those lines as 230 kV equivalents.

Thailand-Lao PDR 115 kV interface). A related issue is that the study wrongly asserts that Lao PDR and Thailand are not synchronized, which undermines the otherwise strong analysis of potential paths to regional synchronization in Section 8.6 “System-to-System Interconnections and Synchronisation”.

Figure 3. Existing Grid-to-Grid Network Topology Assumed by the Studies for the Area of Interest



Source: Delphos International

Findings on Individual Studies

- **AIMS III** is a massive ten-country indicative regional master plan providing conceptual and directional guidance to potential regional interconnection efforts.
    - The study does not purport to develop proposed individual transmission projects or other transmission infrastructure investments beyond the conceptual level, with the focus being mainly on the timing, size, and type of potential cross-border links rather than their grid locations.
    - The study represents an extraordinarily complex, data and labor-intensive effort. The GE India team undertaking the study is well-qualified for the work and the models used are well-established in the industry. The overall modeling approach is sensible.
    - The “base scenario” assumes a regional grid expansion path that is among the most plausible of the studies reviewed, in terms of the timing, sizing and location of the projects. For instance, AIMS III assumed approximately 600 MW total new grid-to-grid transfer capacity in the LMS by 2025 in its Base Scenario, as 230 kV projects. By contrast, the GMS Expansion Plan assumed over 9,000 MW by the same point for the LMS, all at 500 kV, as well as major new connections with Yunnan. The World Bank study, for its part, was organized around “business cases” and specifically highlighted that projects were allowed to enter at the earliest feasible date. Even so, some of the

project sizes and timings are ambitious, including 2,300 MW total transfer capacity by 2023, and nearly 3,000 MW by 2025; nearly all of these are 500 kV projects.[20]

- Significant data gaps resulted in modeling adjustments in the steady state analysis which, while reasonable in the circumstances, amount in the aggregate to important over-simplifications of regional grids and their existing and future interconnections. For instance, the Thailand and Vietnam grids were modeled as "regional equivalent models", wherein national subregions were defined, each "represented by one or two buses at the highest voltage level and total generation (represented separately by fuel type) and load in that area was lumped at those sub-regional buses." There were major simplifications of the other three LMS grids as well. Such simplifications obscure assessment of whether proposed links would require grid improvements at the national level and makes assessment of short circuit fault levels unreliable. It is important to understand, however, that the other studies made similar simplifications and none of the other studies included grid stability analysis[21].
- The solar PV levelized cost of energy (LCOE) assumptions for ASEAN as a whole and for the LMS in particular (as a focus of the present report) are surprisingly high - 50% to 150% above prices achieved in auctions in the region - and show unexpectedly low rates of decline. The impact of assuming higher solar PV LCOEs than would appear realistic is to understate the role that solar PV (and more generally, VRE) can play in reducing the regional cost of energy under the high VRE entry modeling scenarios.

- The **ACMECS** document is not a power sector / transmission master plan. Rather, it presents a vision for regional integration and a list of infrastructure projects across various sectors that ACMECS members agreed to support as priority projects. Within the power sector, 13 transmission projects are listed as priority projects, four of them unique to the ACMECS Master Plan and the remainder listed previously in ADB's GMS RIF - 2022.
- The **GMS Expansion Plan** develops optimal regional generation and transmission plans under different scenarios for 2022-2035.
    - Objectives included determining the potential cross-border power transmission options and identifying and ranking the most economically and technically feasible transmission upgrades and corresponding generation development.
    - The "base scenario" delivered $18 billion in modeled net benefits.
    - Modeling showed several "highly impacting interconnections": Myanmar – Thailand (developed early in the study period); Lao PDR – Viet Nam; and Thailand – Cambodia – Viet Nam.
    - While it is necessary to bear in mind that the study available for review is apparently in draft form, the study's overall findings are undermined by data gaps, incorrect modeling of grid topology, and unrealistic candidate projects as noted above in the AIMS III discussion (see footnote 17 for a few examples).

[20] See footnote 17 for examples of specific unrealistic projects.

[21] The World Bank and JICA studies did not include grid stability analysis. The GMS Master Plan did not report on any stability analysis though there is a single mention of "[d]etailed analysis including AC load flow based reliability studies".

- Of all the studies, the **JICA** study provides the most detail and depth of analysis on the Lao PDR and Thailand grids, and in general, on the regional market. The study elucidates issues related to regional synchronization, both as to the facts on the ground and the challenges to achieving a wider synchronized area, while cautioning about grid-to-grid links (especially AC links) between weak grids. A detailed and realistic roadmap towards greater regional integration is provided. Several potential high priority transmission projects are proposed that appear worthy of further analysis.
- The **World Bank study** provides a thoughtful and careful analysis of potential integration projects, organized as "business cases".
  - The study provides high quality descriptions of regional power systems and matters affecting increased regional integration.
  - Projects are evaluated in terms of net benefits and ranked, then presented in a phased development scenario as a "Proposed Strategy for Cross-Border Expansions", which overall appears reasonable.
  - Findings are somewhat undermined by apparent errors in the modeling of the existing grid topology (discussed above), a curious omission (shared with the GMS Master Plan) of any Thailand – Lao PDR grid-to-grid projects, and a lack of plausible Thailand to Myanmar projects.[22]

Projects Identified for Potential Further Study

The terms of reference for the present report require comparison of individual cross-border transmission project candidates in terms of their ability to support regional integration. The approach taken focused on projects potentially achievable through the medium term (2030). Candidate projects from different sources (including those reviewed in this report) were assembled in a database, together with several potential projects identified by the Delphos Team.

Projects were then screened on factors including the assessed level of country and donor support, achievability within the analysis horizon, and degree of support for regional integration, yielding a short list of 31 projects of potential interest for further study. Of these, nine were identified as high priority projects (see Figure 4) for potential further study and are discussed individually. There are certainly other projects that could merit further analysis, such as between Cambodia and Thailand, Cambodia and Lao PDR, Yunnan and Myanmar, or between Lao PDR and Vietnam.

Projects for further study are the following:

- A 500 kV HVAC grid-to-grid line from Lao PDR (Houn) to Thailand (Nan), and a 230 kV HVAC grid-to-grid line from Lao PDR (Thabok - Paksan) to Thailand (Bungkan). These are two of the three lines identified in the JICA study as high priority projects.
- Thailand (Mae Sot) to Myanmar (Myawaddy) 230 kV HVAC, with a back-to-back facility. This is the third high priority project identified in the JICA report. Myanmar brought a double circuit

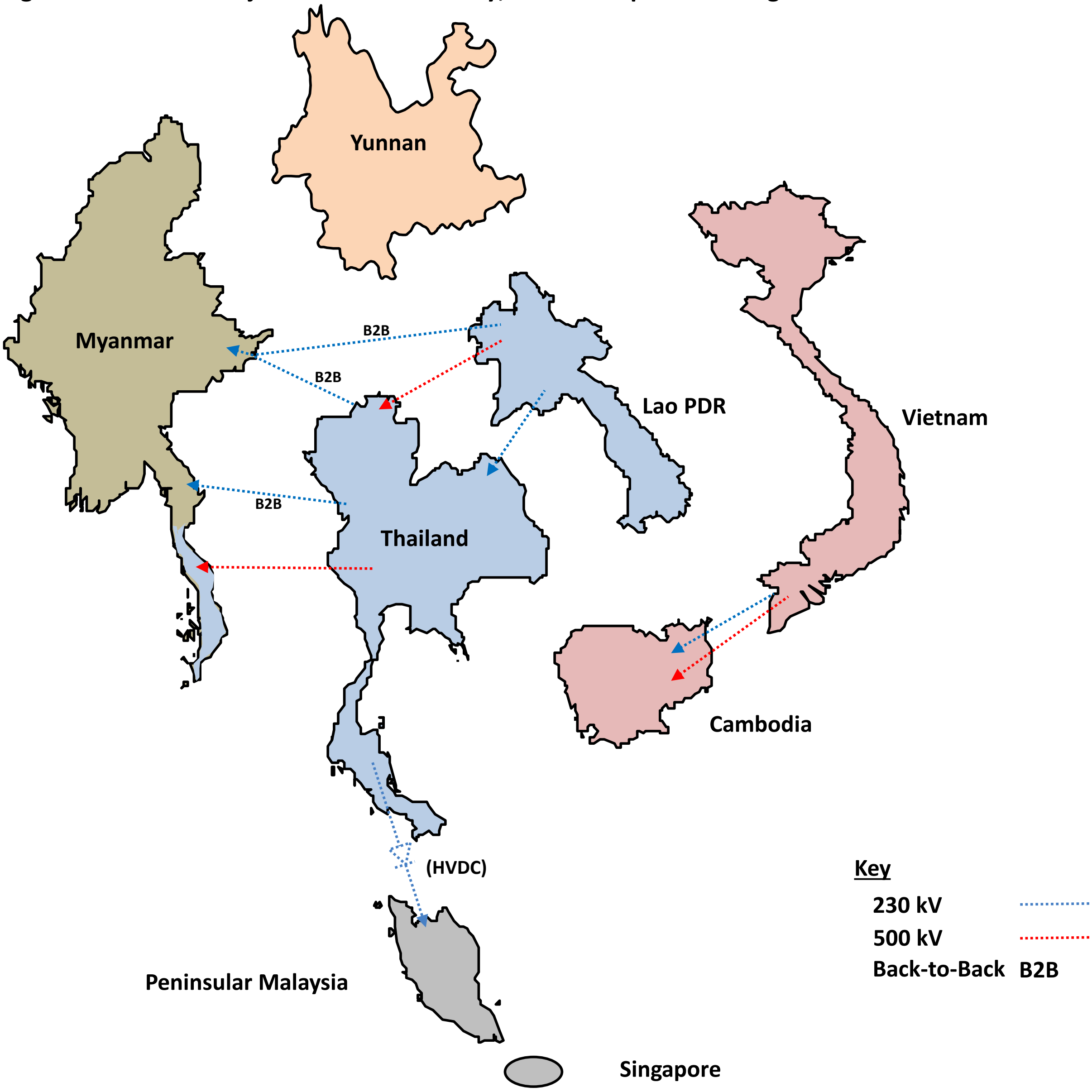
[22] Of the 14 candidate projects evaluated and eight alternatives, there is no grid-to-grid Thailand to Lao PDR project. See footnote 17.

230 kV line up from Mawlamyine to Myawaddy (previously served by Thailand) in 2019. Thailand is already planning on bringing a 230 kV double circuit line to Mae Sot, on the other side of the border from Myawaddy. Prior to the coup in Myanmar, there had been statements by officials on both sides supportive of a potential link at this location.

- Lao PDR (Muong Long) to Myanmar (Keng Tung) 230 kV HVAC, with a back-to-back facility. This well-studied project (by ADB and others) appears technically feasible and there is an MOU between the two countries supporting studies on the project. The project would provide power from northern Lao PDR, which has excess hydropower capacity, to a new substation at Keng Tung in Myanmar.
- Thailand (Mae Chan) to Myanmar (Keng Tung) as a 230 kV HVAC line with a back-to-back facility. This project, proposed by the Delphos Team, appears to be under study by EGAT. The project would connect from the Mae Chan substation in Thailand to the new Keng Tung substation in Myanmar. On the Thailand side, there is understood to be a transmission corridor for a 110 kV line providing service to the Myanmar border city of Tachileik. This project is regarded as technically and operationally simpler than the Lao PDR to Myanmar project in that line length is much shorter and it would connect a strong grid (Thailand) with a weak grid (Myanmar). By contrast, the Lao PDR version of the project would involve sending power from a weak grid that is, in any case, synchronous with Thailand. The business case for this project could be identical to the Lao PDR to Myanmar project above, assuming a wheeling arrangement with Thailand, like the LTM-PIP structure, could be worked out; or the project could involve sales directly from Thailand to Myanmar.
- Thailand (Tha Tako) to Myanmar's currently islanded Tanintharyi region, as a 500 kV HVAC grid-to-isolated load project and connecting at Dawei, likely operated at 230 kV initially. This project would facilitate provision of on-grid power to an area with 1.5 million inhabitants, including nine cities with 100,000 or more inhabitants,[23] and one of Myanmar's three Special Economic Zones (at Dawei). The project would be expected to yield important development impact and environmental benefits by increasing electricity access and displacing inefficient and polluting diesel engines used for most of the region's mini grids.
- Thailand (Khlong) to Malaysia (SS 61214), as a 230 kV HVDC project that is assumed to proceed in 2025 in the AIMS III Phase II study. The project would take the same route as the existing 230 kV HVDC link and would allow for expanded exports to Malaysia and Singapore.
- A 500 kV HVAC Vietnam (Tay Ninh) to Cambodia (Kampong Chan) project and a 230 kV HVAC Vietnam (Tay Ninh) to Cambodia (Stung Treng) project. These projects, which also were evaluated in the GMS Master Plan and the World Bank study, would help address supply challenges in Cambodia.

[23] "The 2014 Myanmar Population and Housing Census: Tanintharyi Region Census Report Volume 3 – F". Population growth is assumed from values reported in the census. Note that over 80 countries have fewer people than reside in the Tanintharyi region.

Figure 4. Potential Projects for Further Study, with Anticipated Average Flow Direction



Barriers and Aids to Regional Integration

There is a perception prevalent among donors that progress towards regional market integration in the LMS has been slow. While it is beyond the scope of this report to compare the pace of integration in the LMS to that in other regional markets[24], it is worth taking stock of the current level of integration. In some respects, there already exists substantial regional integration and there are underlying market features that should impel expanded regional trading, as summarized below.

- A central spine of existing grid-to-grid connections links Lao PDR, Thailand, Peninsular Malaysia, and Singapore. Thus, any country adding grid-to-grid links to the central spine would become a member of a five-country regional market, which in terms of the number of countries involved, would place that market among the largest internationally.

[24] Based on the Delphos Team's experience, the pace of integration within the region of interest is not slow by comparison to that of other regional markets.

- There are high levels (over 5,000 MW) of IPP-to-foreign-grid links across the region, which constitutes real cross-border trade and lays the foundation for other types of links in terms of physical infrastructure, legal documentation, and regulatory/institutional approaches.
- There are multiple, significant, grid-to-isolated load and grid-to-grid (load switchable) connections in the region, including especially across interfaces that do not have direct grid-to-grid connections. Examples include the Yunnan to Vietnam links, the Thailand to Myanmar links at Tachileik and Myawaddy, and the Thailand to Cambodia link. These existing projects can facilitate subsequent direct grid-to-grid linkages and, as with IPP-to-foreign grid projects, they pave the way for more ambitious projects.
- The LTM-PIP project, recently expanded to include Singapore, is an important proof-of-concept involving wheeling through Thailand. Given the regional geography, Thailand is likely to remain the main country across which wheeling might realistically be expected.
- Market fundamentals suggest ongoing trade opportunities. In the short and medium term (through 2030 or so), likely buyers include Vietnam, Cambodia, Myanmar, Malaysia, and Singapore, with likely suppliers being Lao PDR and Thailand. In the longer term, there are (and will be) large bankable potential off-takers in Vietnam, Thailand, Malaysia, and Singapore for potential cross-border PPAs selling grid-to-grid. Lao PDR (hydro potential) and Myanmar (hydro, solar, wind and gas potential) are the natural suppliers over the longer term.
- Concerted years-long efforts by the RPTCC to develop a regional grid code and planning for permanent "brick and mortar" regional market institutions have created a foundation for increasing regional integration.

Below, barriers to achieving greater regional market integration are presented and then potential solutions are summarized.

Barriers:

- Unrealistic ambitions for the regional market and timelines to achieve those ambitions push integration efforts in unproductive directions.
    - Some of the grander visions for regional integration involve multi-directional trade in a meshed grid across numerous interfaces, with open access, standing wheeling arrangements across the different markets, and regional system operational and market institutions. These visions are unrealistic over the period of analysis (through 2030) and most likely through 2040.
    - The underlying reality is that only two countries in the LMS are likely exporters (Lao PDR and Thailand) for at least the next ten years. Each of these two countries can export on existing and new dedicated lines to their own most likely customers within the LMS. Lao PDR can also export to Malaysia and Singapore under LTM-PIP arrangements, which could be expanded. It is difficult to imagine that trading patterns would be much different in a fully meshed regional grid with advanced market structural elements. In other words, the underlying economics would tend to support mainly bilateral initiatives, often involving one-way trade not necessarily requiring grid-to-grid connections, plus expansion of the LTM-PIP framework.

  - There are a variety of technical and institutional/regulatory barriers to implementation of an advanced regional market, including lack of sufficient cross-border transmission facilities; grid and system operational weakness in Lao PDR, Cambodia and Myanmar; missing, inadequate and/or unenforced grid codes in Lao PDR, Cambodia, and Myanmar; lack of regional market and system operating institutions; and lack of coordinated planning.
  - The ongoing attempt to create a GMS or LMS-wide power market involving robust grid-to-grid connections has been paired with efforts to create a GMS-wide grid code. The proposed regional grid code may be appropriate to the vision of such a market, but prospects for adoption and enforcement of the GMS grid code are diminished by the deficiencies mentioned above. In other words, envisioning a simpler, smaller, market would allow for a simpler and more implementable grid code for that market.

- The geographic extent of the envisioned regional market is too large. For historical and institutional reasons, much of the focus has been on the LMS / GMS, whereas the LTM-PIP + Singapore structure would appear to constitute a more natural core regional market. Three of the four countries involved have robust and well-managed national grids while Lao PDR's national grid is already synchronized with Thailand. There are two natural buyers and two natural sellers. Given weak grids and institutions in Myanmar and Cambodia, there are dubious benefits to struggling to implement an organized regional market in which those countries could participate from Day 1 on an equal footing. As regards Vietnam, as noted above, its most natural trading partners are Lao PDR and Cambodia. As documented in JICA's study, grid-to-grid connection with Lao PDR could be challenging, but in any case, could be pursued bilaterally. In other words, it is not clear what is gained by Vietnam's active participation in an organized regional market for the foreseeable future, since it is right next door to its most likely trading partner, with whom it can already trade via dedicated IPP-to-grid projects and since it could pursue new links of all types with Lao PDR on a bilateral basis.

- Grid-to-grid projects are treated incorrectly by some donors and regional forums as being the only types of projects that are supportive of regional trade. Other types of connections are highly supportive of regional trade as well and can be much easier to implement. For instance, grid-to-isolated load or grid-to-grid (load switchable) can make a great deal of sense economically and operationally when a sizeable load in one country is far from generation resources (and especially when supply to the area is inadequate) and relatively near to the grid of another country. Apart from the underlying economic and environmental benefits of such projects, there can be other important benefits as well. Such projects also smooth the path for more direct market integration between the two countries later by facilitating build out of transmission and distribution infrastructure in the importing region and by establishing the rights of way that could potentially allow for additional lines or uprating of existing lines.

- Economic and financing barriers to the building of new cross border transmission lines are significant. For bilateral projects, typically, the two countries agree to fund construction on their own sides of the border, and split funding for related infrastructure. Fiscal limits on the part of the poorer countries in the region are the constraint in this case.

Solutions:

- De-emphasize the consensus-driven GMS RPTCC approach, which attempts to build an advanced regional market that could accommodate all GMS member states.
- Adopt more realistic ambitions for the regional market over the next ten to twenty years, focused on establishing a core market in the LTM-PIP + Singapore group of countries. The LTM-PIP structure reflects the existing and expected future natural trading flows, that is, from Lao PDR to the south. There is no need to undertake in the near term the extremely complicated task of transforming this simple structure into a more flexible wheeling arrangement allowing reverse flow trades, given that south (Singapore and Malaysia) to north (Thailand and Lao PDR) flows are highly unlikely for at least the next ten years based on existing and committed oversupply in the north. This market could potentially be expanded to include Myanmar under similar arrangements, with Lao PDR selling to Myanmar, wheeling across Thailand, over new ties between Thailand and Myanmar. Again, these wheeling arrangements can be unidirectional initially since Myanmar will be short on capacity for many years.
- Evaluate grid-to-isolated load and grid-to-grid (load switchable) projects as potentially supportive of development and regional trade.
- Continue work on "no regrets" objectives:
    - Focus on improving national level grid control for Lao PDR, Myanmar and Cambodia.
    - Improve grid codes and grid code enforcement in the same countries.
    - Improve sectoral planning throughout the region, especially in Lao PDR[25], Cambodia and Myanmar.
    - Examine technical approaches to grid-to-grid linkages across the currently unsynchronized interfaces: Thailand to Myanmar; Lao PDR to Myanmar; Lao PDR to Vietnam/Cambodia; and Thailand to Cambodia. Such approaches might involve HVAC plus back-to-back facilities, HVDC, and creation of subregions within national markets that are synchronized with a neighboring market.
- Funding
    - Development partners should support specific project feasibility studies on projects of bilateral interest. These studies should cover technical, economic, funding, operational, legal, and regulatory aspects.
    - Development partners could provide debt financing to specific projects.
    - Development partners should engage the larger/wealthier countries in structuring arrangements – essentially, loans – involving the larger/wealthier countries financing both sides' capital contributions, in exchange for regular payments for the assets by the smaller/less developed partner.

[25] With USAID support, Laos has begun improved planning through the conduct of an Integrated Resource and Resilience Plan (IRRP). The documentation of this planning process and the analysis results were not made available to the authors. ADB has been assisting (or planning to assist) Cambodia with updating their PDP and several donors (including JICA, the ADB and the World Bank) have assisted the Myanmar government with improved planning.

- If the technical need for common market infrastructure is identified, development partners could consider funding the structuring work. Such work could cover establishment of the ownership vehicle, shareholder arrangements and debt financing.

1. INTRODUCTION

1.1 OVERVIEW OF SCOPE OF WORK

The USAID Clean Power Asia program, implemented by Abt Associates, seeks to scale up investment in grid-connected renewable power in the Lower Mekong (LM) countries. Increasing the amount of Variable Renewable Energy (VRE) on the power grid without reducing grid stability and reliability entails harmonizing renewable energy development with transmission planning, including planned cross-border interconnections. To this end, USAID supported the Heads of ASEAN Power Utilities/Authorities (HAPUA) and the ASEAN Centre for Energy (ACE) on the third ASEAN Interconnection Master Plan Study (AIMS III).[26] Phases 1 and II of AIMS III focus on identifying opportunities for increasing bilateral and multilateral trade along with the accompanying generation and transmission needs and the potential to increase VRE on the grid.

Several other studies, supported by different funding agencies and regional cooperation frameworks, have also analyzed prospects for increased regional power trade. The studies differ in terms of countries evaluated, time horizon, objectives, data sources, as well as the approach and methodology used, resulting in a confusing mix of findings that are difficult to assess. It was in this context that Abt Associates commissioned Delphos International and its subcontractors – AECOM New Zealand, Power Grid International, and SST Venture (together "the Delphos Team") – to conduct a desktop review of all such studies, including AIMS III.

The Delphos Team was tasked with producing the present report, which involves a systematic review of the major studies listed in Table 3 and the transmission infrastructure identified in each study to provide recommendations to USAID on prioritizing cross-border interconnection projects in the Lower Mekong sub-region (LMS). This report compares the studies in terms of their objectives, approach, methodology, and data sources to evaluate the pros and cons of the interconnection projects identified in each study. Relying on prior studies, publicly expressed priorities of the national governments, and technical expertise, the report assesses whether the identified projects are likely to be realized in the near- to medium-term, and if so, whether they also have the potential to facilitate regional power trade. The assessment resulted in a shortlist of nine projects that the Delphos Team recommends as high priority for potential US government support.

The intention is for the report will be used to inform discussions of the AIMS III study in regional forums. Therefore, the report distills regional integration issues and presents findings using non-technical language as much as possible for ease of use by policy makers.

As Table 4 shows, the World Bank, ADB, and JICA studies all focus on the same countries (being GMS focused) whereas AIMS III has a pan-ASEAN scope. The JICA study has a narrower focus on Lao PDR, whereas the other studies evaluate the benefits of power trading at a regional level, either for the GMS or ASEAN-wide. The studies faced similar challenges in obtaining data to model the transmission

[26] AIMS I and AIMS II were completed in 2003 and 2010 respectively.

networks. However, all studies identify the potential for substantial regional benefits from increased cross-border power trade.

Table 3: Main Sources Reviewed

Source	Brief Description
ASEAN Interconnection Master Plan Study (AIMS) III: Final Interim & Phase I Report. USAID. November 2020.	Report covers capacity expansion planning; socio-environmental assessment; economic analysis; production simulation analysis; data collection and gap analysis; and a renewable energy resource assessment.
ASEAN Interconnection Master Plan Study (AIMS) III: Preliminary Phase II Report – Steady State Grid Analysis. USAID. December 2020.	Report covers the consultants' approach to developing country-level and regional transmission models and discussions of power flow analysis, contingency analysis, and short circuit analysis.
Greater Mekong Subregion Power Market Development: All Business Cases Including the Integrated GMS Case. Final Report. World Bank. February 2019.	The report provides an overview of the current state of power sectors in the greater Mekong countries, in terms of the transmission system, power development plans, and cross-border interconnections and power trade. It identifies a list of candidate cross-border projects; discusses the opportunities and barriers; and evaluates the cost and benefits of 9 sub-regional interfaces and an integrated case where all interfaces are jointly optimized.
Harmonizing Power Systems in the Greater Mekong Subregion: Regional Power Master Plan. ADB. 2020.	Reviewed three separate presentations by Manitoba Hydro International regarding its progress on preparing the master plan report. The presentations include material on study methodology; model development; data requirements and challenges; current and planned cross-border projects considered; different scenarios of generation development considered; and evaluated cross-border developments to identify the most economical and technically feasible transmission scenarios. The actual final report was not available for review.
The Study on Power Network System Master Plan in Lao People's Democratic Republic. Final Report. JICA. February 2020.	The report includes extensive detail on the power sector in Lao PDR, including existing facilities and the supply-demand balance; review of forecasted domestic demand; summary of the power sector plans of all neighboring countries and their power trades with Lao PDR; a review of regional integration efforts and expected power trades; planned expansion of domestic power system and exports; analysis on harmonizing grid codes with neighboring countries; export strategy for Lao PDR; discussions of operational challenges on

	regional power trading and expanding power interchanges; and a list of candidate cross-border projects.
ACMECS Master Plan (2019 – 2023). Concept Document.	The concept document shows actions plans intended to advance three "goals" ("Seamless Connectivity", "Synchronized ACMECS", and "Smart and Sustainable ACMECS"). It lists several priority transmission projects, including those sourced from the Greater Mekong Subregion Regional Investment Framework.

Source: Delphos International

Table 4: Countries Included in Each Study

Countries Included	AIMS III	World Bank	ADB	JICA	ACMECS
Brunei Darussalam	✓	✗	✗	✗	✗
Cambodia	✓	✓	✓	✓	✓
China	✗	✓	✓	✓	✗
Indonesia	✓	✗	✗	✗	✗
Lao PDR	✓	✓	✓	✓	✓
Malaysia	✓	✗	✗	✗	✗
Myanmar	✓	✓	✓	✓	✓
Philippines	✓	✗	✗	✗	✗
Singapore	✓	✗	✗	✗	✗
Thailand	✓	✓	✓	✓	✓
Vietnam	✓	✓	✓	✓	✓

Source: Delphos International

The Greater Mekong Subregion Economic Cooperation Program, Regional Power Trade Coordinating Committee (RPTCC) meetings were important sources of information. The RPTCC comprises officials from the energy departments and ministries of the six GMS states. It convenes stakeholders in periodic meetings, facilitating exchange of information on energy sector plans and projects, as well as providing policy recommendations regarding regional power trade. RPTCC meetings are numbered, and presentations made at each meeting are posted to the RPTCC website. Presentations include country updates on the status of generation and transmission projects, including cross-border interconnections; briefing updates by the ADB and its working groups; and progress updates on technical assistance studies by ADB's consultants (e.g., Manitoba Hydro International and Michel Caubet) or the World Bank's consultants. The following four RPTCC meetings were found to be the most relevant for the present report:

i. RPTCC-24 held in Nay Pyi Taw, Myanmar on June 18-20, 2018;
ii. RPTCC-25 held in Bangkok, Thailand on March 20-22, 2019;
iii. RPTCC-26 held in Hanoi, Vietnam on November 26-27, 2019; and
iv. RPTCC-27 held virtually on October 15, 2020.

Other key documents reviewed for the study included country-level energy sector assessment reports for Lao PDR and Cambodia conducted by the ADB, and ASEAN-focused reports by the International

Energy Agency (IEA) on grid integration of renewables and multilateral power trade. Additional description of these studies as well as the full summary of sources considered for the study are included in the bibliography.

The Delphos Team was introduced by Abt Associates to two organizations that were part of the technical advisory group for AIMS III – the National Renewable Energy Laboratory (NREL) and the Hawaii Natural Energy Institute (HNEI). NREL shared specific feedback it had provided on both the production cost modeling conducted for Phase 1 of AIMS III and the transmission network modeling conducted in Phase 2 regarding mapping and assumptions. HNEI shared high-level feedback on the caveats it would place on the findings of the study due to data limitations.

1.2 KEY TRANSMISSION PLANNING ISSUES

This section provides a high-level summary of integrated resource planning (IRP), with a focus on one of its components, transmission planning, and issues in this area that are most relevant to cross-border integration and VRE integration in a general sense, and more specifically, to the modeling efforts underlying the regional planning studies reviewed in this report. While "plain English" is used where possible, some technical terms are introduced and defined to assist in interpreting remaining sections of this report and the other reports reviewed herein.

1.2.1 INTEGRATED RESOURCE PLANNING (IRP)

IRP embraces planning first at the primary energy level (integrated energy planning) and then at the electric power level (generation and transmission). Integrated energy planning is carried out periodically to identify national energy (e.g., petroleum fuels, natural gas, coal, biomass, hydroelectric/solar/wind, and electric power) sources and needs. IRP energy planning recognizes that electric power production relies on underlying energy inputs, which may require development and coordination at different levels of government, across sectors. For instance, an IRP (energy) might establish the tradeoffs between building more gas-fired generation near gas-fields and bringing the electric power to load centers via transmission or building more gas pipelines that would allow generation to be sited nearer the load centers, reducing the need for transmission. Likewise, IRP energy planning can be important in identifying primary energy constraints that might not otherwise be visible to planners conducting electric power IRP; for instance, if gas-fields in an area are forecast to be near maximum output for any reason, then electric power IRP should reflect that constraint as well so that too many new gas-fired power plants are not assumed to be built.

At the electric power level, integrated resource planning is the process that utilities and power sector policy makers take to develop a rational plan for expansion/improvement of the transmission grid and addition of new generating sources. The process formally addresses the integrated nature of a power system, where relatively small incremental changes (addition of a power plant at a specific location, for instance) can have large systemic effects (positive or negative) across a power grid.

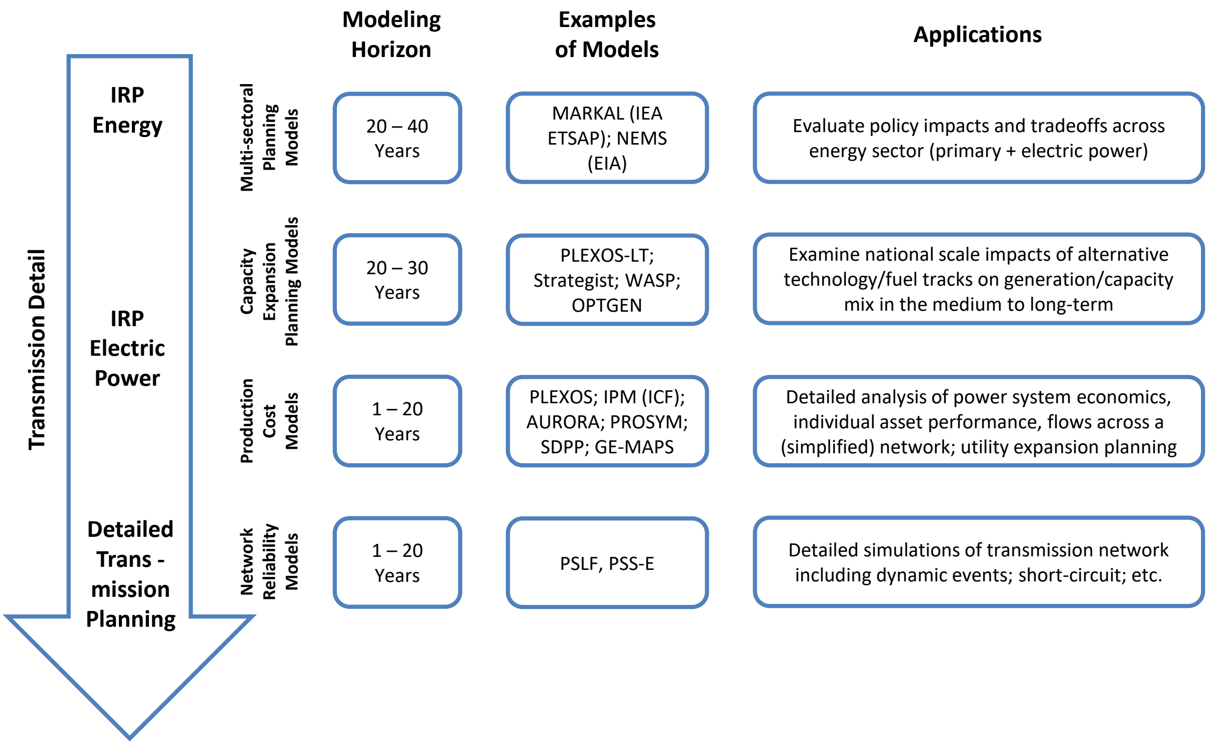
Before explaining what transmission planning is and how it relates to electric power IRP and generation expansion planning, it may be helpful to some readers to define terms. Transmission systems operate at high voltage and connect large power stations (which constitute the bulk of a country's electricity supplies) with medium to large substations (which feed lower voltage transmission lines and distribution systems that in turn feed load, that is, final customers). While there is no fixed definition of the voltage level separating transmission from distribution[27], in general, assets considered to be transmission operate at 69 kV and above and usually at 110 kV and above. This report focuses on lines of 110 kV and above, especially those of 230 kV and above.

Figure 5 shows how different types of planning studies relate to each other and are used. In synopsis:

- IRP (Energy) studies should be conducted every several years, are used primarily in connection with policy development, and may provide relevant input to IRP (Electric Power) studies. Transmission is modeled at a basic level (essentially, as flow gates or "pipes" depicting aggregated regional transfer capacity).
- IRP (Electric Power) studies, which should be conducted annually or at least every other year (with an update in the intervening year), are used to develop power supply and indicative transmission expansion plans. Transmission modeling is considerably more detailed than in IRP (Energy) studies, but not generally sufficient to evaluate and specify transmission asset investments. Note that studies in this category are frequently referred to as capacity expansion plans, least-cost development plans, or power development plans; whatever they are called, they involve both power generation and power transmission components.
- Detailed Transmission Planning studies should be conducted annually and are used to assess short-to-medium term transmission system stability and robustness under a variety of conditions, and to specify the transmission asset investments required for the system. Most key power supply and demand inputs normally would be drawn from the IRP (Electric Power), with validation and adjustments by the team developing the transmission planning model. It is important that the team not simply take for granted the IRP (Electric Power) as inputs, which may be (and tend to be) unrealistically optimistic on the timing of power project online dates and demand growth.

[27] In restructured power markets, the voltage threshold separating transmission from distribution typically is specified in law or regulations.

Figure 5. Relationship of Different Types of Planning



Source: Delphos International

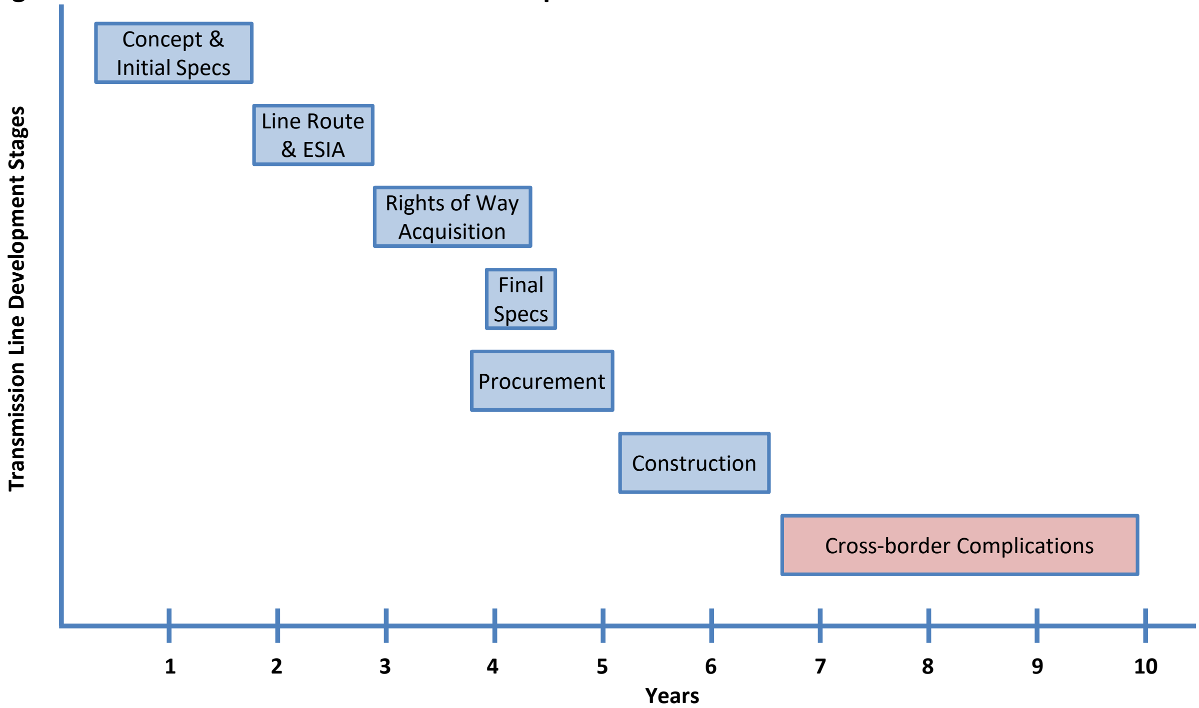
With respect to the transmission planning aspects of the above-mentioned types of studies, the basic tests for transmission system adequacy are: sufficient transmission capacity to meet peak electricity demand without overloading; high reliability; adequate power quality (voltage and frequency within accepted limits and free from harmful distortion); high level of safety for electricity workers and the public; and, supportive of least-cost power supply among a range of alternative transmission configurations and generation supply options. The different types of studies address these issues at different levels of detail (or not at all). For instance, IRP (Energy) studies touch on some of the tests, while detailed transmission planning studies may take the least-cost generation/transmission options test as having been addressed in the IRP (Electric Power).

Returning the focus to transmission planning, these exercises are undertaken with the help of interactive computer models of the power system, which allow simulation of the entire transmission grid, including generators and off-take customer demand.

The model is furnished with data on expected demand (together with its location on the grid) and firm new generation and transmission developments that will be completed within the current planning horizon. The computer programs are interactive and somewhat automated, allowing individual analysis of large numbers of generation/demand scenarios and contingency events. The behavior of the system is reported by the program and the system planner must identify where exceptions occur, such as transmission line overloads or operating voltage outside allowable limits. The transmission planner then evaluates solutions to resolve the underlying exceptions, which might involve asset investments or other types of solutions, such as that specific generating plants operate in grid-support mode, rather than providing power based solely on the position of those plants in the merit order of dispatch.

The process of getting from a transmission plan to a significant completed transmission line on the ground is lengthy, particularly when the project crosses national borders, as outlined in Figure 6, below. In this stylized example, the transmission plan would include the project's concept and basic specifications, which would need to be approved for funding by some entity (e.g., a utility, perhaps with donor support). Additional studies would then need to be performed, including a line routing study and an associated environmental and social impact assessment (ESIA). ESIA's for major transmission line projects (especially those receiving donor support) require six months to a year to produce; approval processes by environmental authorities can add another several months to a year. Once the project has been fully approved at the technical/economic and ESIA levels, the process of acquiring rights of way for the project can begin. Depending on the country's laws regarding eminent domain, it can take months to years to acquire rights of way. Development of final specifications and procurement can proceed in parallel to later stages of the rights of way acquisition. Construction could take six months to a year or two. All told, significant national-level transmission projects are unlikely to be built sooner than 4-7 years after conception. Significant cross-border projects face additional complications, such as having to approve the project at all stages under two separate regulatory regimes, addressing grid integration issues if the project is grid-to-grid, then having to coordinate rights of way acquisition, procurement, and construction across frontiers.

Figure 6. Indicative Transmission Line Development Timeline



Source: Delphos International

In Figure 6, the indicative timeline for a significant cross border transmission project stretches to ten years. There are two scenarios that could involve shorter timelines (perhaps as few as four to seven years):

- Generator-to-Grid projects, wherein a power project (almost always an IPP) in one country sells under a power purchase agreement (PPA) to a buyer in another country (see discussion in the following section), particularly once there are pre-existing models for how this would be done across the two countries. The numerous IPP-to-grid projects in Lao PDR selling into Vietnam, Cambodia and Thailand demonstrate that having a blazed trail to follow can dramatically reduce development timelines.
- Lower voltage projects over relatively short distances. A 115 kV or 230 kV project of under 50 km connecting existing substations and using mainly existing rights of way is a fundamentally different project than a 500 kV project running several hundred kilometers that would require a major rights of way acquisition.

1.2.2 DIFFERENT TYPES OF TRANSMISSION CONNECTIONS

Regional power market integration depends, in the first instance, on the physical interconnection of different national power systems. There are multiple types of transmission interconnection projects that are relevant in this context, as depicted in Figure 7, and summarized below. In the figure, dashed lines indicate the project in question and color indicates dispatch control. “G” represents generators and “L” represents load.[28]

- **Internal Grid:** A transmission line connects two parts of an existing transmission system, for instance from one line to another to a substation. Such lines may be relevant to regional integration if, for instance, the internal grid project would be required to support cross-border transmission projects.
- **Grid to Grid:** A transmission line connects two distinct power systems. This type of connection requires a high level of coordination and trust between the two grid operators since grid instability in one grid can cause problems on the other grid via the interconnection.
- **Generator to Foreign Grid:** A power project, typically an IPP, located in one power system connects directly to the power grid of another system. There are numerous examples of this type of power-plus-transmission project in the GMS, especially IPPs in Lao PDR selling into Thailand, Vietnam, and Cambodia. It is important to understand that, because the importing power system dispatches the power plant and operates its transmission facilities, these projects are, in almost all relevant operational senses, located within the importing power system, even though the power plant itself is located in a foreign country. Note that some “generator to foreign grid” projects are also interconnected with the domestic grid (that is, the exporting grid); nonetheless, there is no grid-to-grid connection. Rather, specific generating units at the power plant (under foreign dispatch control) will be dedicated to and physically connected to the export transmission line, while other generating units (under domestic dispatch control) will be dedicated to and physically connected to the domestic grid.
- **Grid to Isolated Load:** Similar to “generator to foreign grid” projects, in this case, a significant load in one system that is isolated (or “islanded”) from the rest of that system, is

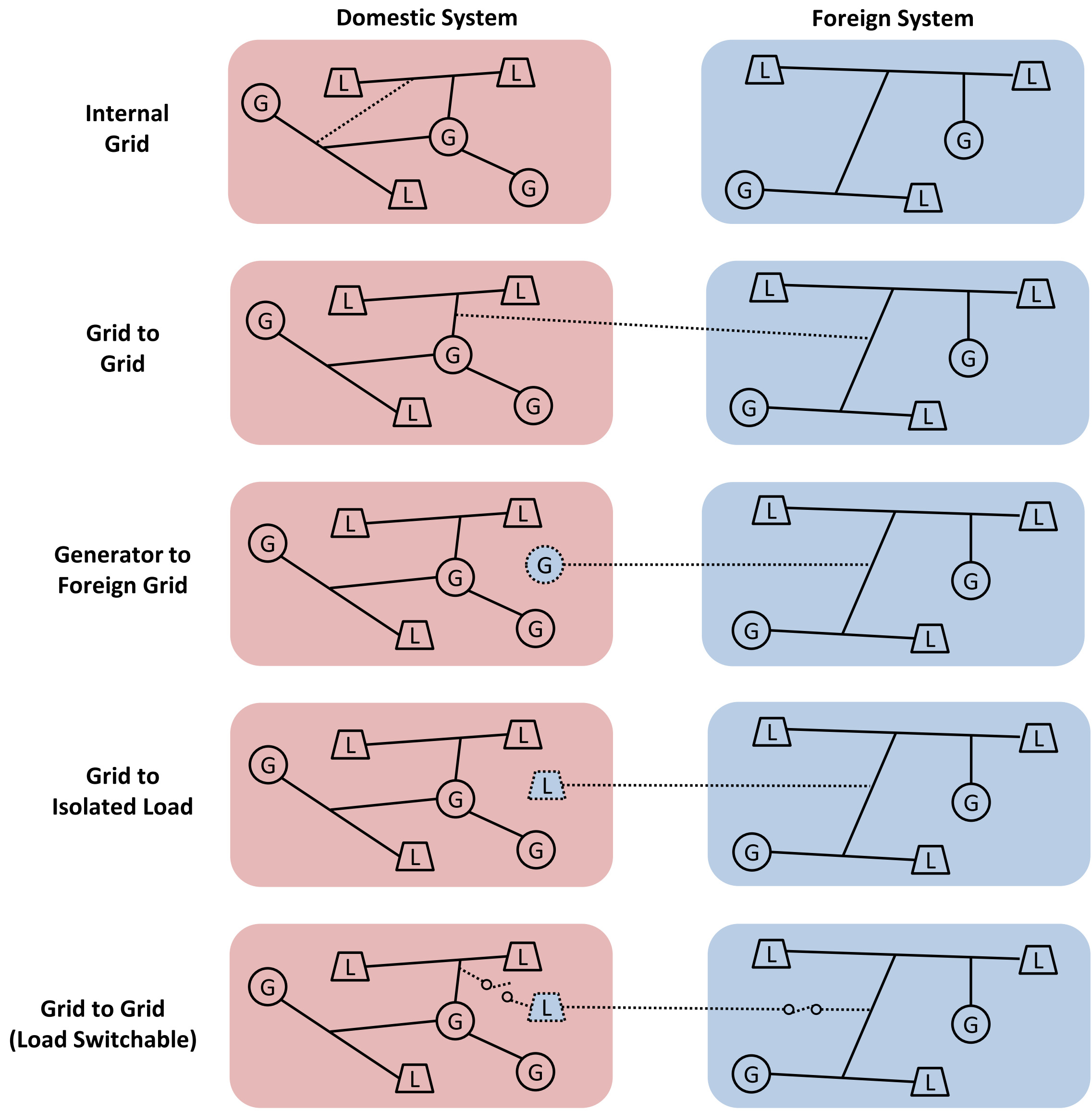
[28] Substations that might allow interconnection of other projects are assumed at G and L locations, as appropriate.

interconnected to a foreign power system. In nearly all operational senses, this load is indistinguishable from other load on the exporting system's grid. There are numerous sub-transmission/distribution projects of this nature throughout the GMS, and several higher voltage (transmission) projects as well.

- **Grid to Grid (Load Switchable):** In this arrangement, two grids are physically connected but separated by switching facilities that allow service to a load area to be provided by either of the two grids (but not by both simultaneously, which would require grid synchronization).

There are variations on the project types summarized above, including "domestic generator to internal isolated load" and (much more common) "domestic generator plus transmission to domestic grid", where the transmission tie-in is *via* a purpose-built transmission line that is not usable by other load or generation on the system.

Figure 7. Main Types of Interconnections



Source: Delphos International

1.2.3 VRE INTEGRATION

Most electric transmission systems are based around conventional generators like hydropower plants and thermal power plants providing the bulk of power supply. VRE generators like wind and solar plants differ from conventional power plants in ways that can create challenges for reliable grid operations, especially as the penetration levels of VRE increase. Wind and solar resources can fluctuate significantly within minutes, leading to sudden increases and decreases in generation injected into the grid. VRE generators are also inverter based, which creates technical differences in how they interact with the grid relative to conventional power plants.[29] These differences can create reliability problems on the grid if not managed through the necessary transmission infrastructure and grid code adjustments to establish technical requirements.

A key attribute of the infrastructure necessary to integrate VRE is flexibility. This can be provided by other generators, in the form of fast-ramping plants that can rapidly increase or decrease output in response to changes in generation from VRE plants. The transmission system can also provide the necessary flexibility if it has robust networks, advanced equipment, and the appropriate protection schemes.

At the national level, strong transmission networks connecting generators or regions with excess supply to load centers help to keep the grid balanced even when there are minor disturbances. VRE plants tend to be located far from major load centers where the grid infrastructure may not be as robust. A strong transmission network with excess capacity would allow generation from elsewhere to be redirected in response to fluctuating output from VRE plants or other inverter-related power quality challenges. Transmission equipment like Automatic Generation Control (AGC), Flexible Alternating Current Transmission System (FACTS), shunt reactors, and capacitor banks also help maintain voltage control to accommodate VRE generation. Furthermore, advanced communication equipment enables real-time monitoring and response by grid operators to immediately identify and resolve potential issues. The emerging use of battery storage and demand response at the transmission level will further support VRE integration.

Cross-border interconnections can similarly support VRE integration by expanding geographic diversification – short-term (minute-to-minute) issues related to VRE are less likely to be correlated across broader geographic areas. Such grid ties add additional transmission capacity that is available to respond to variability from VRE, allowing excess VRE from one region to be exported to a load center or enabling imports to compensate for underproduction by VRE. In the Lower Mekong context, cross-border interconnections between a weaker grid (Lao PDR, Myanmar, and Cambodia) and a stronger grid (Thailand or Vietnam) can make the weaker grid more robust and able to integrate VRE in its domestic system; on the other hand, the connection may expose the stronger grid to ongoing operational challenges.

[29] A few important challenges with inverter-based generation are: (i) lack of rotating mass/inertia; (ii) fault circuit contribution; (iii) power quality; and (iv) voltage support. NB: there are some synchronous wind generators, though low inertia remains an issue.

However, cross-border ties do not automatically yield these benefits. If a weak grid adds VRE without internal mitigation, it may reduce the willingness of a neighboring grid operator to accede to interconnection due to reliability concerns. It could also make it more costly for the country with a stronger grid to add VRE of its own.

VRE resources enjoy customary “priority of dispatch” on the generation merit order stack. This is because the energy VREs produce cannot be stored (without additional investment in storage systems) and must be dispatched (or curtailed) whenever it is available. As VRE penetration has increased, dispatch priority for VRE has created technical problems that grid planners are currently trying to address.

- Conventional base-load generation is increasingly being caught behind transmission constraints or are pushed out by VRE such as solar or wind, which enjoy priority of dispatch. This can reduce their profitability and force retirements, creating additional voltage and frequency control problems for grid operators.
- Inverter-based VRE plants lack mechanical rotational inertia, which is an attribute provided by conventional generators. This means that there is a heightened risk of grid instability at times of light load and high VRE penetration. Currently, the only solution is to curtail output of VREs in favor of conventional power plants in such situations.
- VREs are individually, relatively small capacity and distributed over a wide area compared with conventional power sources. VREs supply energy to the power system through power electronic conversion (PEC) as distinct from conventional generators which use electromagnetic conversion. These differences multiply complexity, and place a significant burden on grid planners, who must plan the system in ways that ensure controllability under all system contingency events, and access to “black start” rapid restoration facilities to cater for the inevitable events when the power system will fail and need to be restarted.

These are currently, unsolved planning problems that can create disincentives to promoting high penetration of VERs.

Cross-border grid-to-grid IPPs are extremely rare internationally for reasons including: (i) challenges in securing consensus among both domestic and international stakeholders due to wider system impacts; (ii) gaps in technical and regulatory harmonization that create reliability challenges; (iii) the need to establish mutually agreeable frameworks to allocate cost/benefits as well as to incorporate impacts of local economic development or national environmental policies; (iv) the need for regional oversight bodies with sufficient authority . Cross-border IPP-to-grid interconnections are relatively common with plenty of such examples in the region, but the generation technology matters. The Delphos Team is aware of no such VRE projects dedicated to exports anywhere.

1.2.4 PLANNING IN A REGIONAL CONTEXT

Planning cross-border transmission projects differs in important aspects from national or utility-scale planning. There are unique considerations, impulses, and process complications; in general, it is just more difficult, as outlined below.

- For national expansion planning, the architecture of analysis, financing and execution is organized around national aims, funding mechanisms and procurement processes. Thus, the need for a given project is justified in terms of the value it adds to that power system; once the project's justification is established, funding for the project is allocated by the utility (and, as the case may be, approved by the regulator), and then the project is procured through ordinary channels. By contrast, for a cross border grid-to-grid project, a separate set of analyses - often performed by third parties – is necessary to establish the value of the project for both parties. The national utilities would then separately need to gain comfort about the technical impacts of the project on their own systems. Identification of funding for the project, and a decision to proceed, would hinge on both national authorities agreeing to proceed: after all, neither side would want to build a line to the border without the connecting line to meet it on the other side.

- Inevitably, there are legal and dispute resolution questions that arise for cross-border projects that do not exist for national projects[30]. For instance, mechanisms for addressing delays to completion once notice to proceed has been given, imbalance flows on the line, unavailability (or unilateral opening of a circuit), poor power quality, and so on, must be negotiated.

- There are additional dimensions of technical complexity for cross-border grid-to-grid projects. At the national (or utility) level, there is usually a single power grid, which is centrally controlled. When a cross border grid-to-grid project is being planned, among the first issues to address is whether the project is HVAC or HVDC[31] technology. If the project is to be the first cross border grid-to-grid project between the two countries, then the technological question is bound up with the broader question of whether the two countries desire to synchronize their grids (using HVAC) or not. Grid synchronization requires significantly more operational compatibility and trust between the two systems and their operators than operating asynchronously. It is important to understand that the two systems do not require a full, common, grid code to interconnect grid-to-grid (whether synchronously or not) but they do require agreement on all relevant operational aspects related specifically to that project.

- Assuming a project has been demonstrated to have economic value and to be technically viable, commercial arrangements must be agreed. One approach, common when both sides agree on the likely direction of flows, is to package the line with a PPA or a similar agreement. Such agreements are complicated to negotiate; in this scenario, negotiations would involve commercial teams from each utility, who would normally only be involved with power projects not transmission lines and interactions with a different utility. Another approach is to use the line for opportunity trade, in which case each utility would post its buy/sell quantity/price offers periodically and a matching algorithm would nominate flows. One can imagine that each side would like to have comfort that the other side is not taking most of the benefits in each trade, which requires a degree of transparency regarding national system operating costs or as a fallback, indexation provisions, usually to a basket of oil and gas prices. Within the GMS, there is practically zero system cost transparency, suggesting that price indexation

[30] One of the basic challenges is deciding on the law under which an agreement would be documented, since neither country would be comfortable with the law of the other country governing. Similarly, for dispute resolution, processes would need to be carefully crafted so that technical disagreements do not evolve into major bilateral political challenges.

[31] Another option to HVDC is HVAC with an AC/DC/AC back-to-back element.

would be necessary. A third and suboptimal approach is to maintain a power trade account and for the utilities to swap power within specific periods. For instance, Utility A could provide 900 MWh on Day 1 and Utility B could provide 900 MWh on Day 2 as a reverse flow.

- Given the challenges mentioned above, grid-to-grid cross-border projects are usually conceived and advanced as bilateral integration initiatives at the executive or ministerial level. That is, national leadership directs the respective utilities to move forward on a given project; the impulse to interconnect is therefore as much political and policy-oriented as it is technical/economic. National-level projects usually are evaluated in a much narrower context.

2. REGIONAL CONTEXT

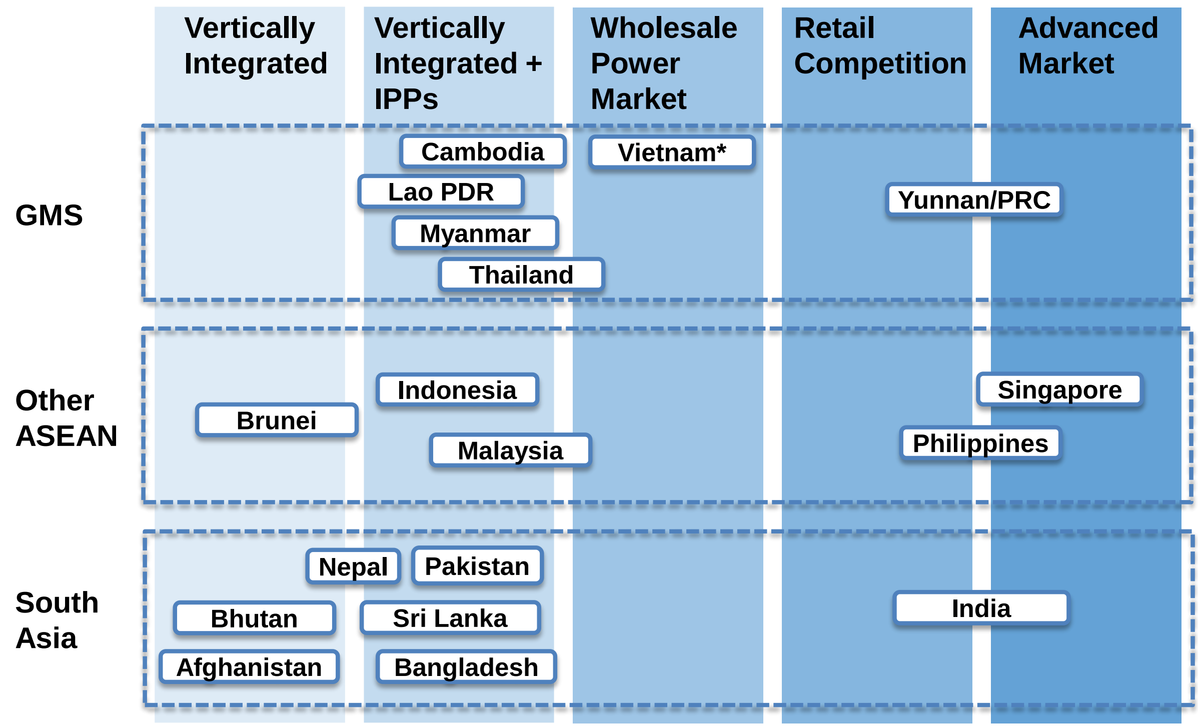
The following two subsections provide overviews of the six markets in the GMS (Cambodia, Lao PDR, Myanmar, Thailand, Vietnam and Yunnan/China) and a brief history of regional integration efforts. It is important to note that GMS-focused studies and models omit adjacent markets in Malaysia and Singapore, despite the participation of both countries in the region's only multilateral power trade framework to date. Likewise, ASEAN-focused studies like AIMS III do not include China's Yunnan province even though the province is already interconnected to Lao PDR, Vietnam, and Myanmar, with plans to expand such connections. While the section focuses on the Lower Mekong countries plus Yunnan, current and potential trading opportunities with Malaysia and Singapore are also considered.

2.1 MARKET OVERVIEWS

2.1.1 SUMMARY OF REGIONAL MARKETS

While the present report focuses on the LMS (and more broadly, the GMS), it is useful to understand how regional market structures compare with one another and with other markets elsewhere in ASEAN and Asia. To this end, Figure 8 depicts regional market structures on a continuum of market development, ranging from traditional vertically integrated utilities to advanced markets featuring independent regulatory and system operators; private participation across the electricity sector value chain; a wholesale power market and/or exchanges where energy and other products (e.g., ancillary services, firm capacity, forwards, etcetera) are traded; and vibrant retail competition.

Figure 8. Market Types in the Region



Source: Delphos International

** Vietnam is in the process of implementing a significant market restructuring.*

As can be seen in the figure[32], most countries in the GMS, other than Yunnan/PRC, are at relatively early stages of market restructuring. Vietnam is currently implementing important market design changes that will result in a more advanced market. Within ASEAN, the country that would constitute the most natural trading partner for GMS/LMS countries, given a shared border with the LMS - Malaysia - is at a similar level of market development as the less developed GMS markets. Singapore, who could be accessed via wheeling through Malaysia, is advanced.

While numerous other factors are relevant to expanding power trade in the region, market size, capacity mix, and grid control are at the forefront, as summarized in Table 5.

Table 5. Market Attributes in the GMS

Item	Cambodia	Myanmar	Lao PDR	Thailand	Vietnam	Yunnan (PRC)
Population, millions	16.5	54.0	7.2	69.6	96.5	48.6
GDP, $ billions	27.1	76.1	18.2	543.5	261.9	347.1
GDP/Capita, $000s	1.6	1.4	2.5	7.8	2.7	7.1
Electrification Rate	91.6%	66.3%	97.9%	100.0%	100.0%	100.0%
System Operations & Grid Control	Weak	Weak	Weak	Strong	Strong	Strong
Peak Demand, MW	1,530	4,493	1,604	32,732	41,332	52,000
Installed Capacity, MW	2,256	5,257	5,506	50,489	57,873	92,455
Hydro, MW	*1,363*	*2,841*	*5,290*	*7,958*	*21,351*	*66,584*
Gas, MW	*43*	*2,231*	*0*	*32,562*	*7,593*	*0*
VRE, MW	*0*	*40*	*100*	*2,761*	*6,012*	*11,872*
Coal, HFO & Diesel, MW	*850*	*145*	*92*	*6,479*	*22,863*	*13,999*
Biomass, MW	*0*	*0*	*24*	*729*	*54*	*0*

Source: Delphos International. Sources for values (from 2019): Population, GDP, electrification rates from World Bank for all except Yunnan (from Statista). GDP/Capita was calculated from underlying values. System Operations and Grid Control based on numerous sources and Delphos Team knowledge. Sources for values for (i) LMS countries (2020 values): demand and capacity mix were taken from "Load – Generation" tables the LMS for 2020 in the AIMS III Phase II Preliminary Report, and (ii) for Yunnan (2018 values): China Trading Power research paper.

Observations from the table are presented below.

- There are three small markets (Cambodia, Lao PDR and Myanmar) and three large markets (Vietnam, Thailand and Yunnan). The large markets are each at least 10 times larger than the smaller markets on both capacity and demand bases. Moreover, as discussed in Section 2.1.7 Yunnan Snapshot, Yunnan is not the relevant counterpart market on the Chinese side, from the perspective of power trade. Rather, the relevant market is the market served by China Southern Power Grid Co, which operates the grid in five provinces (including Yunnan) and by any measure, would be one of the largest power markets in the world. More generally, the

[32] The figure is intended to help orient the reader as to the relative level of market development; it is not intended to represent a complete taxonomy of regional markets. There are numerous variations on market structure within each of the columns, and there are entire market structural types (such as "single buyer" structures) that could fit between the existing columns and might apply to some of the markets. With respect to "vertical integration", the focus is on the vertical integration by government-controlled entities (even if partially unbundled, such as by corporatization and sale of a minority stake to private investors) across the three main sectoral functions: generation, transmission, and distribution.

relevant counterpart market is China (writ large), in the sense that Southern Power Grid Co's international trade development efforts align with (or are identical with) relevant portions of the Belt and Road Initiative[33].

- Systems Operations & Grid Control are weak in the small markets and strong in the large markets. For instance, in each of the three small markets, there is incomplete visibility as to grid conditions such that local conditions on parts of the HV grid are not visible at the national dispatch center but are relayed by telephone from manned substations. Also, in each, there is insufficient fast regulation capacity (or controls to implement it, such as AGC). As a result, in Myanmar, there are persistent failures to maintain frequency and voltage within normal operating limits, and in Lao PDR and Cambodia, grid control is carried out in large part by the markets they are synchronized with, Thailand and Vietnam, respectively.

- Hydropower plays the dominant role in all markets except for Thailand and Vietnam.

- At first glance capacity reserve margins would seem to suggest ample-to-excess generating capacity across the region. Some caveats must be provided.

    - Capacity mix values for LMS countries are from the AIMS III Phase II preliminary report. It was not clear in all instances how the authors of that report attributed capacity supplied to or from another country by PPA (there are numerous IPP-to-foreign grid projects in the region).

    - Myanmar's gas supply is highly constrained, permitting little more than 1,000 MW of the country's over-2,000 MW of gas-fired capacity to run at any time.

    - Hydro-dominated markets in general require much higher capacity reserve margins (30% - 50%) than thermal systems (10% - 15%) to provide the same level of security of supply, given the need to insure against the impacts of prolonged droughts. Relatedly, there may tend to be increased need for non-hydro supply during the dry season of both average and drought years.

    - Static annual values for capacity reserve margins do not capture the impacts of demand growth, which has been and is expected to remain high in the small markets.

    - Reflecting the factors enumerated above, Myanmar and Cambodia face ongoing capacity shortages; Lao PDR is generally long on generating capacity but tends to require expensive thermal imports from Thailand during the dry season; Thailand is substantially long on capacity and actively seeking export opportunities; and,Cambodia and Vietnam are actively seeking imports.

[33] See discussion in section 2.1.7.

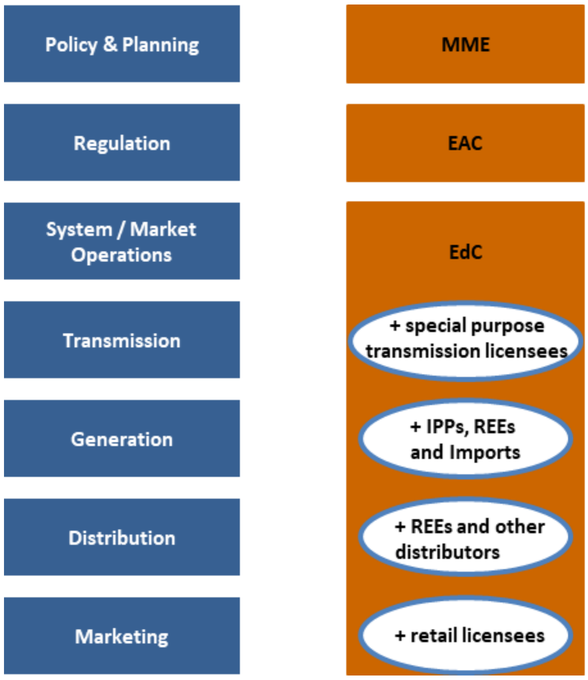
2.1.2 CAMBODIA SNAPSHOT

2.1.2.1 POWER SECTOR OVERVIEW

Cambodia's power sector is governed by the Ministry of Mines and Energy (MME), through the Department of Energy Development (energy and electricity planning), the Department of Energy Technology (technical standards, non-hydro renewables, and energy efficiency), and the Hydropower Department. The Ministry formulates energy policies and strategies, power development plans, and establishes technical and environmental standards. The Electricity Authority of Cambodia (EAC) is the industry regulator, responsible for issuing licenses and regulations, reviewing and approving tariffs, and other activities concerning oversight of the sector.

Électricité du Cambodge (EdC), the state-owned utility, is responsible for generation supply, most of the transmission sector, and part of the distribution sector. EdC owns some generation, purchases power from Independent Power Producers (IPPs) and imports power from neighboring countries. IPPs and other generation licensees supplied 97% of Cambodia's domestic electricity generation in 2019.[34] Some transmission facilities are owned and operated by IPPs or electricity distributors with Special Purpose Transmission Licenses. EdC is responsible for distribution in the capital region and in some of the provinces, with the rest of the country managed by the Rural Energy Enterprises (REE) and other distribution licensees. IPPs also may sell to REE or, in some cases, directly to rural consumers. Some private companies also are licensed to purchase electricity from the Provincial Electricity Authority of Thailand to supply rural areas near the Thailand-Cambodia border.[35] Figure 9 summarizes the power sector structure.

Figure 9. Cambodia Power Sector Overview

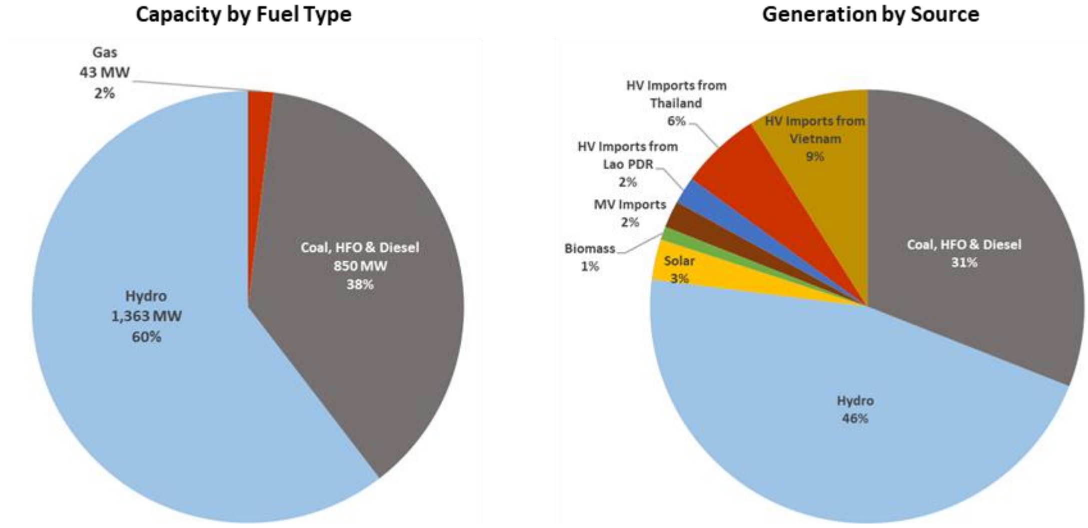


[34] "Report on Power Sector of the Kingdom of Cambodia. 2020 Edition." Electricity Authority of Cambodia. 2020.
[35] *Ibid.*

2.1.2.2 POWER SUPPLY – CURRENT SITUATION

Hydropower is the dominant source of electricity in Cambodia, comprising 60% of installed capacity and 46% of generation in 2019, followed by coal (38% of capacity and 22% of generation). The balance is sourced mostly from imports and diesel-fueled plants, with only a small share of generation supplied by non-hydro renewables, as shown in Figure 10.

Figure 10. Capacity and Energy Mix in Cambodia



Source: Delphos International. Data from "AIMS III Preliminary Phase II Report" for capacity and Cambodia country presentation at RPTCC-26.[36]

Cambodia's power supply plans continue to rely on additional coal-fired, hydro, and imported capacity, complemented by limited efforts to expand levels of VRE. Figure 11 below lists the country's planned supply additions as presented during the 26th Regional Power Trade Coordination Committee (RPTCC-26) meeting in November 2019. Some of these expected new generation sources are already delayed due to the COVID-19 pandemic and other issues.

Figure 11. Planned Capacity Additions in Cambodia

Future Generation Source	Capacity (MW)	Expected Timeline
CEL II – coal	135	End of 2019
EdC – HFO/LNG	400	2020
Hydro import from Lao PDR	700	2020-2023
Oddor Meanchey – coal	200	2021-2022
Solar Park	340	2020-2022
New coal	1400	2022-2025
Renewable park – solar, wind, biomass	580	2022-2030
Domestic hydro	2600	2023-2030
New LNG/CCGT	4800	2027-2030
Coal import from Lao PDR	2400	2024-2027
Potential import from Thailand (230 kV)	300-600	2022-2027

[36] According to RPTCC 26, the mix (as of November 2019) was somewhat different than the more aggregated values in the AIMS III report for 2020: Fuel oil (200 MW); Hydro (1,330 MW); Coal (505 MW); Solar (85 MW); and HV imports: (450 MW).

Source: Cambodia country presentation at RPTCC-26.

EdC also signed three separate PPAs on September 12, 2019: 500 MW with Électricité du Laos; 600 MW with TSBP Sekong Power and Mineral Company; and 1,800 MW with Xekong Thermal Power Plant Company.[37] In 2019, the ADB supported an EdC auction for 60 MW of solar PV capacity that yielded a tariff of 3.9 US cents/kWh. Bids for a follow-on auction for an additional 40 MW were accepted in March 2021, and the auction was still being adjudicated with ADB support as of the date of the present report.

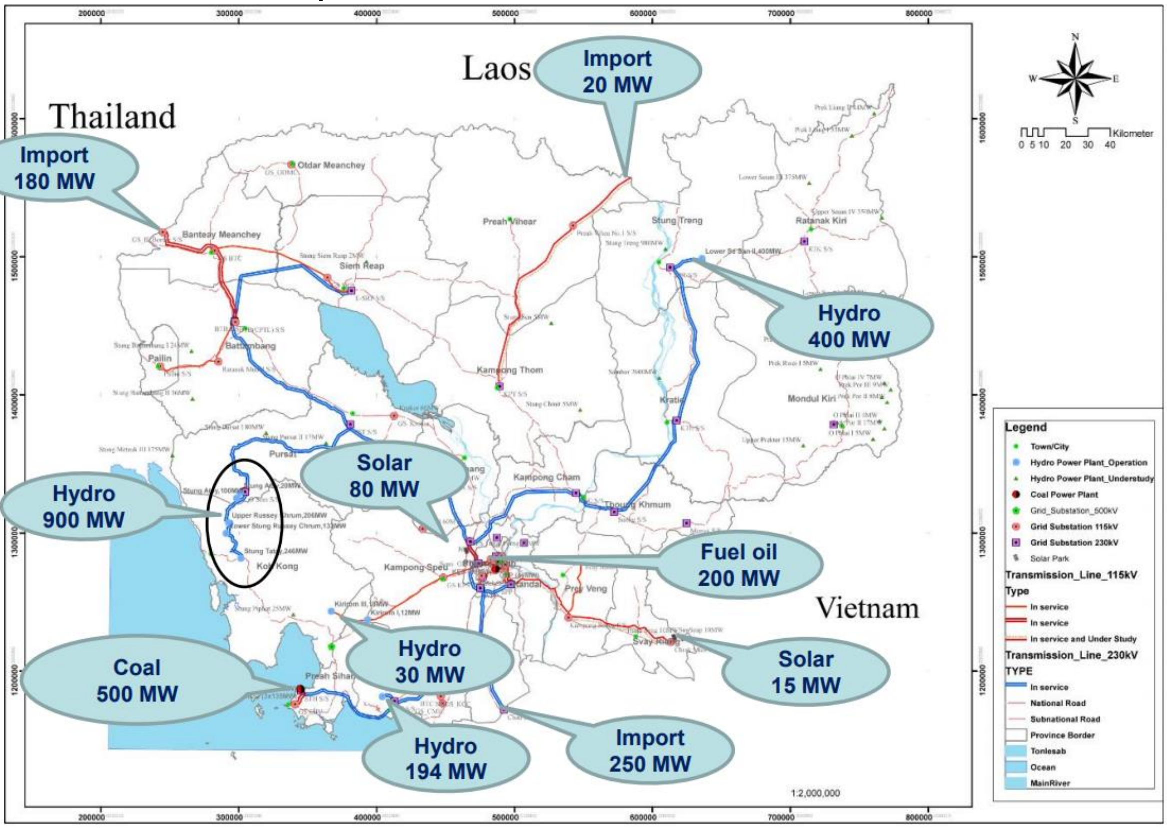
2.1.2.3 TRANSMISSION GRID OVERVIEW

The transmission network in Cambodia consists of 2,249 km of high-voltage lines rated at 230 kV and 115 kV.[38] The lines connect the primary load center in the Phnom Penh area with power plants and imports, as indicated in Figure 12. A 230 kV grid-to-grid line also synchronously interconnects Cambodia's grid with Vietnam, and two 115 kV grid-to-grid (load switchable) lines connect to Thailand and Lao PDR.

The national grid supplies electricity to 23 out of 25 provinces: transmission voltage substations exist in 19 provinces, from which supply is further extended; two provinces are supplied by private licensees.[39] Medium-voltage (22 kV) sub-transmission lines supply electricity to local distribution licensees. REEs supply customers in rural areas through distribution mini-grids, many of which are now also connected to the national grid.[40]

[37] RTPCC-216. Cambodia country presentation.
[38] EAC 2020.
[39] "Cambodia Energy Sector Assessment, Strategy, and Road Map." ADB. December 2018.
[40] As of 2018, over 99% of electricity consumers were reported to be connected to the national grid. Source: *Ibid*., page 19.

Figure 12. Cambodia Grid Map - 2019



Source: Cambodia country presentation at RPTCC-26.

Cambodia's 2015 Power Development Plan (PDP) included plans for over 300 km of 500 kV transmission lines[41] linking Phnom Penh with distant generators or import sources, the first of which was completed in 2020.[42] EdC is also seeking to increase cross-border interconnections with neighboring countries (IPP-to-grid with Lao PDR, grid-to-grid with Thailand and Vietnam) to expand import transmission and distribution voltage projects, as outlined below.[43]

- Thailand
  - Current: seven 22 kV, one 115 kV.
  - Planned/Requested: seven 22 kV and 35 kV.
- Vietnam
  - Current: nineteen 22 kV and 35 kV, one 230 kV.
  - Planned/Requested: three 22 kV and 35 kV.
- Lao PDR
  - Current: two 22 kV, one 115 kV, one 230 kV.
  - Planned/Requested: 500 kV upgrade to the 230 kV line in progress.[44]

In summary, based on various sources cited in this report, including the excerpt below from the EAC 2019 Annual Report, the national grid is connected synchronously to Vietnam via a 230 kV line, as well

[41] ADB 2018. Cambodia Energy Sector ASR.
[42] Electricity Authority of Cambodia. Annual Report 2019. Page 26.
[43] RPTCC-26. Cambodia Country Presentation.
[44] Kmer Times (the listed "writer), "Laos links 195MW power to Cambodia", *Bangkok Post*, January 8, 2020.

as to Thailand and Lao PDR via 115 kV lines (and distribution-level connections as well). The links to Thailand and Lao PDR are grid-to-grid (load switchable), such that sometimes, portions of the Cambodia grid are served by Thailand and Lao PDR (at which times those areas are synchronized with Thailand/Lao PDR) and at other times, those portions of the Cambodia grid are served by resources on the Cambodia grid, including imports from Vietnam (at which times those areas are synchronized with Vietnam).

> *"During 2019, apart from generation plants in Cambodia, the National Grid gets electricity supply from Vietnam at 230 kV, from Thailand at 115kV and from Laos at 115kV. It is not possible to run the supply from Vietnam, Thailand or Laos in parallel with each other, and hence the grid network supplied from each supply is operated as an system isolated from each other. Depending on the generation in Cambodia, the area supplied from each system above is decided and changed. During rainy season, the generation from Hydropower stations in Cambodia increases, and the import from Thailand is reduced or discontinued. During dry season supply from Thailand is increased and more area is supplied from this system. By end of 2019, supply from National Grid covers areas in all provinces except Mondulkiri Province.*[45]

2.1.2.4 LONG-TERM SYSTEM PLANNING

Integrated expansion planning in Cambodia is infrequent. The Ministry of Mines and Energy first prepared a PDP in 2007 for 2008 to 2020, which was updated in 2015 for 2015 to 2030. The PDP includes planned expansion of supply sources and transmission networks. The current energy policy objectives are set in the National Strategic Development Plan for 2019-2023. Power development plans are said to potentially reflect "unsolicited bids and business-to-business arrangements for new power generation, primarily from hydropower and coal."[46] A comprehensive strategy for the energy sector with more frequent updates to the PDP to reflect latest costs of new technologies would support more efficient development.

2.1.2.5 GRID CODE OVERVIEW

Cambodia's current grid code, issued by EAC in May 2009, remains the most recent technical manual providing guidelines around power system operations. Through JICA's technical assistance, the "Specific Requirements of Electric Power Technical Standards (SREPTS) on Thermal Generation, Transmission, Substation and Distribution" was prepared between 2004 and 2007 and promulgated as regulation in July 2007; likewise, an SREPTS on Hydropower was also prepared between 2008 and 2009 and promulgated as regulation in 2010.[47] EAC issued further regulations for connecting solar PV plants to the grid in January 2018, which includes process and technical rules regarding interconnection as well as certain operational restrictions.[48]

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[45] Electricity Authority of Cambodia. Annual Report 2019. Page 27.
[46] RPTCC-26. Cambodia Country Presentation.
[47] "Preparatory Survey for Phnom Penh City Transmission and Distribution System Expansion Project Phase II in the Kingdom of Cambodia – Final Report." JICA. December 2014.
[48] Regulations on General Conditions for connecting Solar PV Generation sources to the Electricity Supply System of National Grid or to the Electrical System of a Consumer connected to the Electricity Supply System of National Grid.

The 2009 grid code document includes provisions for ancillary services; in practice however, EdC implicitly relies on the Vietnam grid, to which it is synchronously interconnected, to provide frequency response.[49]

With regards to cross-border trade, the 2009 grid code includes this reference to external interconnections regarding scheduling and dispatch:[50]

> *5.4.2 External Interconnectors: External Interconnectors shall provide the hourly MW and MVAr export and import or agreed availability for the next day to the Control Center by 10.00 hrs on each day. In the event of no intimation from an External Interconnector, the Control Center shall make an estimate of the export and import.*

2.1.2.6 APPROACH TO REGIONAL INTEGRATION

Cambodia imports power from all its neighbors. While the plans for additional domestic capacity from coal, hydro, and gas reflect a desire to reduce reliance on imports, Cambodia also plans to increase cross-border interconnections for further imports, as described above. In particular, Cambodia is planning to increase imports of hydro generation from Lao PDR. If plans to expand domestic generation capacity are not realized, current plans to increase imports may underestimate the levels required to meet expected growth in demand.

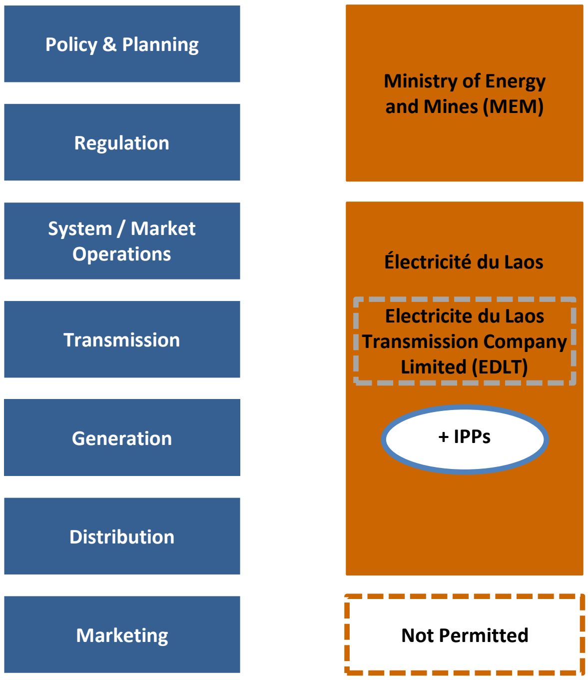
2.1.3 LAO PDR SNAPSHOT

2.1.3.1 POWER SECTOR OVERVIEW

Lao PDR's power sector is regulated by the Ministry of Energy and Mines, primarily through its Department of Energy Policy and Planning (responsible for formulating national energy policy and plans, including strategic plans for generation, transmission, renewable energy and energy exports) and its Department of Energy Management (drafting energy-related laws and regulations, compliance monitoring). Figure 13 summarizes the power sector structure.

[49] "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map." ADB. November 2019. See footnote 75 of the referenced source. Also see footnote 10 of the present Delphos report.
[50] Grid Code. Electricity Authority of Cambodia. May 2009.

Figure 13. Lao PDR Power Sector Overview



State-owned Électricité du Laos (EDL) is the vertically integrated utility covering generation, transmission, and distribution functions, as well as acting as the single buyer for wholesale energy. IPPs (some with EDL-affiliates as minority shareholders) sell to EDL as well as under PPAs to foreign buyers.[51] There are nuances to the "vertically integrated utility" designation for EDL given its partial unbundling and recent developments. The entity owns a majority stake in its subsidiary, EDL-Generation, and given this controlling stake, EDL-Generation is not broken out separately in the figure above. And, in September 2020, EDL sold a majority stake in a newly created transmission company - Electricite du Laos Transmission Company Limited (EDLT) - to China Southern Power Grid Co. While the agreement apparently involves buyback options that would allow EDL to recover its control of the transmission entity, the details are unclear. It appears that as long as China Southern retains its major stake, it would serve as the country's power grid operator and invest in, construct and operate the 230 kV-and-above power grids in Laos and implement grid interconnection projects between Laos and its neighboring countries.[52] In the figure above, EDLT is depicted as not fully separated from EDL, given the buy-back options (though the details of these options and the ability of Lao PDR government to execute them is unknown).

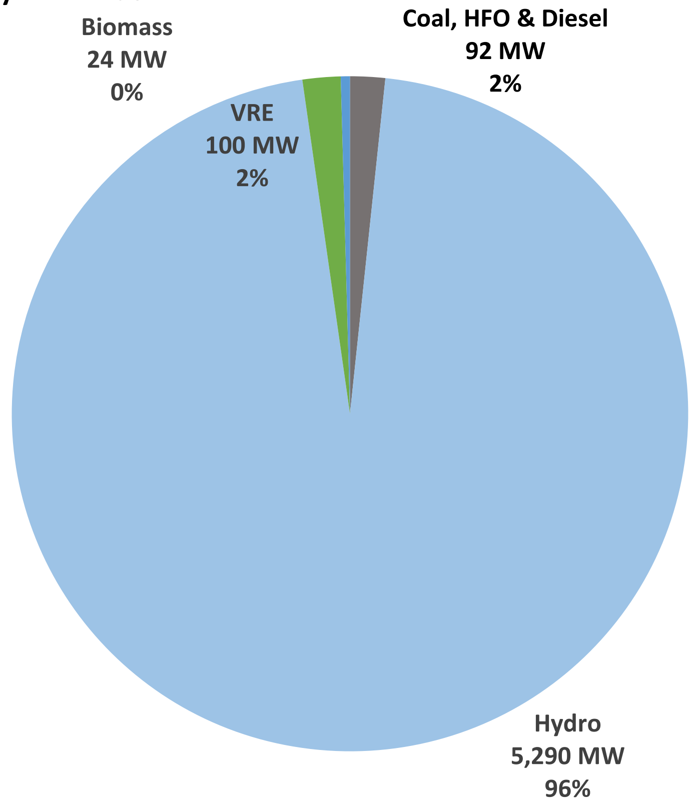
[51] "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map", ADB. November 2019.
[52] Sources include (i) "China to take a share in the Lao national grid", *Economist Intelligence Unit*, September 7, 2020; (ii) By Keith Zhai, Kay Johnson, "Exclusive: Taking power - Chinese firm to run Laos electric grid amid default warnings", *Reuters*, September 4, 2020; (iii) "Chinese, Lao grid joint venture signs concession pact with Lao gov't", *Xinhuanet*, March 12, 2021; and (iv) "The Study on Power Network System Master Plan in Lao People's Democratic Republic." JICA February 2020. Section 7.2. contains a lengthy and detailed history and analysis of options to create a transmission entity.

2.1.3.2 POWER SUPPLY – CURRENT SITUATION

Hydroelectric power predominates in Lao PDR, with a small amount of coal-fired capacity (lignite), VRE and biomass capacity making up the balance, as shown in Figure 14 (capacity committed to exports not included).[53]

The capacity mix is expected to remain centered on hydroelectric capacity for the domestic system and to account for nearly all new export project capacity through at least 2030. VRE potential in Lao PDR is limited, with solar PV potential evaluated as the second lowest in Lower Mekong region (though there may be a role supporting the system in the dry season); wind resources appear to be significant, but in somewhat remote areas. A newly completed and USAID Clean Power Asia-sponsored "Integrated Resource and Resilience Planning" (IRRP) study for Lao PDR included solar providing 3% of generation by 2040, and the Ministry is considering establishing a new target of 200 MW solar by 2028. There is significant biomass potential in the country, though this technology is likely to remain a marginal player in the overall capacity mix.[54]

Figure 14. Capacity Mix in Lao PDR



Source: Delphos International. Data from "AIMS III Preliminary Phase II Report".

[53] The chart reflects capacity for domestic consumption only and thus does not include capacity for export projects, such as the 1,878 MW Hongsa Lignite-fired power plant (92 MW net capacity being for domestic use).
[54] "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map." ADB, November 2019. Section 2.1.

2.1.3.3 TRANSMISSION GRID OVERVIEW

The Lao PDR's transmission network comprises four grid regions across the north, central 1, central 2, and south, operating mainly at 115 kV and 230 kV. Figure 15 depicts the Lao PDR grid as of 2017. The separate grid regions reflect the history of development of the national grid, which until 2012 consisted of four separate islanded systems. There are numerous export-dedicated or export-oriented HV lines, including (as of 2017) three 500 kV lines and two 230 kV lines for export to Thailand; two 230 kV lines for export to Vietnam; and seven 115 kV lines for trade with Cambodia (1), Yunnan (1)[55], and Thailand (5). There are also several lower voltage ties with all neighboring countries.[56]

Power generally flows from hydro projects in the north to the south, but in the dry season, lower storage hydro capacity and inter-regional transmission constraints from the north to the south require imports in the south, mainly from Thailand.

Control of the HV grid is limited, as explained in the extended excerpts below. Note that the first source suggests control is poor for the entire grid while the latter source is directed only at the 115 kV grid.

Excerpt from "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map", ADB. November 2019. Section 4.3.

> *[T]he EDL grid lacks any formal provision for ancillary services, and the governor control function of generating units is not managed properly. As a result, EDL essentially relies on the neighboring EGAT transmission grid, with which it is interconnected, to implicitly provide frequency response. While the Lao Grid Code refers to frequency control and voltage levels, many of them are not implemented due to lack of resources.*

Excerpt from The Study on Power Network System Master Plan in Lao People's Democratic Republic." JICA February 2020. Section 11.5.2.

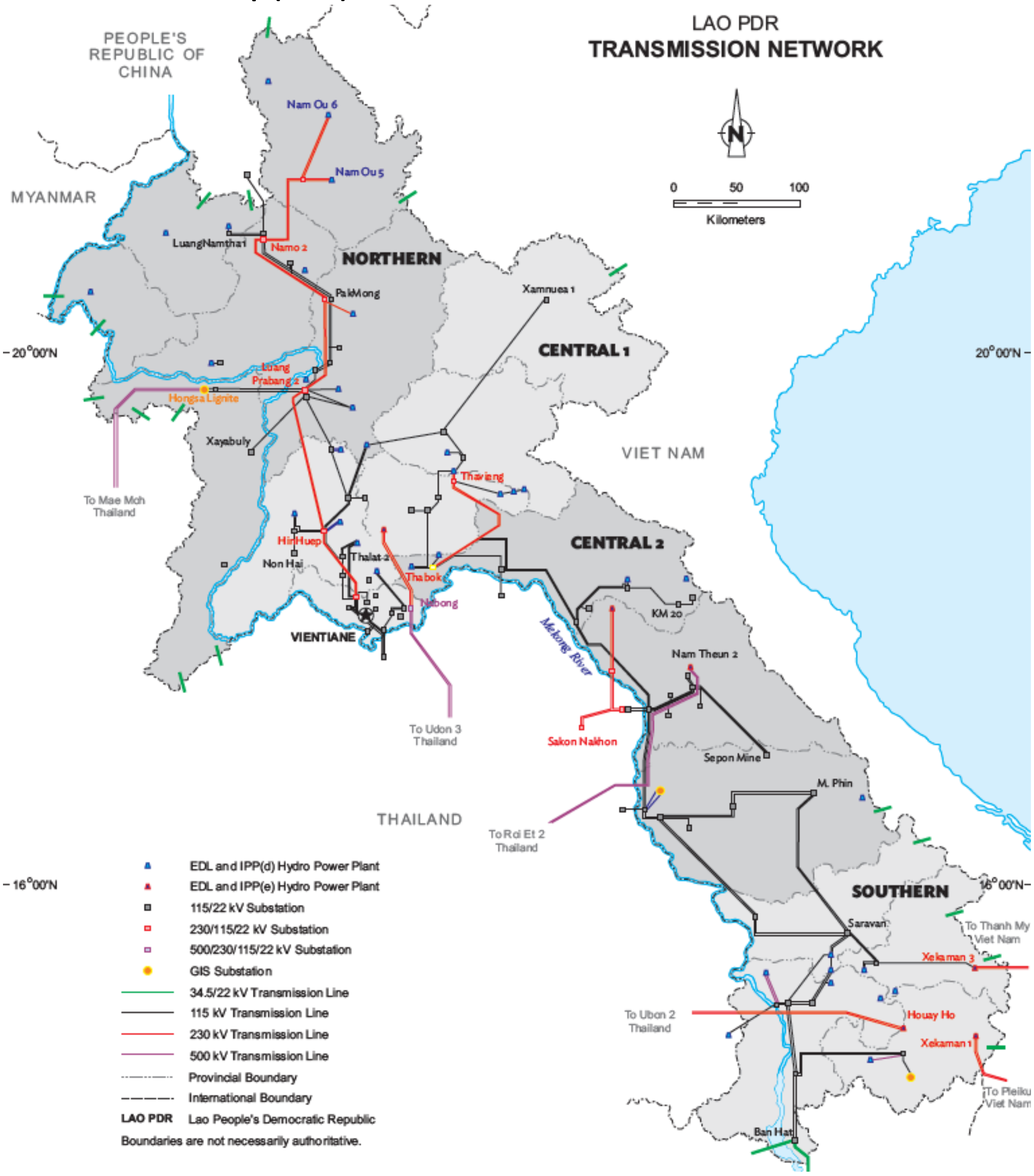
> *At present, Laos does not control the frequency of its own system, and it cannot control the power flow of the 115 kV interconnections used for power exchange with the existing system in Thailand. Currently, the frequency is controlled by the EGAT generators and, as mentioned above, the power flow of the 115 kV interconnections is also controlled by the EGAT power dispatching center or the EDL dispatching center. However, control of generators in Laos is not adequately performed, causing a problem. Also, if AC interconnections are performed at different places, changes in the power flow of the interconnections occur at other points due to faults on the interconnection line and it is not easy to control this. Therefore, in order to realize interconnections between main*

[55] While various sources identify the Lao PDR – Yunnan tie as 115 kV, the following source indicates a single circuit 230 kV tie. It is understood this tie is operated for load switching and has not been used recently due to excess supply in both northern Lao PDR and southern Yunnan. "CSG Starts Ban Boun Tai 230-kV Switching Station Expansion Program in Laos", China Southern Power Grid Press Release, June 18, 2019.

[56] Key sources consulted for this section include: (i) "The Study on Power Network System Master Plan in Lao People's Democratic Republic." JICA February 2020. Section 11.4, and (ii) "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map." ADB, November 2019. Section 4.3.

systems, it is necessary to improve the control system for the system operation side in Laos, and the rules for system operation, etc. It is thought that this would take time to achieve. Therefore, in the scenario up to 2030, the linkage between Laos and its neighboring countries (apart from Thailand, where interconnection has already been realized) should be carefully considered.

Figure 15. Lao PDR Grid Map (2017)



Source: "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map." ADB, November 2019.

2.1.3.4 LONG-TERM SYSTEM PLANNING

Integrated expansion planning in Lao PDR is infrequent and has been inadequate, reflecting insufficient regulatory guidance and lack of planning capacity at MEM and within the power sector generally.

As "exhibit 1" of problematic expansion planning, a power development plan was released by MEM in 2017 that involved over 35 GW of total installed capacity by 2030, compared to total installed capacity of under 5 GW at the time. In 2030, 17 GW of this capacity would be dedicated to serving domestic demand, and 14 GW to export demand[57], implying over 20% compound annual growth rate for domestic demand through 2030, and huge growth in export demand. By contrast, historical domestic compound annual demand growth rates have been below 12% for the past 10 years. If demand grows at 12% compared to 20% through 2030, peak demand in that year would be approximately 7 GW lower.[58]

It appears that one of the underlying flaws behind such an optimistic expansion plan – at least with respect to export projects – was the MEM's apparently unquestioned acceptance of the off-take forecasts of export IPP developers and taking MOUs for such projects as sufficient documentation that the projects would proceed.

Reacting to a negative reception of the power development plan, in March 2019, the government announced a moratorium on new power sector investments through 2020, and in April 2019, a new power development plan was released, this time with 6 GW for domestic supply and (it appears) a range of 8-14 GW for export supply.[59]

Major development partners have been active in areas related to integrated expansion planning in Lao PDR, including USAID, the World Bank, ADB, the Agence Française de Développement (AFD), and JICA. (JICA's "The Study on Power Network System Master Plan in Lao People's Democratic Republic" (February 2020) contains an enormous amount of technical analysis on the Lao PDR power sector.)

2.1.3.5 GRID CODE OVERVIEW

The Electricity Law of 1997, later revised in 2008, 2011, and 2018, provides the legal framework underpinning the Lao PDR's power sector and establishes the principles, regulations, and measures that govern all activities pertaining to the power sector. The most recent revision to the Electricity Law was completed in August 2018.

The Lao PDR grid is linked with the Thai grid through five 115 kV AC international tie-lines. The system capacity of the Thai grid is 30 times larger than Lao's, which makes the Lao grid relatively stable from a frequency aspect, although autonomous frequency and tie-line power flow control is not performed. The current EDL system is practically operated by Thailand's Electricity Generating Authority of Thailand (EGAT), including supply and demand balance and frequency control. The instructions to the generators are issued by EDL-National Control Center (NCC) according to requests from EGAT by telephone; Load Frequency Control (LFC) and AGC are not applied at all. Governor-free operation (frequency sensitive mode operation), according to an interview with the NCC, is rarely implemented, except for some large capacity hydropower generators like the Nam Ngum hydropower plant. Power flow management is handled by monitoring and instructions by telephone. And even in emergency

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[57] "The Study on Power Network System Master Plan in Lao People's Democratic Republic." JICA February 2020. Section 10.

[58] The assertions related to demand growth rates assumes 955 MW peak demand in 2017 and a 50% capacity reserve factor for 2030, which is reasonable for a hydro-dominated system.

[59] "The Study on Power Network System Master Plan in Lao People's Democratic Republic." JICA February 2020. Section 10.

situations, there is no device that automatically controls the power flow which will lead to grid failures. Besides this, there are many other shortcomings in the grid code.

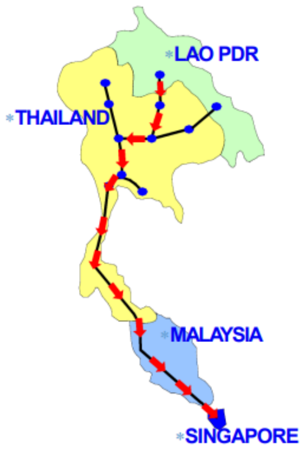
Late last year, as mentioned earlier in this section, China Southern Power Grid Co, one of the biggest Chinese electric utilities, took control of the Laos transmission grid as part of a 25-year agreement. It will allow China Southern Power Grid Co to build and manage a large part of the country's power grid. This takeover could impact the current technical framework, including grid codes, to be aligned with the China Southern Power Grid standards to facilitate smooth exchange of power with its network. This could have a significant impact on GMS and ACE plans for the grid code harmonization in GMS and ASEAN regions.

2.1.3.6 APPROACH TO REGIONAL INTEGRATION

Lao PDR's economic development strategy has long emphasized hydroelectric power for export. The country's approach to regional integration reflects this export-oriented power sector vision. A variety of large export-oriented IPP projects are planned or under development (these would be generator to grid projects), as are multiple 230 kV and 500 kV grid-to-grid cross-border interconnections. Over the medium to long term, additional export-oriented HV (mainly 500 kV) interconnections are envisioned with all neighboring countries (Myanmar is the only one with whom Lao PDR does not currently have an HV interconnection).

Expanded grid-to-grid trading is a national planning objective. The country has been supportive of regional integration activities, including through the GMS RPTCC, and via the Laos-Thailand-Malaysia Power Integration Project (LTM-PIP) PPA and wheeling agreement under which Malaysia purchased up to 100 MW from Lao PDR, wheeled across Thailand's grid; the LTM-PIP represented the first multinational power trade in the region.[60] This has been increased to 300 MW and is being extended to include Singapore (such that the updated acronym is LTMS-PIP), which would import 100 MW from Malaysia.[61] Figure 16 shows an illustrative depiction of power trade and direction under this project.

Figure 16. Power trade under the Laos-Thailand-Malaysia-Singapore project



[60] "Lao People's Democratic Republic Energy Sector Assessment, Strategy, and Road Map", ADB. November 2019. Section 4.3.
[61] Matthew Mohan, "Trial to import electricity from Malaysia a 'useful first step' as Singapore prepares to connect with regional grid: Experts", *Channel News Asia*, January 1, 2021.

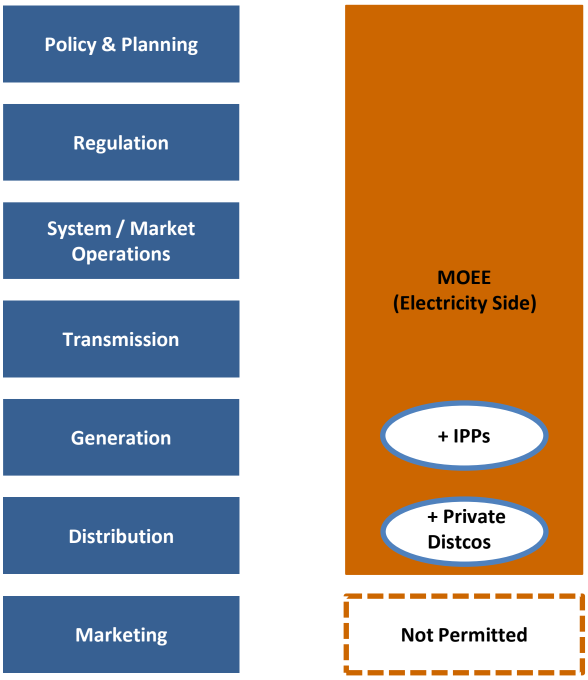
Source: "ASEAN Power Grid: Multilateral Power Trade." ASEAN Power Grid Consultative Committee, November 2017.

2.1.4 MYANMAR SNAPSHOT

2.1.4.1 POWER SECTOR OVERVIEW

Myanmar's power industry is of the "single buyer" type.[62] The Ministry of Electricity and Energy (MOEE), formed by the merger in 2016 of the Ministry of Energy and the Ministry of Electric Power, is the chief energy sectoral entity. MOEE is split between electricity and energy sides. The electricity side is responsible for planning, operation and commercial aspects of the electric power system. The energy side focuses on production, import/export, and distribution of oil and gas and related products. Private participation in generation is *via* IPPs and joint ventures with MOEE, and there are several small private distribution company concessions. Figure 17 depicts the sectoral structure.

Figure 17. Myanmar Power Sector Overview

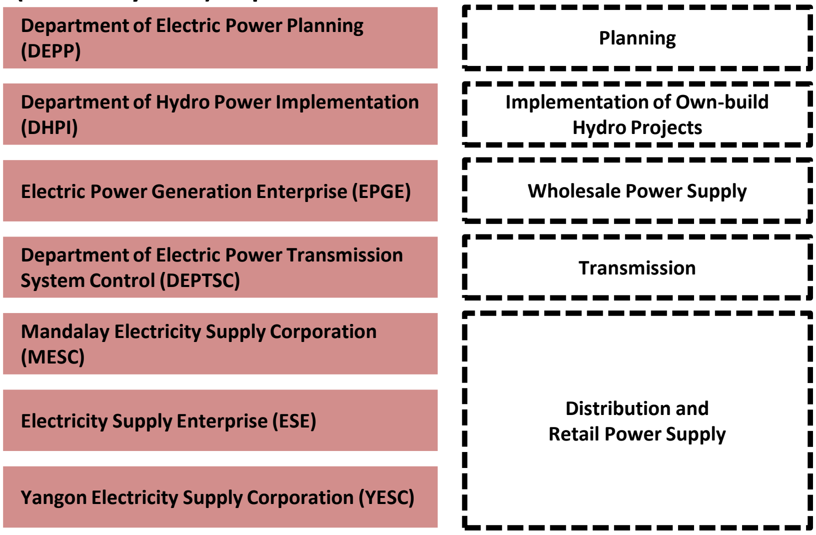


Source: Delphos International

Figure 18 shows the functional organization of the electricity side of MOEE.

[62] Information regarding Myanmar's power industry structure and other relevant information was sourced from "Burma: Energy Project Development and Technology Advisory Services." USTDA (Delphos International), September 2017.

Figure 18. MOEE (Electricity Side) Departmental Structure

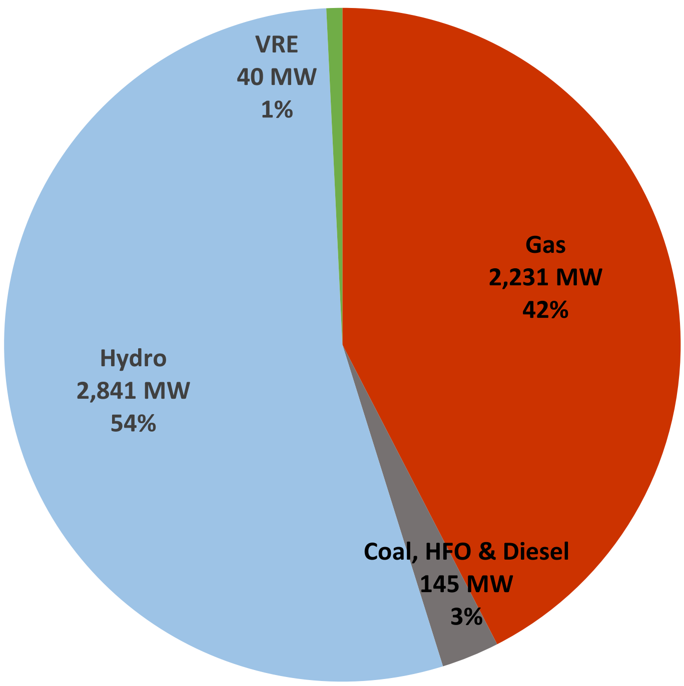


Source: Delphos International

2.1.4.2 POWER SUPPLY – CURRENT SITUATION

Myanmar's on-grid power system is dominated by hydroelectric and gas-fired generating capacity. A small amount of coal-fired capacity and small diesel gensets, plus a single 40 MW solar PV project, makes up the balance.

Figure 19. Capacity Mix in Myanmar



Source: Delphos International. Data from "AIMS III Preliminary Phase II Report".[63]

[63] Full details on the capacity mix are not available in the AIMS III report. See Section 3.1 for a discussion of the treatment of export hydro projects and other relevant matters.

Hydro projects (and most remaining hydro resources) are located mainly in the north of the country, while most demand is located farther south, especially in the Yangon area. Peak demand occurs late in the dry season (April – June) when total hydroelectric production is at its lowest[64]. Gas-fired capacity is fueled by domestic natural gas; it is important to understand that, although Myanmar exports substantial amounts of natural gas, this is required by contract. The reality is that the country is extremely short of natural gas for domestic uses, including its power industry. Apart from the lack of domestic supply, the gas transport network (particular in the south) is aging and poorly maintained, suffering in many locations from low pressure and other challenges. Consequently, gas-fired generation capacity is severely constrained by lack of usable gas supply.

While some expansion plans prepared by development partners since 2015 have emphasized hydropower and coal-fired capacity[65], the focus on the thermal side subsequently shifted to LNG-to-power projects as it became clear that there was little political support for coal-fired projects domestically and given the opposition of key development partners.[66] In 2016, the World Bank funded several studies examining the domestic gas supply demand balance and the feasibility of LNG import projects. Subsequently, the IFC funded further work specifying potential LNG import and LNG-to-power projects, as part of a broader engagement that envisioned competitive tenders for those projects. However, in January 2018, MOEE signed "notices to proceed" for three LNG-to-power projects (approximately 3,000 MW total – termed the "NTP Projects"), blindsiding the World Bank/IFC and *de facto* ending their work in this area.[67]

Due in part to delays implementing the NTP Projects, MOEE more recently has shifted its focus to solar PV to bring capacity online quickly. New Zealand's Ministry of Foreign Affairs and Trade (MFAT) was invited to prepare a tender process, and undertake related technical studies, for approximately 1,000 MW of solar PV. After much of the requested work was completed, MOEE blindsided MFAT with the announcement of its own tender process for 1,060 MW in May 2020.[68] The full tendered capacity was awarded to bidders (nearly all Chinese) in September 2020 at prices averaging below $50/MWh.[69]

2.1.4.3 TRANSMISSION GRID OVERVIEW

Myanmar's HV grid comprises mainly 230 kV and 132 kV transmission lines, as shown in Figure 20. Several 500 kV lines have been added since 2017 on a central north-south spine to support typical power flow from hydro plants in the north of the country to load centers farther south. Key links on the north-south 500 kV spine were delayed but were either completed in 2020 or are expected to be completed by 2021. Note that the 500 kV segment from Mawlamine to Kanbauk, shown as under construction in the figure, is not under construction and currently is not planned.

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[64] There is limited storage hydro capacity.

[65] In December 2015, the ADB completed an "Energy Master Plan for Myanmar", which included heavy coal-fired capacity expansion. JICA had produced a draft expansion plan around the same time (which has not been released) also emphasizing coal-fired capacity.

[66] The World Bank and other development partners, together with NGOs, argued against the coal-fired capacity expansion called for under the ADB and JICA expansion plans (see footnote above).

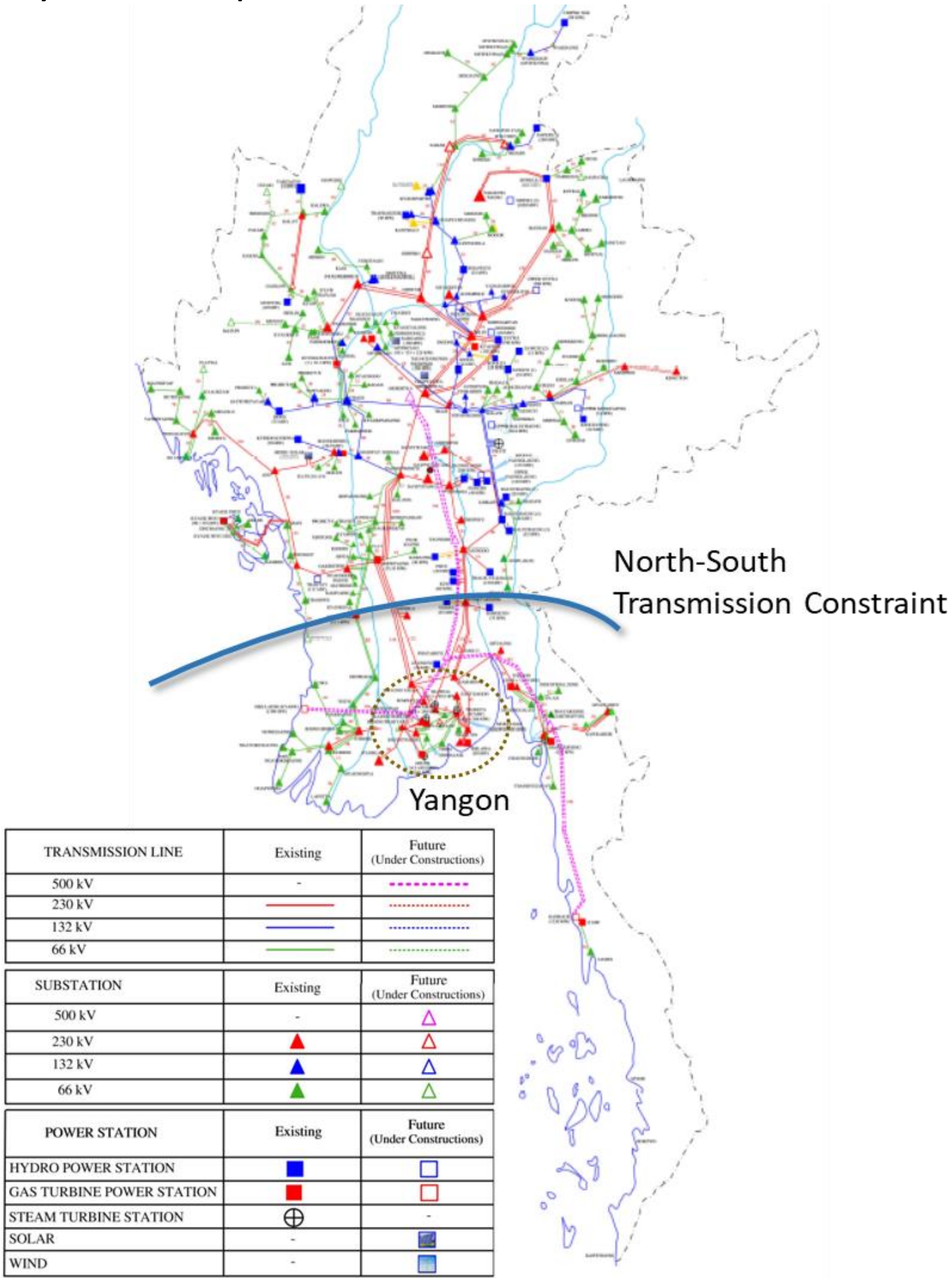
[67] See: (i) Thomas Kean, "Does Myanmar's LNG power plan stack up?", *Frontier Myanmar*, February 8, 2018; and, (ii) Kyaw Ye Lynn and Thomas Kean, "LNG projects: delayed, not dead", *Frontier Myanmar*, June 28, 2019

[68] Thompson Chau, "Myanmar's hasty solar tender draws criticism from investors", *Myanmar Times*, May 24, 2020.

[69] Emiliano Bellini, "Myanmar's 1 GW solar tender concludes with lowest bid of $0.0348/kWh", *PV Magazine*, September 24, 2020.

Much of the country is not served by the national grid, notably most of northern Kachin and Chin states, eastern Shan, and all of Tanintharyi in the south. For reference, Tanintharyi is approximately as long as Portugal. The gap in grid infrastructure can be seen clearly in Figure 20 from the large white spaces in the east (Shan), south (Tanintharyi), and north (Kachin and Chin).

Figure 20. Myanmar Grid Map

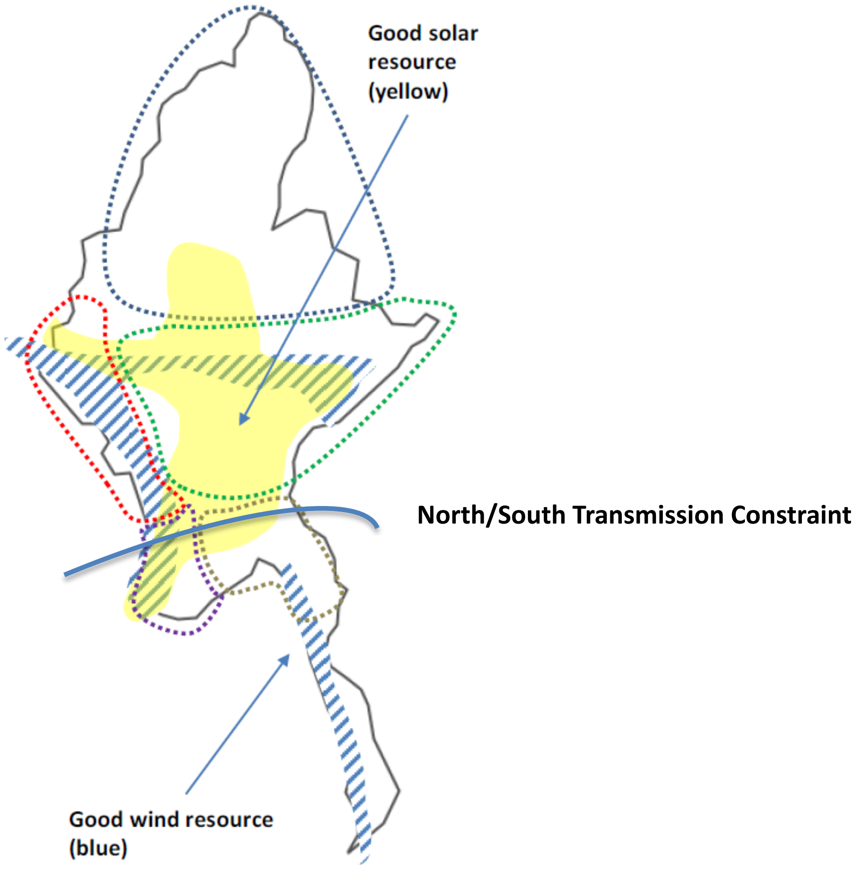


Source: MOEE – Grid Map (the full map from 2019 is available for download).

Power system control is weak, due to issues such as lack of SCADA at many (if not all) power stations; incomplete system information from some HV substations (and unreliable data communications in general), and lack of fast governor response (or "fast regulation").

VRE resources are located mainly in the north and central (especially solar) regions; the southern peninsular region has good wind resources, as shown in Figure 21. Myanmar's hydro resources are also further north to where the majority of VRE resources are located – if grid infrastructure is not strengthened, Myanmar is likely to have reliability challenges as it integrates planned VRE development. As previously mentioned, the southern region which also has strong wind resources already lack transmission infrastructure. New connections with Thailand in this region could facilitate future development of wind projects in this region, in addition to serving load.

Figure 21. Location of VRE Resources on Myanmar Grid



Source: "Burma: Energy Project Development and Technical Advisory Services." Delphos International

2.1.4.4 LONG-TERM SYSTEM PLANNING

MOEE lacks the capacity and tools to conduct integrated expansion planning. In practice, expansion planning has been *ad hoc*, guided by periodic, separate, power and transmission expansion plans produced by different development partners. On the transmission side, to the extent that transmission expansion plans have used basic planning criteria (such as N-1[70] analysis), the ground reality has been that system improvements have not materialized fast enough to enact the plans timely, resulting in a system that cannot be said to reflect these basic planning criteria.

There is limited information sharing or coordination across the relevant MOEE departments shown in Figure 18: DEPP, DHPI (which, though its name suggests a more restricted role, is also involved in hydro

[70] The "N-1" planning criterion requires that a power system be able to withstand an unexpected outage of a single system component, e.g., the largest generating unit or a key transmission circuit.

project planning), and DEPTSC. A newly formed National Renewable Energy Committee also is involved in planning.

2.1.4.5 GRID CODE OVERVIEW

MOEE does not have an official grid code. A draft grid code was developed by DNV GL through technical assistance funded by European development agencies, but it has been formulated specifically for conventional synchronous generators. This draft grid code is referred to by MOEE as well as IPPs as benchmark technical requirements. In 2019, New Zealand's Ministry of Foreign Affairs and Trade engaged AECOM to develop a technical framework and standards for connecting utility-scale solar PV plants connected to the transmission grid. This document was used as reference for connecting the recently awarded solar power plants totaling 1,000 MW of capacity. In depth data for hydropower plants are being collected to formulate a more accurate grid code based on electromechanical transient modelling. This is planned for 2023.

2.1.4.6 APPROACH TO REGIONAL INTEGRATION

While Myanmar's vast hydro and VRE endowment has led to an assumed role as a regional net exporter under some regional power market integration analyses, Myanmar's approach to regional integration has in fact focused on imports in recent years.[71] Below are high-level observations on the power supply/demand balance and power grid in Myanmar, and the expected stance of the country on cross-border interconnections.

- The transmission grid and system controls are weak. The key system transmission constraint, located just north of Yangon, is on north to south flows. Completion of a north/south 500 kV spine will alleviate this constraint in the near term but significant additions of new generating capacity to the north of the Yangon area would require major new investments to move power to the south.
- Power supply on the HV grid is unreliable, with frequent outages driven by inadequate generation supply as well as by grid failures.
- Myanmar suffers from dual energy constraints - hydropower generation is limited by water availability and there is an extreme gas shortage for thermal plants, which are almost all gas-fired - an unusually challenging situation for any power system.
- Large amounts of new capacity are required to serve load in the face of rapid demand growth. Hydro capacity will continue to be added but nearly all hydro projects in the country have been severely delayed, and implementation of new large hydro projects will not add substantially to supply within the next ten years. The most plausible capacity expansion technologies over the near-to-medium term are LNG-to-power and VRE (mainly solar PV).[72]

[71] Three of the authors of the present report have lived and worked in Myanmar in recent years: Delphos (Eric Shumway), AECOM (Nasser Faarooqui) and SST Ventures (Aung Myo Lwin). Information provided here is based on numerous conversations and prior project experience.
[72] "The ministry needs to move fast to keep the lights on", *Frontier Myanmar*, interview with Eric Shumway (head of the Delphos Team for the present report), July 12, 2017. Eric Shumway has worked nearly continuously on Myanmar power sector engagements since 2015.

- As mentioned in Section 2.1.4.2, nearly 3,000 MW of LNG-to-power projects have been procured but it seems likely much of this capacity will be considerably delayed or cancelled.
- VRE resources are located mainly to the north of the north/south constraint. As noted above, even with completion of the 500 kV spine, there is not much room for more north to south flows.
- Given the factors mentioned above, there is no realistic prospect of Myanmar becoming a net exporter for a minimum of 10 years, even before evaluating the impacts of ongoing political upheaval there.
- Officials from MOEE and others have emphasized imports as a way to augment supply over the near to medium term (China, Thailand, Lao PDR, India). In November 2019, EGAT revealed that it was planning to talk to power authorities in Myanmar and Cambodia for a combined 500 MW of exports from Thailand; MOEE also discussed plans to buy 1,600 MW from India in September 2020; Myanmar has also announced intentions to buy 1,000 MW from China Southern Power Grid in 2019 and signed another agreement in January 2020 to study cross-border projects to import power from China.[73]

2.1.5 THAILAND SNAPSHOT

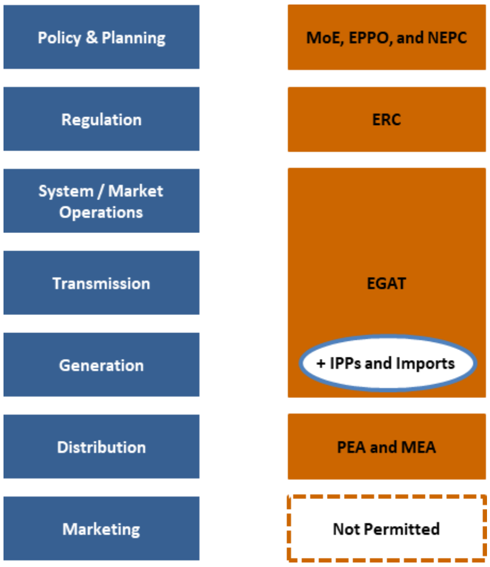
2.1.5.1 POWER SECTOR OVERVIEW

The Ministry of Energy (MoE) is responsible for oversight of the energy sector. The Energy Policy and Planning Office (EPPO), the operational body of the MoE, formulates proposals on national energy policy. Policy proposals are then reviewed by the National Energy Policy Council (NEPC), which is chaired by the Prime Minister. The electricity sector is partially unbundled and organized as a single buyer system. The state-owned Electricity Generating Authority of Thailand (EGAT) owns and operates the transmission system. EGAT is also responsible for system operations and securing power supply, which it does through a combination of its own generation, Power Purchase Agreements (PPAs) with Independent Power Producers (IPPs) in Thailand, and imports from neighboring countries.[74] EGAT sells wholesale power to two other state-owned entities, the Provincial Electric Authority (PEA) and Metropolitan Electric Authority (MEA), which own and operate the distribution grids.

[73] Yuthana Praiwan, "Egat talks power trade with Cambodia, Myanmar", Bangkok Post, November 5, 2019; Chan Ma Htwe, "Myanmar to buy 1600 MW of power from India", Myanmar Times, September 4, 2020; Nan Lwin, "Chinese Electricity: Blessing or Curse for Myanmar?", *The Irrawaddy*, March 13, 2020.

[74] IPPs in Thailand here covers utility scale generation, Small Power Producers (SPPs), and Very Small Power Producers (VSPPs).

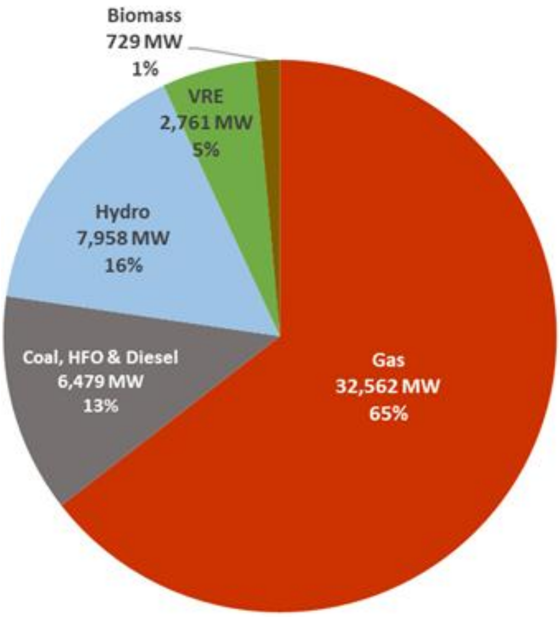
Figure 22. Organizational Structure of Thailand's Power Sector



2.1.5.2 POWER SUPPLY – CURRENT SITUATION

Thailand has a more developed power sector infrastructure relative to its neighbors in terms of supply, demand, transmission grid, and institutional capacity. Most of EGAT's transmission system operates at higher voltage levels (230 kV or 500 kV). Thailand's capacity mix is also substantially different from all other GMS countries – it has by far the lowest reliance on hydropower at 16% of capacity and the largest gas-fired generation fleet in the region. Nearly 6 GW of contracted capacity is delivered through imports, primarily through cross-border interconnected generation ("gen-ties") and a 300 MW High-Voltage Direct Current (HVDC) transmission line from Malaysia. Thailand also carries out power exchanges through 115 kV lines with Lao PDR and Cambodia.

Figure 23. Capacity Mix in Thailand



Source: Delphos International. Data from "AIMS III Preliminary Phase II Report".

The Power Development Plan 2018-2037 (PDP 2018), summarized in the figure below, informs the country's current long-term planning. Total installed capacity is expected to reach 77 GW by 2037, with over 56 GW of new capacity added and 25 GW of existing capacity retired during that period. The majority of new capacity added is expected to be what could be called clean energy, including "renewable energy" (understood to comprise conventional renewable technologies such as biomass and hydro) as well as "new renewable technologies", understood to include solar and wind, plus energy conservation and pumped hydro. Other capacity additions would include 15 GW of gas-fired generation. Natural gas is expected to provide over half (53%) of actual generation in 2037.

Figure 24. Thailand PDP 2018: Capacity Additions by Type between 2018 and 2037

Type	Capacity Added: 2018-2037 (MW)	Share (%)
Renewable energy	20,766	37%
Pumped-storage hydro	500	1%
Cogeneration	2,112	4%
Coal	1,200	2%
Natural gas (combined cycle)	15,096	27%
Imports	5,857	10%
New renewable technologies	6,900	12%
Energy conservation	4,000	7%
Total	**56,431**	**100%**

Source: Summary of PDP 2018 from Thailand Board of Investment[75]

PDP 2018 reflects the government's priorities of energy security alongside affordable and sustainable supply of electricity. Compared to PDP 2015, the revised plan seeks to lower tariffs by increasing renewable energy, promoting micro grids to align local electricity production and consumption, and relying on smart grid technologies to improve power system efficiency.[76]

2.1.5.3 TRANSMISSION GRID OVERVIEW

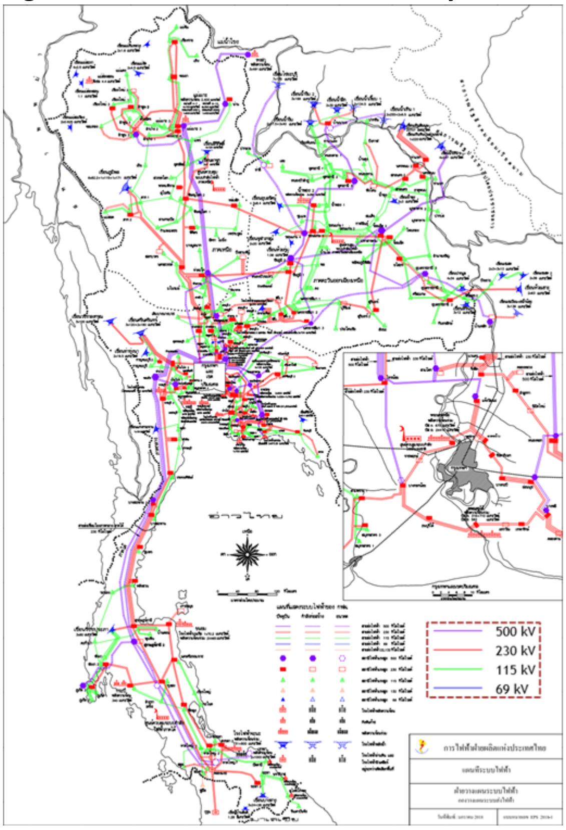
The country has a well-developed transmission grid that has successfully delivered near-universal access to electricity while maintaining relatively high levels of grid reliability and stability. 500 kV lines connect major generation sources to load centers in Bangkok and other metropolitan areas. EGAT also imports power from hydro and coal plants in Lao PDR on 230 kV and 500 kV lines. The southern part of the country is relatively isolated (see Figure 25) and presents some challenges in maintaining reliable operations, but the HVDC connection with Malaysia also provides frequency response.

The Thai grid is well-placed to integrate higher levels of VRE than its neighbors. Thailand's gas-heavy generation fleet provides more flexibility compared to power systems (such as Lao PDR's) dominated by run-of-river hydro. EGAT is adding additional 500 kV transmission lines in the northeastern, metropolitan, and southern areas to support power imports, demand growth, and grid reliability. Transmission system expansion plans also place emphasis on flexibility and smart technologies – a

[75] Thailand Board of Investment. Electricity. <https://www.boi.go.th/index.php?page=electricity&language=ja>
[76] "The Study on Power Network System Master Plan in Lao People's Democratic Republic – Final Report." February 2020. Japan International Cooperation Agency.

Renewable Energy Forecast Center in 2021, Demand Response Control Center (DRCC), and Battery Energy Storage System (BESS) pilots for ancillary services and frequency regulation.[77]

Figure 25. Thailand's Transmission System - Map and Statistics



Voltage Level	Substations (#)	Transformers Rated (MVA)	Transmission Line Length (circuit km)
500 kV	22	41,950	6,907
230 kV	82	66,000	15,732
115 kV	125	15,123	14,244
132 kV	-	133	9
69 kV	-	-	19
300 kV HVDC	-	388	23
Total	**229**	**123,594**	**36,934**

Source: PDP 2018; RPTCC 27 – Thailand Country Presentation

2.1.5.4 LONG-TERM SYSTEM PLANNING

The MoE prepared the Thailand Integrated Energy Blueprint (TIEB) to align several separate but related plans – Energy Efficiency Plan (EEP), Alternative Energy Development Plan (AEDP), Power Development Plan (PDP), and Oil Plan. There have been periodic updates of the PDP, in 2010, 2015, and 2018, rev 1 (current version). The PDP includes demand forecasts and long-term development plans for energy efficiency, alternative energy, overall power supply, and the transmission system. The long-term system planning has a 20-year outlook and addresses demand growth (including regional focus), yearly capacity additions and retirements, reliability concerns, integration of generation from IPPs and imports, grid-to-grid connection projects, and smart grid initiatives. The key frameworks for the PDP are: (i) reliability; (ii) fuel diversification (reduced natural gas reliance, increase clean coal technology, increase imports up to 20% of total capacity, encourage renewables); (iii) 15% reserve margin; and (iv) manage PPAs with IPPs.

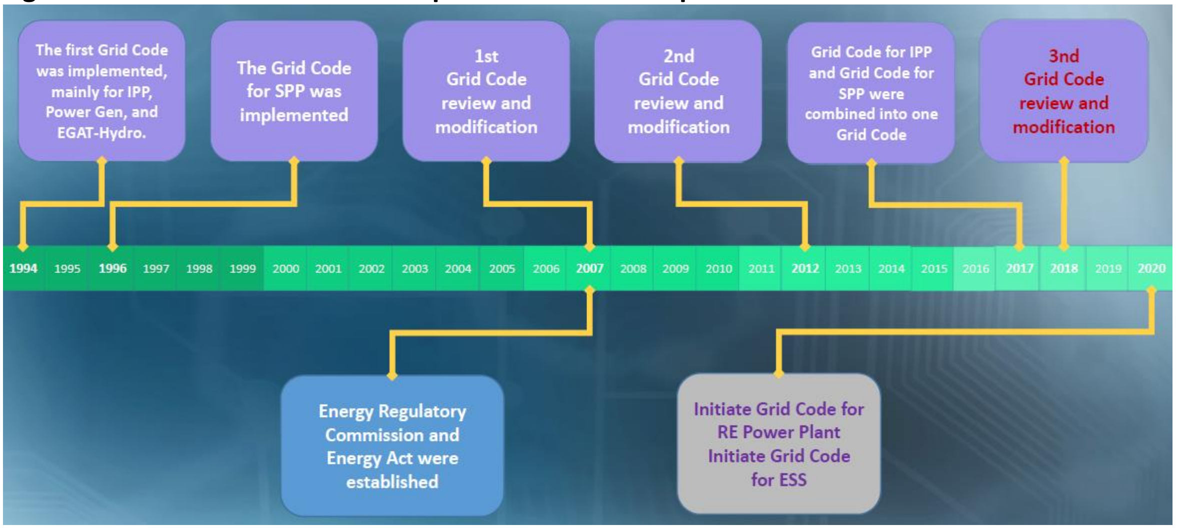
[77] RPTCC 27 – Thailand Country Presentation

2.1.5.5 GRID CODE OVERVIEW

Each of EGAT, PEA, and MEA have their own grid codes. EGAT's grid code was first implemented in 1994 and has subsequently undergone three revisions, most recently in 2018. The structure of the current grid code is:

i. Connection Code – provides rules on connecting generation resources to the grid, both at the distribution level and to EGAT's grid;
ii. Operation Code – covers operational parameters for overall transmission and distribution systems, and particularly for IPPs; and
iii. Service Code – defines qualifications of system users and outlines their duties and responsibilities and also covers the necessary forms, regulations, and fees.

Figure 26. Timeline of Grid Code Implementation and Updates



Source: RPTCC 27 – Thailand Country Presentation

EGAT's most recent grid code revisions from 2019 address some of the gaps that existed previously with respect to requirements specifically for VRE, including data requirements in the Connection Code and requirements to submit 15-minute generation plans for solar and wind generators in the Operation Code.. Connection and operational requirements for synchronous generators are well defined in PEA's and EGAT's grid codes whereas there are some shortcomings in the MEA grid code. The PEA grid code provides the technical framework to connect inverter-based renewable energy resources. Typical test requirements for inverter-based renewable energy resources are active power control, reactive power control, frequency and voltage ride through, harmonics, DC injection and anti-islanding. The typical requirements for synchronous generators are well defined

As illustrated in Figure 26, efforts are currently underway to make additional updates to the grid code for VRE-specific requirements, provide appropriate guidelines for battery storage and other new technologies, and define rules and operations of the DRCC including exchange of data and information with load aggregators.

2.1.5.6 APPROACH TO REGIONAL INTEGRATION

In 2019, Thailand imported 25.5 GWh of electricity and exported 2.4 GWh.[78] Although reserve margins are typically well above the target reserve margin of 15%, EGAT is likely to continue to remain a net importer in the immediate future because the hydro plants in Lao PDR provide lower cost generation than Thailand's gas plants and of course because of PPA obligations to Lao PDR's export IPP projects. However, over the medium- and long-term, net imports are expected to decrease according to Thailand's PDPs. PDP 2015 and PDP 2018, rev 1 both expect to continue current levels of thermal imports from Laos and increase hydro imports from Laos and Myanmar, after 2027 in the case of Myanmar. However, the planned hydro imports in the long-term are lower in PDP 2018 than in PDP 2015, especially from Myanmar. Planned hydro imports from Myanmar were expected to grow from 3,500 MW from 2027 to ~31,500 MW in 2036 in PDP 2015. The corresponding forecast in PDP 2018 dropped to 3,570 MW in 2026 increasing to ~16,750 MW in 2037.

Thailand is continuing to expand gen-ties and grid-to-grid connections with Laos and is also exploring further grid-to-grid connections with Cambodia and Myanmar. Higher levels of regional grid connectivity are expected to provide multi-fold benefits: energy security, energy access, energy resource sharing, investment cost saving, integration of VRE, and long-term decarbonization.[79] Thailand's renewable energy resources are predominantly in the northern and northeastern part of the country, so the country would likely seek to increase power trade with Lao PDR and also establish cross-border connections in Myanmar.

The country is also taking the first step towards multilateral power trade through the LTM-PIP, under which Thailand wheels power from Laos to Malaysia, importing from Laos and selling to Malaysia, receiving a wheeling charge. The first phase of the project was launched in 2018 at 100 MW, which has now been expanded to 300 MW and includes sales by Lao PDR of 100 MW to Singapore, wheeled through by Malaysia.

2.1.6 VIETNAM SNAPSHOT

2.1.6.1 POWER SECTOR OVERVIEW

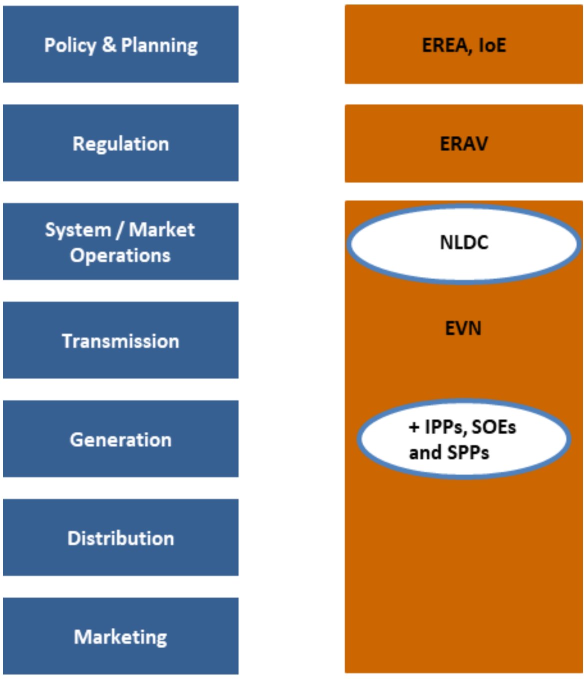
Vietnam's electricity sector is governed by the Ministry of Industry and Trade, primarily through two agencies – the Electricity and Renewable Energy Authority (EREA) and the Institute of Energy (IoE). EREA is responsible for formulating energy policy and long-term plans for the power system, renewables, and fuels (oil, gas, and coal) sectors. IoE supports EREA as a policy research think tank housed within the Ministry. The Electricity Regulatory Authority of Vietnam (ERAV) regulates the sector by developing regulations, implementing and regulating power markets, and setting tariffs.

The state-owned Electricity Vietnam (EVN) is responsible for transmission, distribution, and a large portion of generation. EVN is now a holding company with three generation companies, the transmission company, five distribution companies, the single buyer – Electric Power Trading

[78] "Electricity regulation in Thailand: overview." Thomson Reuters Practical Law. October 2020.
[79] "The Role of Long-Distance Transmission and Cross-Border Electricity Flows in Mid-Century Decarbonization. Thailand Transmission Planning Perspective." October 2019. EGAT.

Company (EPTC), and the system operator – National Load Dispatch Center (NLDC). Figure 27 summarizes the power sector structure. NLDC functions as a quasi-independent entity within EVN. According to the government's plans, NLDC would function as an independent System and Market Operator and be converted to an independent accounting unit of EVN by 2021, with full separation from EVN by 2025.[80]

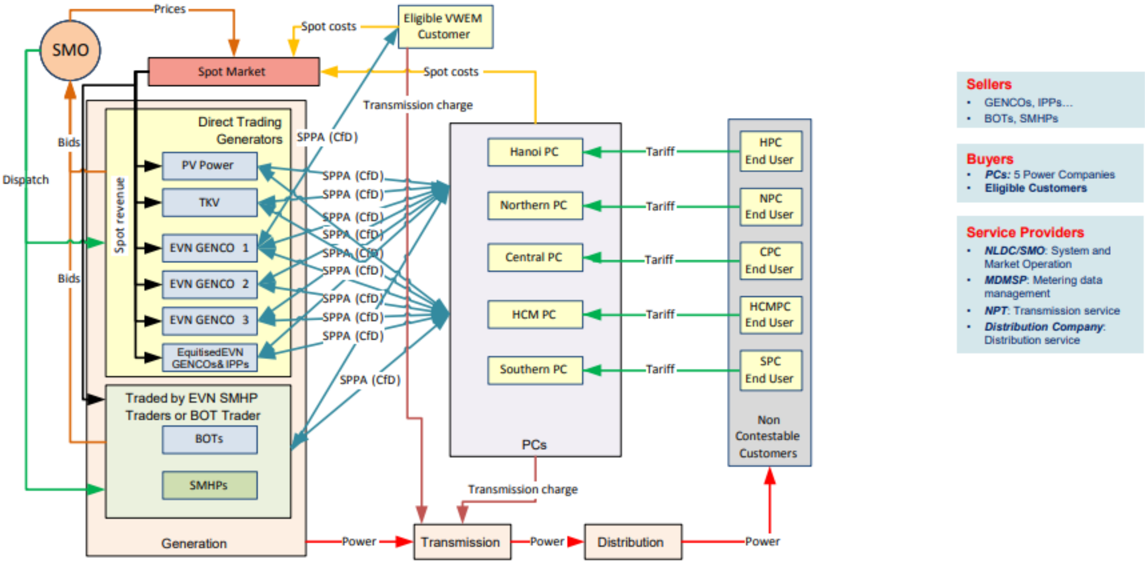
Figure 27. Vietnam Power Sector Overview



Vietnam's electricity market is currently in transition from a competitive generation market with a single buyer to an energy-only wholesale electricity market (VWEM). Under the single buyer structure, EPTC was responsible for purchasing all power, including from EVN's generation subsidiaries, foreign and domestic IPPs, and other state-owned generation companies. In the fully operational stage of the wholesale market, EPTC would no longer exist, and the distribution companies would purchase directly from the generators. Distribution companies are expected to contract directly with generators and settle the balances at spot market prices.[81] The expected market structure of VWEM is shown in Figure 28. Vietnam is also seeking to implement a competitive retail electricity market.

[80] "Learning from Power Sector Reform Experiences: The Case of Vietnam." World Bank Group. March 2020.
[81] "TA 8851: Establishing the Vietnam Wholesale Electricity Market (VWEM). Task 2 – Final Report." Ricardo Energy & Environment. March 2018.

Figure 28. Vietnam Long-term VWEM Arrangements

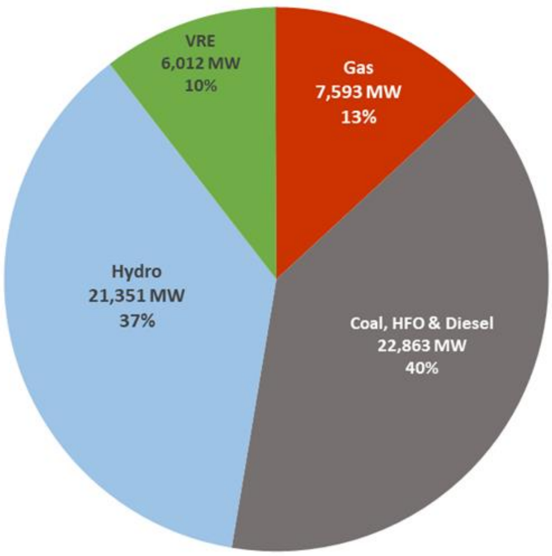


Source: EVN NLDC. Vietnam Wholesale Electricity Market (VWEM) Overview

2.1.6.2 POWER SUPPLY – CURRENT SITUATION

Vietnam has rapidly added generation capacity in recent years to support its economic development objectives – since 2015, total installed capacity increased from 38 GW to about 57 GW. The overall capacity mix continues to be dominated by hydro and coal, as seen in Figure 29. Recently, the government has also supported rapid growth in renewable energy through feed-in tariffs solar, floating solar, onshore wind, and offshore wind. In 2019 alone, Vietnam added over 4 GW of solar PV, and there are over 20 GW of approved wind and solar projects in the pipeline.[82]

Figure 29. Capacity Mix in Vietnam



Source: Delphos International. Data from "AIMS III Preliminary Phase II Report".

[82] RPTCC-27. Vietnam country presentation.

In February 2021, the Ministry issued a draft National Power Development Plan for 2021-2030, with a vision to 2045 (Draft PDP8). The base case plan seeks to grow installed capacity (including imports) to over 137 GW by 2030 with increased supply from new renewables, gas, and coal plants. As detailed in Table 6, 82% of the new capacity added is expected to be gas-fired, wind, and coal-fired. The planned capacity expansion is aggressive and may strain EVN's finances since most of the planned new coal-fired capacity are expected to be supplied by imported coal.[83]

Table 6. Vietnam – Planned Capacity Additions

Source	Capacity 2020 (MW)	Capacity 2030 (MW)	Change
Coal (including imported)	20,431	37,323	16,892
Gas (domestic gas and LNG)	7,097	28,733	21,636
Oil/Diesel	1,933	138	-1,795
Hydro	20,685	24,792	4,107
Solar	16,640	18,640	2,000
Wind (including offshore)	630	18,010	17,380
Biomass	570	3,150	2,580
Storage (battery and pumped hydro)	0	1,200	1,200
Imports from China	700	700	0
Imports from Laos	572	4,977	4,405
Total	**69,258**	**137,663**	**68,405**

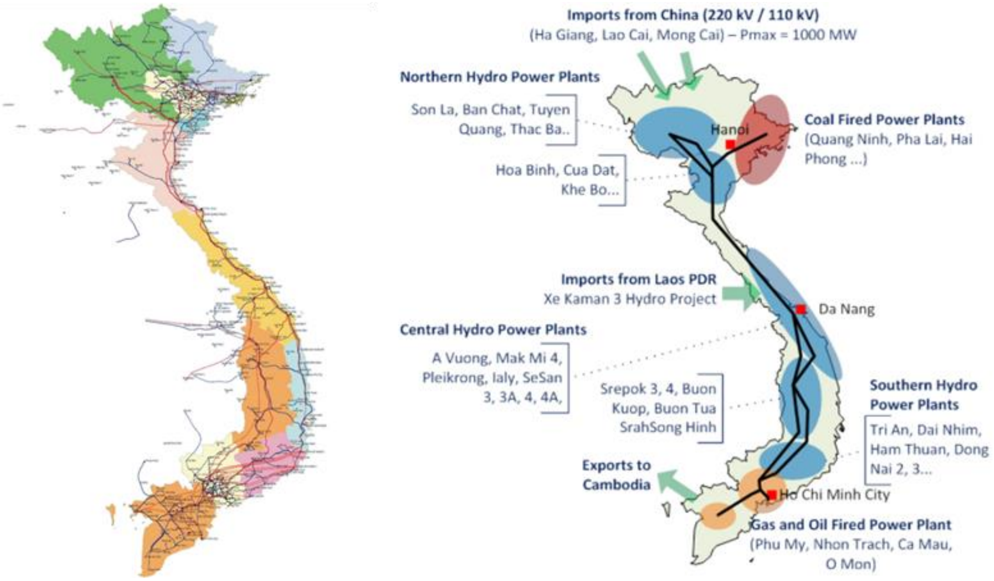
Source: Baker McKenzie – Highlights from Vietnam's Draft PDP8.

2.1.6.3 TRANSMISSION GRID OVERVIEW

The transmission system in Vietnam operates predominantly at 500 kV and 220 kV voltage levels. A "backbone" of 500 kV transmission lines stretching from north to south integrates the power network in the country. As illustrated in Figure 30, the northern region is supplied by hydropower and coal-fired power plants as well as imports from China[84]; the central region by hydropower plants and imports from Lao PDR (hydro); and the southern region by hydro and gas-fired plants. Vietnam also exports power to Cambodia through a 220 kV synchronous interconnection in the southern region.

[83] "Vietnam: Key highlights of new draft of national power development plan (Draft PDP8)." Baker McKenzie. March 2021.
[84] These ties from China are understood to be grid-to-grid (load switchable).

Figure 30. Vietnam Transmisison System



Source: RPTCC-27, Vietnam country presentation (left); World Bank "Greater Mekong Subregion Power Market Development" (left).

Vietnam's power imports from Lao PDR are expected to grow in the near term. The two countries signed an MOU in October 2016 specifying the following import (into Vietnam) levels[85]:

- Up to 2020, minimum capacity of ~1,000 MW.
- From 2021 to 2025, minimum capacity of ~3,000 MW.
- From 2026 to 2030, minimum capacity of ~5,000 MW.

2.1.6.4 LONG-TERM SYSTEM PLANNING

The country's power sector continues to be characterized by a strong and centralized technical planning approach. Ten-year master plans with a long-term outlook are developed and updated every five years. The proposed Draft PDP8 would be an update to the previous version (PDP7) from March 2016. Master plans from the Ministry are treated as authoritative government direction guiding investment decisions, which has helped the recent rapid expansion in generation capacity.[86] Transmission development is strongly influenced by generation plans. It is unclear how the planning process would evolve as the full implementation of the wholesale electricity market proceeds.

2.1.6.5 GRID CODE OVERVIEW

ERAV has established grid codes (transmission and distribution codes) in Vietnam since 2005 which govern access to the grid, relationships between different entities, and technical and performance criteria for safe and reliable grid operations. The current grid code is set out in Circular 25/2016/TT-BCT for the transmission code and Circular 39/2015/TT-BCT for the distribution. To meet the current development requirements of the new power sources (including VRE), the Vietnamese government revised these two circulars, by issuing the Circular 30/2019/TT-BCT in November 2019.

[85] "The Study on Power Network System Master Plan in Lao People's Democratic Republic." JICA February 2020. Section 6.2.
[86] "Learning from Power Sector Reform Experiences – The Case of Vietnam." World Bank Policy Research Working Paper. March 2020.

The grid codes detail the connection rules for hydropower, thermal, solar and wind generation projects. The revised version also specifies the reactive power requirement for inverter-based energy resources and the active power-frequency droop above 50.5 Hz.

Compared to neighboring countries like Cambodia and Lao PDR, Vietnam has a well-detailed grid code for connecting inverter-based renewable energy resources. This could create challenges for EVN to add additional connections with the weaker neighboring grids that lack the same level of stringent grid connection and operational requirements.

2.1.6.6 APPROACH TO REGIONAL INTEGRATION

Vietnam is expected to remain a net importer of power in the near and medium terms. Although the country has aggressive plans to expand its generation capacity, the Draft PDP8 indicates that expanded imports from Lao PDR is likely to remain a key part of planned supply growth – even more so if planned increases in domestic thermal generation capacity fall short of targets. As Table 6 shows, Vietnam expects to add over 4 GW of imports from Lao PDR by 2030 but not expand current levels of imports from China. Therefore, new cross-border interconnections in the central region of Vietnam would align well with the country's power sector strategy. Additional hydro imports from Lao PDR may also help Vietnam integrate its expected growth in renewables since Vietnam's solar and wind resources are strongest in the southern and central regions.

2.1.7 YUNNAN SNAPSHOT

Yunnan is a southwestern province of China.

Power sector reforms in China began in the 1990s. In March 2015, a further set of reforms/restructuring was decreed. Presently, China's power market may be summarized as moderately advanced, restructured. Transmission and distribution remain state-owned; there is vibrant competition in generation and retail subsectors; there are several power exchanges; and there is a regulatory framework.

Yunnan's interaction with the power sectors of the LMS occurs through state-owned China Southern Power Grid (China Southern), which operates the power grids in five southern provinces, including Yunnan. In this context, China Southern's ambitions and activities are part of the Belt and Road Initiative[87], specifically through the related "Global Energy Interconnection Initiative" sponsored by China. Thus, while Yunnan is often presented as the counterpart government entity in regional forums, notably in the GMS RPTCC, the fact is that China Southern, or more appropriately, China's central government, is the counterpart.

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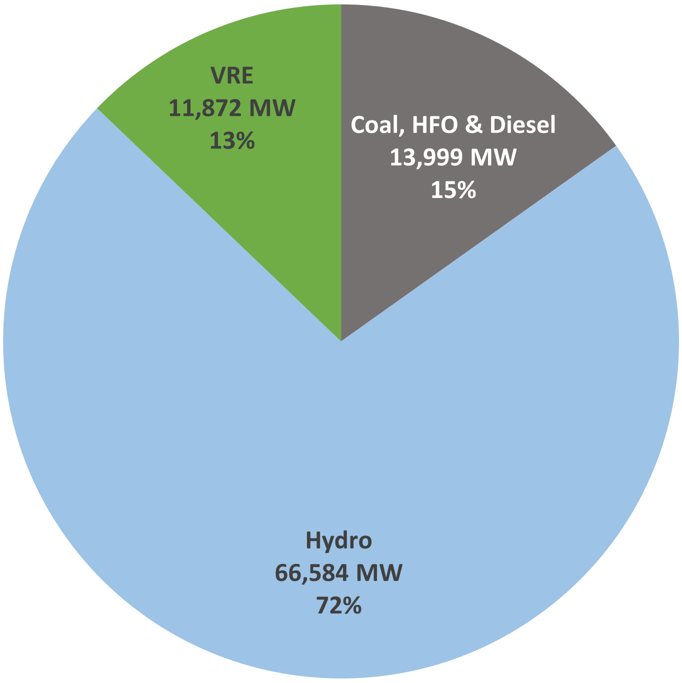
[87] See Edmund Downey, "Powering the Globe: Lessons from Southeast Asia for China's Global Energy Interconnection Initiative", Columbia University's Center on Global Energy Policy, April 23, 2020; and, Tian-tian Feng *et al*, "Electricity cooperation strategy between China and ASEAN countries under 'The Belt and road'", *Energy Strategy Reviews*, (Volume 30), July 2020.

To the extent the capacity mix in Yunnan is relevant to potential trading arrangements, it is notable that hydroelectric capacity accounts for 72% and VRE 13% of installed capacity, as shown in Figure 31.

Figure 31. Capacity Mix in Yunnan



Source: China Power Trading: Improving Environmental and Economic Efficiency of Yunnan's Electricity Market.

China's grid code is advanced and should be compatible in most respects with other advanced grid codes and the draft GMS grid code (a detailed review of China's grid code was not conducted).

2.2 HISTORY OF REGIONAL MARKET INTEGRATION

There is a long history of inter-government cooperation through organized frameworks in Southeast Asia, including in the energy sector. Heads of ASEAN Power Utilities/Authorities (HAPUA) was established in 1981, although it has had several reorganizations. The ADB has coordinated economic cooperation, including in the energy sector, under the GMS framework since 1992. The ASEAN Centre for Energy (ACE), an intergovernmental organization representing the ASEAN member states' interests in the energy sector, was established in 1999. Particularly since around 2000, there have been several additional sub-regional frameworks established by external powers like China, India, the US, Japan, and South Korea. The many frameworks reflect both the uneven distribution of resources, such as hydropower or natural gas, across the region as well as geopolitical considerations.

The Ayeyawady-Chao Phraya-Mekong Cooperation Economic Strategy (ACMECS) is one such intergovernmental cooperation framework between Thailand, Cambodia, Lao PDR, Myanmar, and Vietnam. ACMECS was formed in 2003 and in recent years, has held summits in 2015, 2016, 2018, and 2020. In the 2018 summit, Thailand initiated an ACMECS Master Plan that was adopted. Thailand would be crucial to regional power market integration due the size and growth of its power system. It already has existing cross-border interconnections with neighboring countries for both import and export and has plans to expand such interties. Therefore, ACMECS may be more influential than other sub-regional groupings that have proliferated recently.

Of the various regional and sub-regional frameworks, HAPUA/ACE – which includes all 10 ASEAN member states – and GMS – comprising Cambodia, Lao PDR, Myanmar, Thailand, Vietnam, and China (particularly Yunnan Province and Guangxi Zhuang Autonomous Region) – are the most prominent.

ASEAN formally adopted the concept of the ASEAN Power Grid (APG) in 1997, which is seen as a means of stimulating regional economic growth and development the member states. HAPUA and ACE work closely with ASEAN member states' government representatives. ACE functions as a think tank and knowledge hub, reporting to senior officials from national government bureaucracies. HAPUA helps to coordinate ministerial level dialogue to promote cooperation. Together, they help implement the ASEAN Plan of Action for Energy Cooperation, a blueprint to improve coordination for regional benefits in the energy sector. HAPUA is explicitly focused on regional energy market integration efforts, as evidenced from its website:[88]

> *"Our current focus is to support ASEAN Economic Community through ASEAN energy market integration by succeeding the implementation of ASEAN power Grid (APG) as HAPUA is assigned to based on MoU of APG. APG is the most important element of energy connectivity. APAEC 2016 – 2025 listed it as project program no. 1 and put the Laos-Thailand-Malaysia-Singapore Power Integration Project (LTMS PIP) as prioritized pilot project."*

Likewise, the mission of ACE is to "accelerate the integration of energy strategies within ASEAN by providing relevant information and expertise to ensure the necessary energy policies and programmes are in harmony with the economic growth and the environmental sustainability of the region."[89] The objectives of HAPUA and ACE reflect ASEAN-level goals of multilateralism and economic development.

To further their objectives of greater regional cooperation in the energy sector along with greater focus on environmentally sustainable pathways to power sector expansion, HAPUA and ACE are supporting AIMS III and other complementary studies conducted by the IEA and the Economic Research Institute for ASEAN and Southeast Asia (ERIA). AIMS III seeks to determine the combined generation and transmission needs for Southeast Asia, the opportunities for increasing bilateral and multilateral power trade, and the potential for increasing the amount of VRE on the ASEAN power grid.[90] Phase 1 of AIMS III was focused on capacity expansion planning and production cost modeling to understand least cost generation expansion pathways utilizing renewable energy. Phase 2 is focused on the transmission infrastructure needed to integrate different national grids under the expansion plans in Phase 1 while maintaining system reliability. The next step, Phase 3, would focus on harmonizing regulatory frameworks, grid codes, and technical standards amongst the ASEAN member states. Altogether, AIMS III is expected to inform the eventual formation of an ASEAN Power Grid with bilateral and multilateral trade facilitating greater integration of VRE in the generation mix and utilizing regional power generation resources more efficiently (least cost).

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[88] See "*About HAPUA"* on the HAPUA website: https://hapua.org/main/hapua/about/
[89] ASEAN Centre for Energy – Introductions. https://aseanenergy.org/introductions/
[90] Abt Associates. Scope of Work for the present report.

The efforts of HAPUA and ACE are both complementary to and in competition with the initiatives led by the ADB under the GMS framework. The launch of the GMS program in 1992 also coincided with the gradual emergence of the region's economies from central-planning structures. Energy has been a focus area of the GMS program since the beginning, focused on facilitating mutually beneficial sharing of unevenly distributed resources across the region to expand electricity access and support economic development. The distribution of resources can be complementary: hydropower resources are concentrated in the north of the sub-region (Myanmar, Lao PDR, China, and northern Vietnam); natural gas deposits are predominantly in Myanmar, Thailand, and Vietnam; China is the biggest coal supplier; and Thailand, Vietnam, and China have rapidly growing power-hungry economies providing the demand-pull to develop additional capacity. In addition, the need for dialogue on the many issues concerning the shared Mekong River create a natural need for cooperation.

The first energy sector study with a GMS focus was completed in November 1994 and led to the formation of the Electric Power Forum (EPF) in April 1995. The EPF prioritized regional power trade from the beginning, creating two areas of focus – one on policy and institutional framework for promoting power trade and another on facilitating physical interconnections for cross-border dispatch of power.[91] An indicative regional master plan for interconnections was completed in 2002. RPTCC was created in 2004 and has met 27 times since then, facilitating multilateral cooperation at high levels of the government and providing strategic direction. Within a year of its establishment, the RPTCC had prepared technical and commercial guidelines to support the establishment of a regional power market in the GMS in the draft Regional Power Trade Operating Agreement.

GMS envisions that regional power trade would develop in four stages:[92]

i. Stage 1: IPP in one country selling power to the utility in the neighboring country.
ii. Stage 2: Trading takes place between any pair of GMS countries, eventually including the use of power wheeling through a third country. At this stage, power trade is associated primarily with contracted capacity from dedicated projects.
iii. Stage 3: Interconnections are developed specifically for power trade and third parties can trade power through the cross-border lines.
iv. Stage 4: A regional competitive market where multiple buyers and sellers may trade across countries.

Since around 2000, regional studies have identified cross-border interconnection projects to promote power trade/exchanges between countries, primarily focused on minimizing costs. Table 7 includes a non-exhaustive list of studies conducted to expand power trade in the region.

Table 7. Studies Conducted to Facilitate Greater Regional Market Integration

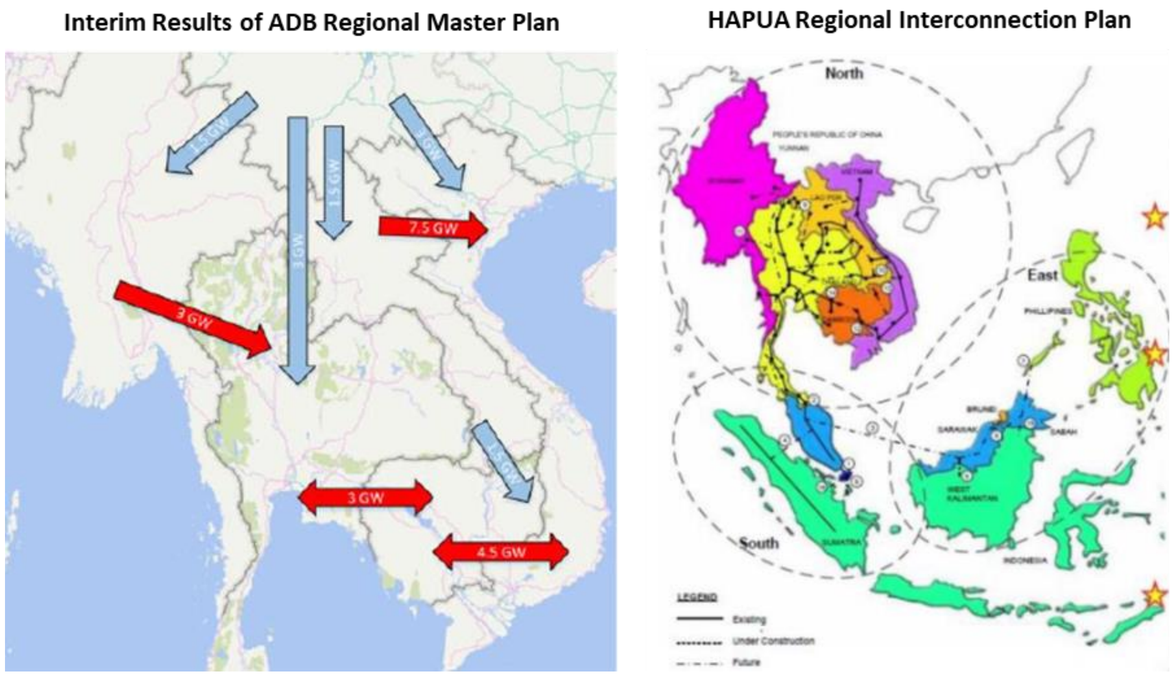
Study	Framework/Funded By	Year
Subregional Energy Sector Study for the GMS	GMS/ADB	1993
Power Trade Strategy Study	World Bank	1999

[91] "Greater Mekong Subregion Power Trade and Interconnection – 2 Decades of Cooperation." ADB. September 2012.
[92] Ibid.

Regional Indicative Master Plan on Power Interconnection	GMS/ADB	2002
AIMS I	HAPUA	2003
Building a Sustainable Energy Future	GMS/ADB	2009
Update of the Regional Indicative Master Plan on Power Interconnection	GMS/ADB	2010
AIMS II	HAPUA	2010
Regional Power Master Plan, Harmonizing the Greater Mekong Subregion Power Systems to Facilitate Regional Power Trade	GMS/ADB	2019
GMS Power Market Development	World Bank	2019
AIMS III	HAPUA	2021

The different studies can reflect several competing objectives and priorities – those of the funding organization, member countries, or the cooperation framework. Figure 32 below shows two different visions of regional integration under different frameworks – GMS on the left and HAPUA on the right. The GMS/ADB plan indicates substantial amounts of power being exported from China into Myanmar, Thailand, Laos, and Vietnam. On the other hand, the HAPUA framework has a broader geographic focus but does not count China amongst its members. It is important to note such differences in evaluating the results of various studies, even before study methodology and assumptions are considered.

Figure 32. Visions of Regional Integration



Source: JICA study on Power Network System Master Plan in Lao PDR, citing ADB and ACE presentations.

A few common elements across different studies on regional power sector integration are:

- reliance on Lao PDR's abundant hydro resources for low-cost supply during the wet season;

- electricity demand growth in Thailand and Vietnam driving their desire for more cross-border interconnections;
- reliance on the stronger grids of Thailand and Vietnam for grid stability; and
- a near-term focus on cross-border generation interties to gradually lead to greater grid-to-grid connections.

The region has also had its first multilateral power trade under the LTM-PIP project in which power from Lao PDR is wheeled through Thailand to Malaysia. The successful implementation of the LTM-PIP, which has been expanded from an initial 100 MW to 300 MW, may provide impetus for expanded multilateral trade under similar arrangements. The LTM-PIP is also being extended to include Singapore, which would import 100 MW from Malaysia during an initial two-year trial period starting in late 2021.

3. REVIEW OF REGIONAL TRANSMISSION STUDIES

This section provides summary reviews of recent regional expansion plans and transmission studies that have been performed with funding by major donors and other regional entities. The reviews provide the basic facts and background of each study, summarize the study's findings, and then present the Delphos Team's own findings on the study.

3.1 AIMS III

Background: The "Third ASEAN Interconnection Master Plan Study" (AIMS III), still in progress as of the writing of the present report, was funded by USAID Clean Power Asia and is being produced in coordination with HAPUA (through ACE). GE India Industrial Private Limited – GE Energy Consulting is the lead consultant on the study.

The AIMS III study is the current iteration of earlier versions: AIMS I was released in 2003 and AIMS II in 2010. The AIMS III study was kicked off in September 2018, with an original target completion in 2020, though the project has faced delays related to COVID and data acquisition.

The main objectives of AIMS III are to determine the combined generation and transmission needs for Southeast Asia, the opportunities for increasing bilateral and multilateral power trade, and the potential for increasing the amount of variable renewable energy (VRE) on the ASEAN power grid. Work was planned to include three phases, as shown in Figure 33. As of the writing of the present report, it was uncertain when Phase 3, "Multilateral Market", would be carried out.

Snapshot: AIMS III
Funded by: USAID
Performed by: GE (India)
Report Date(s): Nov-Dec, 2020
Focus: ASEAN
Summary:

- This is an indicative regional master plan providing conceptual and directional guidance to potential regional interconnection efforts.
- This study does not purport to develop proposed individual transmission projects or other transmission infrastructure investments beyond the conceptual level.
- Significant data gaps resulted in modeling adjustments which, while reasonable in the circumstances, amount in the aggregate to important over-simplifications of regional grids and their existing and future interconnections.
- The LMS grid topology that was modeled incorrectly depicts more grid-to-grid integration than exists or is currently planned, though the small size of the modeled links suggests minimal modeling impact.
- Assumed solar PV LCOEs are strikingly high compared to actual values achieved in the region and internationally in recent years.

Figure 33. AIMS III Phases and Focus of the Present Report

Focus of Analysis (Phase I and Phase 2)

Phases	Activities
Phase I – Capacity Expansion Planning	I.1 Data Collection and Gap Analysis
	I.2 RE Resource Assessment
	I.3 Capacity Expansion Planning: Generation, Transmission, RE Planning
	I.4 Socio-Economic-Environment Analysis
	I.5 Production Cost Simulation
Phase 2 – Grid Study	2.1 Grid Analysis
Phase 3 - Multilateral Market	3.1 Multilateral Power Trade Market
	3.2 Regulatory Framework
	3.3 Grid Code and Technical Standards

Source: AIMS III, Phase 1, page 7. "Focus of Analysis" added by Delphos International.

The Delphos Team reviewed the following draft versions of the Phase 1 and Phase 2 studies.

- "FINAL INTERIM & Phase-1 Report (Rev.3)", 30 November 2020. 993 pages.
- "Preliminary Phase-2 Report – Steady State Grid Analysis", 24 December 2020. 219 pages; and, "Deliverable: Phase-II Report – Steady State Grid Analysis – Steady State Grid Analysis – Revision 1", 16 April 2021. 272 pages. (Note: both documents present detail on "Phase II, Task (7a): Steady State Grid Analysis").

These reports do not represent the full body of deliverables produced by GE under AIMS III and made available to the Delphos Team. Below are examples of other materials provided to the Delphos Team. The Delphos Team does not have access to all materials produced.

- "ASEAN INTERCONNECTION MASTERPLAN STUDY (AIMS) III INTERIM REPORT PHASE I", 31, July 2020. 48 pages. Its annexes:
    - "Annex A: Interim Meeting Feedback & Discussions arranged by country". 24 pages.
    - "ANNEX B: Capacity Expansion Planning - Detailed country information". 417 pages.

  The Delphos Team did not review these documents in detail as they represent an earlier version of the Phase 1 report.
- A deck produced in April 2021 by GE in response to an information request by the Delphos Team providing additional detail on data gaps and modeling approach.
- A deck: "The ASEAN Interconnection Masterplan Study (AIMS) III Phase I Results & Findings (Regional/Sub Regional) / AIMS III: The Final Meeting of Phase 1 and Phase 2." 22 April 2021.

Methodology: Work streams for the AIMS III have received input and review by ASEAN Member States and a Technical Review Group (TRG), with members including the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), Hawaii Natural Energy Institute (HNEI), and National Renewable Energy Laboratory (NREL).

The figure above provides a capsule summary of the overall work plan in the form of the named "Activities" performed in each Phase, with work in earlier stages informing (and being required by) later stages. In more detail, the work in each Phase is as follows.[93]

- Phase 1 develops generating capacity and regional transmission expansion plans for several scenarios.
  - These expansion plans build upon national-level information about existing systems and expansion planning information. Demand forecasts provided by national authorities are extended through the modeling period, where necessary.
  - VRE resource assessments for the entire ASEAN region are developed, guiding the grid location of new VRE projects.
  - Assumptions for a range of candidate new generating technologies and fuel inputs (plus solar/wind resources, as mentioned) are developed.
  - An initial set of capacity/transmission expansion plans are developed using PLEXOS, a model specialized for this purpose. Candidate projects are added to each national system/transmission zone in each scenario such that each new entrant receives its required return on capital based on its simulated performance in (and earnings from) the power market into which it sells. A similar approach is used to assess addition of new cross-border transmission projects. The modeling software has the objective of achieving minimum system cost on a discounted basis over the modeling horizon for each interconnected region, subject to ensuring power system reliability at a specified level. That is, the model implicitly assumes centralized dispatch and complete commercial integration within each interconnected region. Note that generation and transmission investments are "co-optimized" by the model such that (in principle) neither investment type is favored.
  - The initial capacity/transmission expansion plans are then validated with more detailed production cost modeling using GE-MAPS.
- Phase 2 reviews the technical feasibility of the interconnection projects that were identified as proposed projects in Phase 1, with more detailed modeling of ASEAN grid stability and reliability under the different scenarios. PSS-E is used for this Phase.
  - Modeling work in this Phase begins with initial assumed grid conditions at specific points in time, such as peak demand, minimum demand and so on. The underlying conditions at those times reflect demand levels, system dispatch to meet that demand, and flows across the grid. These initial grid conditions are taken from the production cost modeling in Phase 1.
  - Deliverables were expected to include an integrated ASEAN Grid model in PSS/e format; power flow and Contingency analysis results; short circuit analysis results; stability analysis results; and recommendations to mitigate any constraints found in proposed interconnections.

[93] The focus of the discussion in the present report is on assessing transmission projects in terms of their ability to support regional trade and VRE entry. In this sense, the present report takes the benefits of VRE for granted and therefore does not examine the socioeconomic/environmental portion of Phase I.

- The modeling work relied on assumptions to develop grid models for individual countries since the consultants did not receive complete data from most countries. The capacity and type of interconnections were based on capacity expansion plans from the Phase 1 study and not actual planned or proposed projects. Likewise, the substations on either side of the border were also indicative. The power flow analysis assumed that individual countries added appropriate reactive power sources to mitigate constraints.[94]

Figure 34, below, shows the models used by GE in its AIMS III modeling. These are all well established and highly regarded modeling platforms.

Figure 34. Models Used in AIMS III

S. No.	Task	Tool Utilized
1.	RE Resource Assessment	RE Data Explorer, Windmap, PVSyst
2.	Capacity Expansion Planning	PLEXOS
3.	Production Cost Simulations	GE-MAPS
4.	Grid Analysis	PSS/E

Source: AIMS III, Phase 1, page 8.

The AIMS III modeling period covers 2020 through 2040. Phase 1 modeling was conducted for each year but Phase 2 modeling was limited to each five years (reflecting the computational intensity of the underlying work), beginning in 2020.

The Phase 1 modeling using PLEXOS is organized around national-level nodes, organized into regional blocks, as shown in Figure 35. In the figure, existing transmission links are represented by solid lines and proposed links with dashed lines. Within each node, there are assumed to be no transmission constraints. Trade between nodes occurs through simplified versions of existing and new transmission facilities. These transmission links are modeled as trade-supporting but not as supporting the capacity reserve margin requirements of individual nodes (countries).[95]

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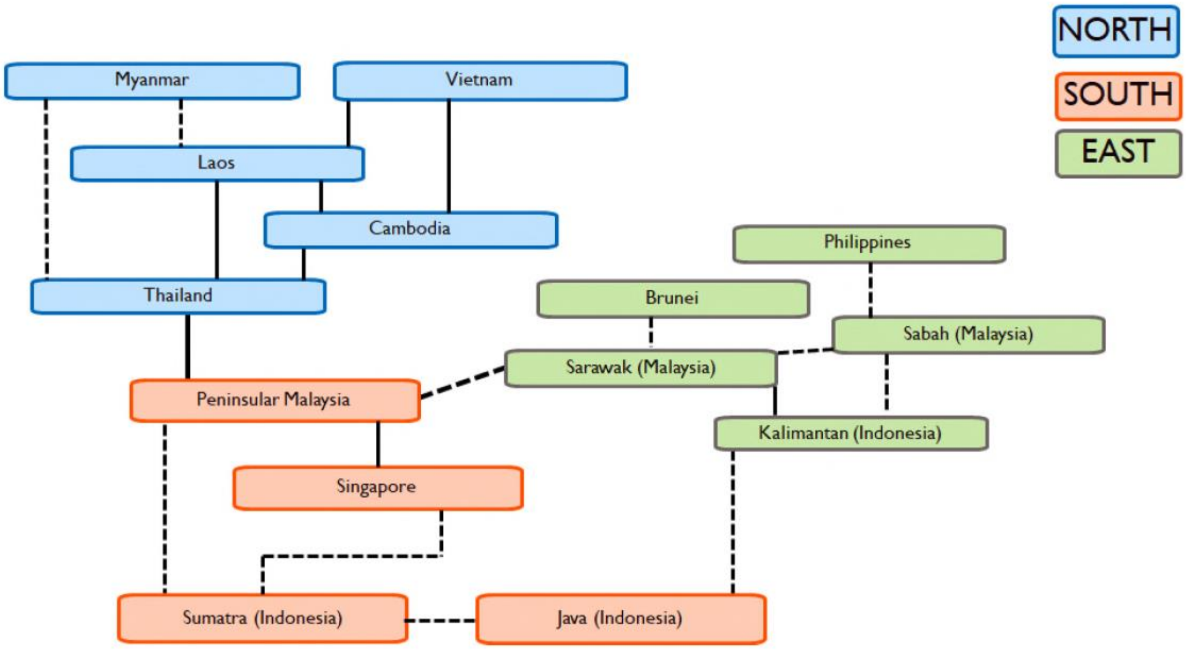
[94] AIMS III, Phase 2 Preliminary Report, page 17.
[95] AIMS III, Phase 1, page 79.

Figure 35. Nodes and Blocks Modeled in AIMS III



Source: AIMS III, Phase 1, page 37.

The existing transmission links (2020) and new links (2025 and thereafter) that are assumed for the LMS, as stated in the Phase II report, are shown in the figure below. As indicated in the notes at the bottom of the figure, 2020 links with Thailand are not intended to be actual new transmission lines but rather are rollups of existing links operating at a voltage (115 kV) below what was modeled for Thailand (230 kV and 500 kV).

Figure 36. Transmission Links Assumed in Base Scenario for "Northern Region"[96]

Year	Interconnection	From S/S AMS	To S/S AMS	Capacity planned as per CEP	Voltage Level	Line Length	Technology	Conductor Size	Thermal rating in MVA/ckt
2020	Cambodia - Vietnam	Chau Doc Cambodia	Takeo Vietnam	200MW	230kV	160km	HVAC D/C#	Twin – 400sqmm	344
	Lao PDR - Vietnam	Nam Mo Lao PDR	Ban Ve Vietnam	200MW	230kV	90km	HVAC D/C	Single 410sqmm	860
	Lao PDR – Thailand*	Nbo and Tve Lao PDR	Khon kean Thailand	700MW	230kV	100km	HVAC D/C	Twin – 630sqmm	860
	Cambodia - Thailand*	IE Cambodia	Aranyaprathet Thailand	120MW	230kV	50km	HVAC D/C	Single 240sqmm	209
2025	Lao PDR - Myanmar	M Long Lao PDR	Keng Tung Myanmar	306MW	230kV	240km	HVAC D/C	Twin 795 MCM	690
	Lao PDR - Cambodia	Ban Hat Lao PDR	Stung Treng Cambodia	306MW	230kV	85km	HVAC D/C	Quad 630sqmm	883
2030	Thailand -Myanmar	Tha-Tako Thailand	Hutgyi Myanmar	920MW	500kV	370km	HVAC D/C	Twin 795 MCM	1500
	Cambodia - Thailand	Battambang Cambodia	Prachin Buri Thailand	500MW	230kV	240km	HVAC D/C	Twin 630sqmm	860
	Lao PDR -Vietnam	Ban Hat Lao PDR	Pleiku Vietnam	400MW	500kV	260km	HVAC D/C	Twin 630sqmm	1870
2035-2040	Cambodia-Vietnam	Seung Cambodia	Tay-Ninh Vietnam	1353MW	500kV	100km	HVAC D/C	Twin 630sqmm	1870

*As existing interconnection between Thailand - Lao PDR & Thailand-Cambodia are on 115kV and the network model considered is above 230kV, all the existing 115kV interconnections are modelled as equivalent 230kV interconnection from major substations modelled

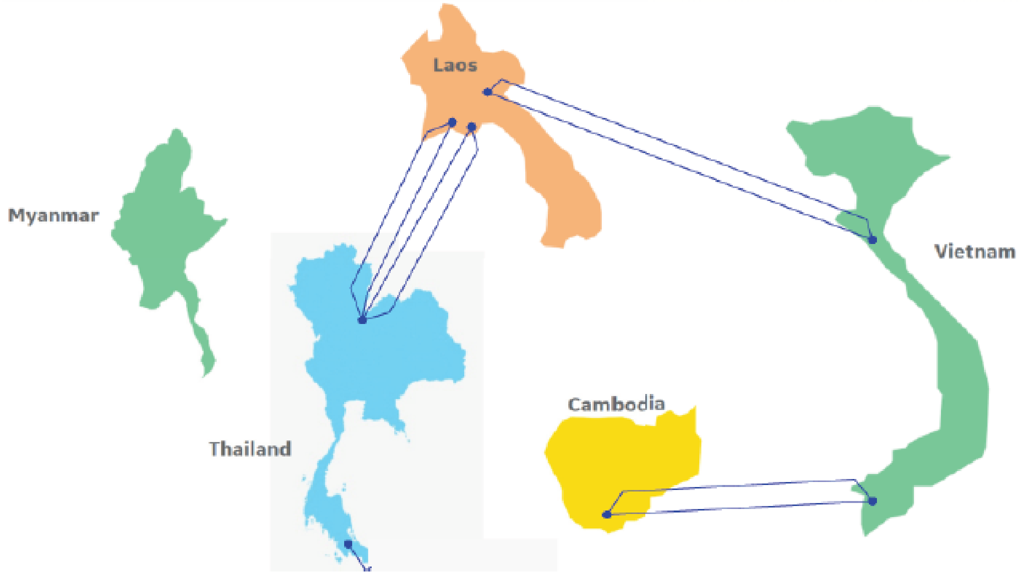
Double Circuit

Source: AIMS III, Phase I, page 102.

[96] AIMS III, Phase II, page 102.

Phase II modeling assumed a slightly different network configuration for the LMS than Phase I, as can be seen by comparing Figure 35 and Figure 37. Specifically, in the Phase II configuration, there are (correctly) no grid-to-grid links[97] between Lao PDR and Cambodia and between Thailand and Cambodia. Confusingly, Figure 36, which is from the Phase II report, and purports to show the modeled interconnections for Phase II in more detail, includes a Thailand to Cambodia link. Adding to the confusion is the text describing the modeled interconnections status: "Currently there are 4 interconnections (Cambodia-Vietnam, Cambodia-Thailand, Lao PDR-Vietnam & Lao PDR-Thailand) in northern region mainly HV AC lines at 115 kV or 230kV level."[98]

Figure 37. Existing LMS Network Configuration in Phase II



Source: AIMS III, Phase I, page 103.

Four modeling scenarios were developed and evaluated across Phase 1 and Phase 2, as summarized below. These scenarios vary principally in their treatment of "committed projects" (that is, those that are assumed to be completed and are taken as "hard wired" by the models) versus those that are "optimized" (that is, candidate projects are evaluated for their ability to cover costs, including returns on capital, and reduce overall system costs). It appears that GE took national-level power development plans as definitive with respect to hydro in all scenarios while taking different approaches to other technologies in the scenarios. Since scenario definition is a fundamental driver of the modeling approach and findings, the excerpts below are included verbatim from the AIMS III Phase 1 report.[99]

- *Base Scenario: While the committed projects are fully respected and treated as fixed plans, those non committed thermal power plants in PDP will be re-optimized. VRE will be as per PDP, and beyond PDP will be increased proportional to the demand growth. No new interconnection will be added to the existing ones.*
- *Optimum RE Scenario: the aim was to develop optimized thermal, VRE and transmission interconnections projections. For this purpose, all capacity beyond the PDP was*

[97] As noted elsewhere in the present report, there are grid-to-grid (load switchable) links between these countries, but there are no "regular" grid-to-grid links.
[98] AIMS III, Phase II, page 100.
[99] AIMS III, Phase 1, pages 39-40. See also Table 2-3 on pages 42-43.

reoptimized (except hydro). The non-committed thermal plants under PDP namely the ones where construction has not commenced or where the PPA has not been signed were also re-optimized under this scenario. This was done to make this case outputs purely taken on an economic basis (with minimal 'hard inputs') by PLEXOS which also co-optimizes generation and interconnection requirements. We are referring to this as free economic optimization.

- *ASEAN RE Target Scenario: under this scenario, the main point of difference with the Optimum RE Scenario was that the VRE capacity additions were provided as a firm input in PLEXOS, determined in line with the projections under Progressive Scenario (APS) as laid out in the ASEAN Energy Outlook 5 (AEO5) for key study years of 2025, 2030, and 2040. These targets were set to achieve regional RE target in energy mix as per AEO5 (10-12% of VRE by 2025 and 15% by 2040).*
- *High RE Target Scenario: in this scenario, the target VRE capacity additions were determined considering higher aspiration level of RE penetration in the ASEAN Region (25%-30% in the generation mix by 2040). For this purpose, the targets under the previous scenario were suitably enhanced. This VRE penetration is proposed as an aspirational target by 2040 and is considered as per the suggestions from USAID and ACE.*

Generation optimization (i.e., evaluation of new entry candidates) was restricted as summarized below, based on feedback from AMS and "extant preferences" (in the words of the AIMS III study)[100].

- Singapore – only gas additions;
- Lao PDR – only coal capacity additions;
- Kalimantan – add gas units such that capacity equals at least 30% of coal capacity additions; and,
- Myanmar – new coal addition is capped at 1,000 MW.[101]

Data gaps were substantial and particularly problematic for Phase 2. Examples for the LMS are provided below:

- Lao PDR - missing dynamic data in PSS/E format for 2019;
- Cambodia - PSS/E or equivalent software files for Future system beyond 2023. Note that the simplified modeling treatment of Cambodia and other information suggests that limited information was provided about the existing system as well;
- Myanmar - missing PSS/E or equivalent software files for existing and future system and PSS/E or equivalent software files for dynamic model for existing system;

[100] AIMS III, Phase 1, page 78.
[101] While the AIMS III report does not discuss the matter further, Myanmar is known to have only limited amounts of poor quality coal and there has been significant political opposition as well.

- Vietnam – missing PSS/E or equivalent software files for existing system, PSS/E or equivalent software files for dynamic model for existing system, and power development master plan with transmission planning[102]; and,
- Thailand PSS/E or equivalent software files for dynamic model for existing system.

The AIMS III consultant made reasonable efforts to adjust for missing information, though, as discussed later in the present report's findings on the AIMS III study, these adjustments have important modeling implications.

The approach to addressing data gaps for Phase 2[103] is described below.[104]

- Approach I – Reduced Transmission Equivalent Model (Myanmar, Lao PDR) was followed for countries where PSS/E software files or a substantial amount of data in other formats was provided. The software network model received was reduced to an equivalent model retaining the highest voltage and one voltage level below, with connections on the lower voltage network represented as aggregated at higher voltages. Thus, generation and load connected to the higher voltage network were connected at their actual bus connection, whereas load and generation connected at lower voltages were lumped to the nearest higher voltage bus.
- Approach II – Nodal Equivalent Model (Cambodia) was followed for geographically compact countries which provided only limited models and data. A one-to-three node equivalent model was developed (three nodes in the case of Cambodia) by lumping the equivalent load and generation (represented separately by fuel type) at each node.
- Approach III – Regional Equivalent Model (Thailand and Vietnam) was followed for large countries where relevant grid and other information was missing. The national grid system was divided into multiple sub-regions. Each sub-region was represented by one or two buses at the highest voltage level and total generation (represented separately by fuel type) and load in that area was lumped at those sub-regional buses. Inter-regional transmission was modelled based on the information provided.

In short, all five LMS grids were substantially simplified for modeling purposes. Figure 38 provides examples of two of the three simplifications described above.

[102] A modelling summary deck produced by GE described the data challenge as follows: "Almost negligible grid data available for modeling".
[103] The Phase 1 study provides little detail on how missing grid information was accommodated for production cost modelling.
[104] AIMS Phase II, pp 24-25.

Figure 38. Examples of Grid Modeling Simplifications Employed for AIMS III Phase II

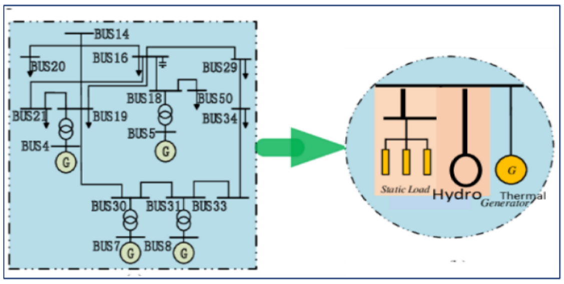


Figure 2-2: Modelling Architecture of Nodal Equivalent Model

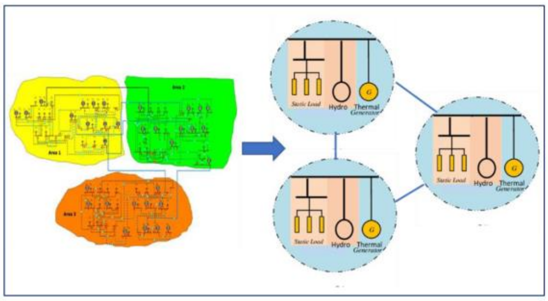


Figure 2-3: Modelling Architecture of Regional Equivalent Model

Source: AIMS III, Phase II, page 25-26.

Findings of the AIMS III Study: The Phase I report does not summarize findings. Rather, it presents findings for each scenario, regional grouping, and country separately, over its 993 pages.

To the extent that summary findings can be gleaned by comparing "production costs" across scenarios[105], the utility of these values is not clear. It appears Phase I modeling takes "production costs" as the sum of fuel costs and variable O&M; that is, these are "variable" production costs and do not include fixed O&M or capital recovery. It is believed that the methodology employed to trigger entry of candidate generating plants (and transmission projects) <u>does address</u> the totality of relevant costs[106]. Nonetheless, if the only cost results presented are for variable production costs, there is little that can be inferred about <u>overall</u> cost outcomes across scenarios. Thus, for instance, results show lower production costs under the VRE scenarios compared to the Base Case scenario, as would be expected no matter what, given that VRE has zero or near-zero production cost; but it is not possible to conclude based on the information provided that these represented the lowest cost system expansion options, when other costs are counted. Other costs would include capital recovery cost, fixed O&M, and any additional system investments necessary to provide capacity backing/grid support. To be sure, there are non-market benefits to VRE as well that should be reflected but, at minimum, the core known cost categories must be presented.

While the Phase 1 report itself does not summarize findings, an 83 slide presentation summary, apparently provided to stakeholders, does do so.[107] The summary includes a "total cost" table, breaking out "total build costs" and "cumulative production costs", as excerpted in the figure below. As can be seen, the lowest cost scenarios are the renewable energy ("RE") scenarios. It is noteworthy that results are so close, with less than 1% total cost difference across all scenarios, 1/10th of 1% separating the two RE scenarios, and no difference at all between the Base and ASEAN RE Target scenarios. As explained in more detail in the "findings" discussion below, part of the explanation for the small spread in total costs across the scenarios is the high assumed LCOEs for VRE.

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[105] See, for instance, Section 17 "SUB-REGIONAL RESULTS – EASTERN REGION".

[106] It is understood that the objective function of the expansion planning phase was to minimize the discounted sum of capital investments, production costs and fixed O&M over the planning horizon. Other modelling approaches seek to minimize marginal cost (that is, "avoided cost"). In theory, these two approaches should produce identical results.

[107] "The ASEAN Interconnection Masterplan Study (AIMS) III Phase I Results & Findings (Regional/Sub Regional) AIMS III: The Final Meeting of Phase 1 and Phase 2". Slide deck. April 22, 2021.

Figure 39. NPV of Total Costs for Scenarios

Particulars	Base	Optimum RE	ASEAN RE Target	High RE Target
Total Build costs	USD 184.64	USD 185.76	USD 211.93	USD 247.63
Cumulative Production Costs	USD 586.32	USD 579.29	USD 559.02	USD 516.32
Total Cost (Build + Production Costs)	US$ 771	US$ 765	US$ 771	US$ 764
vRE Penetration in 2040 in terms of Generation (%)	6%	8%	8%	25%

Source: "The ASEAN Interconnection Masterplan Study (AIMS) III Phase I Results & Findings (Regional/Sub Regional) AIMS III: The Final Meeting of Phase 1 and Phase 2". Slide deck. April 22, 2021. Slide 81.

The main finding of the Phase II report is that it is feasible to integrate the transmission systems of ASEAN and operate the combined systems at "N-1 contingency" level over the study horizon. This finding is qualified by the observation that in-country grid-level reinforcements (" – national level grid strengthening on both sides of interconnection[s]") will be necessary to achieve the stated goal under all development cases. Suitable reinforcements are proposed to support the power flows imposed by the chosen interconnections. Figure 40 shows the findings presented in the Phase II report.[108]

Figure 40. AIMS III, Phase II Findings

1. The power flow, (N-1) contingency and short circuit analysis was performed to evaluate the steady state performance of the ASEAN Grid for existing system (2020) and 4 future horizon years (2025, 2030, 2035 and 2040). For each horizon year, three cases were investigated including Base Case, ASEAN RE and Optimum RE. Five operating scenarios per horizon year were studied.
2. For all the cross-border interconnections proposed as part of Phase I capacity expansion planning study, the technology options and high-level conductor configurations were suggested. Based on that, interconnection models were developed.
3. In order to facilitate the proposed cross-border power transfer for optimum utilization of resources within the ASEAN Grid, National level grid strengthening within the AMS on both sides of interconnection will be required especially in case of very high interconnection capacities.
4. Based on the power flow analysis, it was observed that, with adequate AMS level grid strengthening schemes as proposed, for all horizon years, the proposed interconnections are feasible.
5. Based on the (N-1) contingency analysis, it was observed that all the interconnections are complaint with (N-1) contingency philosophy, except Peninsular Malaysia to Singapore connection. To make it compliant, one more circuit needs to be added for this interconnection.
6. The short circuit analysis showed that the maximum short circuit contribution for 3-phase faults was within the standard switchgear rating. Due to unavailability of sequence impedance data, the short circuit levels for S-L-G faults could not be evaluated.
7. Overall, from the steady state analysis, it can be concluded that with the adequate grid strengthening at national grid level of individual AMS, the proposed cross-border interconnections can be feasible for three scenarios (Base case, ASEAN RE and Optimum RE). However, the feasibility of the interconnections cannot be confirmed without performing the stability analysis, which will be included in the next revision of this report.
8. The high renewable scenario seems very challenging from practical implementation perspective. The detailed pre-feasibility analysis may result into nonviability of these interconnections technically and economically. Hence, High RE scenario was not considered for stability analysis.

Source: AIMS III, Phase II, revision 1, page 266.

Findings by Delphos Team Based on Review of AIMS III: The Team's findings are presented below, first for the overall effort and then for each of the Phase I and Phase II components.

[108] The figure shows findings from the April 2021 "revision 1" version of the report.

Overall Findings

1. The AIMS III study represents an extraordinarily complex, data and labor-intensive effort. For reference, the authors of the present report have considerable experience modeling national-level power systems, sometimes half a dozen systems together, but never ten national systems together. Underlying complexity is added to by linguistic differences across ASEAN, disparate power systems and grid codes (or lack thereof), data challenges and, one supposes, numerous countervailing pressures emanating from AMS and others as to what assumptions to use and how to approach the modeling. COVID 19 has doubtlessly impeded the project's progress with respect to its original timeline, as well as complicated efforts to obtain information.
2. The GE India team undertaking the study is well-qualified for the work and the models used are all well-established in the industry.
3. The overall modeling approach is sensible.
4. Reasonable accommodations were made to address major data gaps, based on information about assumptions presented in the AIMS III report. It must be noted here, however, that there are broad categories of information and assumptions that are not presented in the documents reviewed by the Delphos Team, such as: the data that was available and the approach to allocation of demand on each national grid; the specific generation new entry profiles for each country; and, the details of grid investments at the national level required to enable the proposed cross-border projects (as well as how such costs are reflected in scenario evaluation).
5. The existence of data gaps in a study of this magnitude in Southeast Asia is not surprising and it is certainly not the fault of the study's lead consultant, but the breadth and depth of the data gaps are nonetheless a crucial indicator of the lack of technical and institutional readiness and/or willingness of the nations of the region for playing their respective parts in progressing towards the vision represented by the AIMS III grid study result.
6. "Scenario" specification is reasonable, on balance. The Base Scenario is not really a "best guess" or "expected" scenario, as one might expect from its title. The Base Scenario is intended to reflect national power development plans (PDPs). Because of the way the "committed" new entry of different technologies is developed (based in part on the PDPs) and given the treatment of VRE new entry (uncommitted VRE new entry enters in proportion to load growth), the Base Scenario locks in implausibly low levels of VRE across ASEAN. It is understood that such a Base Scenario may have been necessary to address the expectation of AMS that their own PDPs would not be (excessively) undermined by the AIMS III Base Scenario, even if it is widely known in the industry that PDPs are almost always optimistic as to demand growth and the timing of new entry. Understood this way - and considering that the other scenarios involve large amounts of VRE in different mixes - it is noted that the Scenarios provide a good range of new entry of different technologies.
7. As part of the overall modeling process, the AIMS III study develops a set of proposed cross-border transmission projects. These projects are not intended to be taken as actual, specific, projects that might be progressed through the transmission project development cycle. Rather, the projects are generic and conceptual in nature, connecting nodes in simplified depictions of transmission grids. While substations are identified for the connections at either end of a line, within the modeling framework (with simplified grids), these grid locations are not definitive, by any means.

8. It appears that the assumed nature of existing cross-border interconnections in the LMS may be inaccurate. (At the least, there are confusing and contradictory descriptions of those interconnections, as discussed above.) As can be seen in Figure 35, Figure 36 and Figure 37, existing links are modeled in Phase I across all LMS countries except for Myanmar, forming a single interconnected region.[109] Within the modeling framework, it would be possible, therefore, to meet demand in, say, Vietnam, with any combination of resources in Thailand (or elsewhere in the interconnected region), subject to the transmission constraints between Thailand and Vietnam. However, it is known that there are no grid-to-grid connections (other than load switchable connections grid-to-grid connections) between Lao PDR and Vietnam or between Lao PDR and Cambodia. Rather, there are numerous IPP-to-foreign grid projects, generally with IPPs located in Lao and selling into Vietnam and Cambodia. (There are also numerous IPP-to-foreign grid projects in Lao PDR selling into Thailand, but those appear to have been handled correctly). In other words, there are currently three separate interconnected grids in the LMS: Myanmar, Thailand – Lao PDR, and Vietnam – Cambodia, rather than the two that are modeled (Myanmar and the rest). There are several implications:
    a. Dispatch and pricing outcomes will be affected, though perhaps not substantially, given the relatively small capacities of the "extra" grid-to-grid interconnections that were modeled.
    b. The incorrect depiction of existing grid-to-grid linkages forming a single interconnected market comprising Thailand, Vietnam, Lao PDR and Cambodia radically misrepresents underlying grid coordination and control issues. Such a depiction suggests a high level of grid code and operational harmonization that simply does not exist. The ground reality, as documented throughout the present report, is that most of the Lao PDR grid is controlled directly or implicitly by Thailand; the Cambodian grid is controlled implicitly by Vietnam; there are no existing or planned (at a reasonably advanced level) grid-to-grid connections of these two blocks; and at least one credible and detailed analysis[110] argues persuasively that such a grid-to-grid interconnection is something that should only be considered post 2030, once a long list of grid reinforcements, grid control, and grid code harmonization, is accomplished.
9. Related to item [8] above, it is striking that there is no discussion in either Phase I or Phase II of a fundamental regional integration subject: whether national grids in the region are or should be synchronously interconnected, as opposed to asynchronously[111]. While the issue is presumed to be a key subject for Phase III, it is also a critically important topic for Phase I and Phase II inasmuch as the decision largely determines the interconnection technology (HVAC versus HVDC or AC/DC back-to-back arrangements) and is therefore a directly relevant modeling input at both the technical and economic levels. Moreover, for the LMS, AIMS III modeling appears to assume (incorrectly) regionwide grid synchronization from 2020 (the start of the modeling period).[112] The LMS is modeled (correctly) as connected via HVDC to peninsular Malaysia.[113]

[109] In Phase I, as noted, there are links between Lao PDR and Cambodia and between Thailand and Cambodia that were cut (it appears) in Phase II; nonetheless, the four countries of Thailand, Cambodia, Lao PDR and Vietnam still form an interconnected network.
[110] JICA Study on Lao PDR Power Network System Master Plan, Sections 19.3 and 19.4.
[111] The words "synchronous" and "asynchronous", and related terms do not appear in either Phase I or Phase II reports.
[112] AIMS III, Phase I, page 79 indicates HVAC technology for all overland paths.
[113] AIMS III, Phase II, page 115.

10. It is notable that there is essentially zero mention in either the Phase I or Phase II studies of China or Chinese provinces neighboring the LMS, especially considering that there are significant existing and planned cross-border projects (particularly those involving Myanmar-Yunnan and Lao PDR-Yunnan) and considering that other regional studies do include Chinese projects. Obviously, for modeling purposes, one does need to determine the modeling frontier as part of the overall decision-making process about market topology, and in a modeling framework that already involves ten countries, it is certainly appropriate to exclude the 11^{th}. However, there should at the least be a brief discussion of the subject.

11. As described above, various regional "blocks" were specified for modeling purposes. Peninsular Malaysia was included in the "South" block while LMS is the "North" block. While this decision may well make modeling sense for AIMS III (which examines ASEAN-wide trade), it must be noted that analysis of market integration in the LMS, through separate studies, really must include Malaysia. At the market physical level, Thailand is connected to Malaysia via a 230 kV 300 MW HVDC tie, and the AIMS III modeling assumes the tie will be doubled to 600 MW at 230 kV in 2025 and a new 500 kV HVDC link added in 2035. Thus, currently the Thailand-Malaysia tie is larger than any single grid-to-grid tie in the LMS and it is assumed to remain the largest through 2025. At the commercial level, one of the most significant regional market integration developments is the Lao-Thailand Malaysia Power Integration Project (LTM-PIP) project, involving sales from Lao PDR, wheeled across Thailand, and sold to Malaysia (see Section 2.1.3.6). This type of unidirectional trading structure is replicable in the region: for instance, Lao PDR through Thailand to Myanmar, or extending through Malaysia to Singapore. Such a structure may even have bearing on proposed physical cross border links between countries within the LMS, such as between Lao PDR and Myanmar versus Thailand to Myanmar.

12. A summary presentation of findings is required for both Phase I and Phase II that would allow the reader to grasp wholistically the level and type of trading modeled under each scenario. As an example for Phase I, average net and peak flows across interfaces should be presented[114], as should marginal cost (or total system cost – but not solely "production cost") and the magnitude of total net cost differences should be presented. It is noted that a slide deck summary of Phase 1 and II has been shared with stakeholders (see discussion above); inclusion of a similar summary as part of an executive summary to the Phase 1 and II studies would be helpful. If that is not done, then it is recommended that the public version of AIMS III documents should include the summary slide deck.

13. Overall, the AIMS III grid study must be understood for what it is (an indicative regional master plan) and what it is not (a detailed regional transmission plan developing specific recommended investments). Master planning is a valuable exercise for illuminating a strategic direction, which may be optimal under a particular set of circumstances. The master plan gives guidance that provides the ability to make better choices among alternatives that are encountered on the road to incremental development. Master planning allows the creation of components ("building blocks") with characteristics that are supportive of the eventually-to-be-completed structure. By contrast, and particularly in a regional planning context, detailed and actionable transmission expansion plans would develop the components in detail, but without any clear vision of the "big picture". Both types of exercises – (i) regional master planning and (ii) detailed, more focused,

[114] The AIMS III Phase II report does report flows for selected periods but the Phase I report does not.

more local, and are more actionable transmission expansion planning – are therefore critically important and tightly interrelated.

Phase I Findings of Delphos Team

14. The levelized cost of energy (LCOE) assumptions for solar PV for ASEAN as a whole and for LMS in particular (as a focus of the present report) are surprisingly high and show unexpectedly low rates of decline, particularly given their high staring points. For instance, some solar LCOE values assumed for the region are as follows: Indonesia - $125/MWh in 2020/25 & $105/MWh in 2036/40; Cambodia - $69/MWh in 2020/25 & $58/MWh in 2036/40; Thailand - $62/MWh in 2020/25 & $52/MWh in 2036/40; Vietnam - $56/MWh in 2020/25 & in $48/MWh in 2036/40; and Myanmar - $71/MWh in 2020/25 & in $60/MWh in 2036/40. These values contrast dramatically with the $39/MWh price secured in a 2019 Cambodia tender[115], the $35/MWh - $51/MWh secured in a 2020 Myanmar tender[116], and trends elsewhere, including numerous major tenders internationally around the world yielding sub-$50/MWh results and some below $20/MWh.[117] The impact of assuming significantly higher solar PV LCOEs than would appear realistic is to understate the role that solar PV (and more generally, VRE) can play in reducing the regional cost of energy under the modeling scenarios. As noted above, the Renewable Energy scenarios modeled were only 1% or so lower on a total cost basis than the other scenarios; if lower VRE LCOEs had been used, the differential would have been larger.
15. The Myanmar Phase I modeling (which sets the boundary conditions for Phase II modeling) appears to have made no adjustments to reflect severe gas-supply constraints. While Myanmar has over 2,000 MW of installed gas-fired capacity, it can rarely sustain more than 1,000 MW of gas-fired output due to the supply constraints and the advanced age and unreliability of most of the gas-fired fleet. Since Myanmar's system is extremely short of supply and possesses a weak grid with poor controls, incorrectly modeling an extra 1,000 MW or so of available, flexible, gas-fired capacity may misrepresent the underlying market, though the impacts on regional market modeling are expected to be minor, given that Myanmar is already shown to be an importer and transmission links to that country are reasonably specified.
16. A key underlying modeling assumption, that the entire interconnected ASEAN region would be centrally dispatched with the goal of minimizing regional costs, leads to excess trade with respect to what would be expected under most regional integration visions, certainly through 2040. In reality, national dispatch planning (if not actual grid control in all cases) would almost certainly remain within the control of national authorities. Leaving aside the numerous technical, bureaucratic, and political reasons why this is so, there is an important economic reason, which is that centralized dispatch of systems with significant amounts of resources with low dispatch costs tends to result in the benefits of trade accruing to trading partners, because exporting low-cost power reduces regional system costs more than not exporting it. The effect is particularly pronounced for energy-constrained resources such as storage hydro. Where coordinated

[115] Max Hall, "Cambodia tender secures lowest solar power price in Southeast Asia", *PV Magazine*, September 6, 2019.
[116] Emiliano Bellini, "Myanmar's 1 GW solar tender concludes with lowest bid of $0.0348/kWh", *PV Magazine*, September 4, 2020.
[117] Marian Willuhn, "Brazil A-4 auction signs 211 MW of solar for record-low price of $0.0175 kWh", *PV Magazine*, July 1, 2013.

dispatch exists in the real world across national markets, dispatch is planned at the national level for pre-dispatch and then coordinated at the regional level (which may identify “win-win” trading opportunities). To be clear, this finding does not impugn AIMS III modeling work; rather, the intent is to highlight that the AIMS III study, like other studies of this type, may somewhat overstate the benefits of trade within any given scenario.

Phase II Findings of Delphos Team

17. While justified perhaps by data gaps, the study methodology takes a fundamental step away from realism by aggregating the complexity of the actual national transmission systems into simplified blocks of generation and load. This makes the regional power flow tractable for analysis, but it runs the risk that it may cover up serious unintended consequences within those national/regional networks, which could be expensive and time consuming to remedy, creating unforeseen impediments to developing transmission projects along the lines indicated by the study.
18. Short circuit analysis: It is noted that this attribute is highlighted as a key observation from the study although it is the normal outcome for reasonably configured transmission systems.[118]
19. The study lacks observations regarding grounding practice and phase displacement compatibility between the various voltage levels of the various grids. Maybe this is because they are all operating in compatible phase displacements/rotations amongst the various voltage levels, but if not so, this would be a major difficulty in integrating the grids, requiring great expense, as well as time consuming detailed works at all affected substations to bring the systems into line.
20. "In absence of the sequence impedance data for the individual AMS Grid network, short circuit analysis was performed for 3-Phase faults only. For simulating unbalanced faults like Single-Line-to-Ground-Fault, zero and negative sequence impedances are required which were not available. Sometimes, S-L-G faults are higher than 3-Phase faults. However, due to data limitations, this aspect was not evaluated". The degree of aggregation of modelling data undertaken to complete the study, makes assessment of short circuit fault levels unreliable. This is the case for both 3-Phase faults and for S-L-G faults. Whereas S-L-G fault levels might be marginally higher than 3-Phase short circuit levels, their absence from consideration does not cast any additional material uncertainty onto the study findings.

[118] Also of concern is the reference to lack of sequence impedance data. These data are rarely used or available within power systems development studies but are required in connection with more detailed engineering studies when S-L-G short circuit levels drive considerations of system grounding practices.

3.2 ACMECS

ACMECS, standing for "Ayeyawady-Chao Phraya-Mekong Cooperation Economic Strategy", is an intergovernmental cooperation framework for Cambodia, Lao PDR, Myanmar, Vietnam, and Thailand.

Formed in 2003, the entity normally meets every two years, but there were summits in both 2015 and 2016, followed by 2018 and 2020. At the 2018 summit, an "ACMECS Master Plan" was adopted that was initiated by the Thai side and was the first of this type of document to be agreed by ACMECS.[119]

Snapshot: ACMECS Master Plan

Funded by: ACMECS

Performed by: Thailand

Report Date(s): Undated, but released in 2018

Focus: Cross-sectoral infrastructure investments

Summary:

- This is not a power sector / transmission master plan. Rather, it presents a vision for regional integration and a list of infrastructure projects across various sectors that ACMECS members agreed to support as priority projects.
- Within the power sector, 13 transmission projects are listed as priority projects, four of them unique to the ACMECS Master Plan and the remainder listed previously in ADB's GMS RIF – 2022.

The Delphos Team was provided with an undated ten-page document titled "ACMECS Master Plan (2019 – 2023)". The document comprises PDF excerpts of a larger document, which was said to have originally been posted on the ACMECS or another website but is no longer available. The excerpts are focused on energy sector projects. The pages provided were a summary page, a page 2, plus pages 16-17, 28, and 30-34. Web searches turn up images that include some of the same pages, but a complete document was not located.

Based on the document provided and other contextual information, it appears that the "Master Plan" is not, in any sense, a power sector planning report. Rather, it identifies priority projects to pursue over the five-year planning period across various sectors, including health, transport, education and "Energy Infrastructure and Connectivity". The section covering this final topic lists four projects ("ACMECS 1 – 4" in the list below), as well as other priority projects identified in the Greater Mekong Subregion Regional Investment Framework (GMS RIF) 2022 (from 2017). These are presented below and covered in more detail in Section 4.2.

- ACMECS 1: Na Bong (Lao PDR) to Udon Thani 3 (Thailand);
- ACMECS 2: Ban Lak 25 (Lao PDR) to Ubon Ratchathani 3 (Thailand);
- ACMECS 3: Pak Beng or Pak Nguyen (Lao PDR) to Tha Wang Pha (Thailand);
- ACMECS 4: Mae Sot (Thailand) to Thaton (Myanmar);
- East-West Corridor Power Transmission and Distribution Project in Lao PDR;
- Design and Funding of Backbone Grid for Lao PDR;
- 500 kV line from Mawlamyine to Main Grid in Myanmar;
- Transmission Interconnection Project from Lao PDR (Luang Namtha) to Myanmar (Shan State with possible extension);

[119] Press statement by Prime Minister of Thailand at the 8th ACMECS Summit.

- Transmission Interconnection Project from Lao PDR (Na Bong) to Thailand (Udon Thani 3);
- Transmission Interconnection Project from Lao PDR (Ban Lak25) to Thailand (Ubon Ratchathani 3);
- Transmission Interconnection Project from Lao PDR (Pak Beng or Pak Nguyen) to Thailand (Tha Wang Pha);
- Transmission Interconnection Project from Lao PDR (Ton Pheng) to Thailand (Mae Chan); and,
- Transmission Interconnection Project from Lao PDR to Vietnam (Nam Mo 1 and Nam Mo 2).

Seven of the 13 projects involve lines from Lao PDR to Thailand; two are internal Lao projects that would facilitate other interconnection projects; two involve links between Thailand and Myanmar (one being an internal grid project that supports the cross-border project); and there is one project each from Lao PDR to Myanmar and Vietnam, respectively. The latter appears to be a generator-to-grid transmission project for the Nam Mo hydroelectric project.

No details, other than those given in the list above, are presented in the ACMECS Master Plan document reviewed by the Delphos Team.

The Mae Sot (Thailand) to Thaton (Myanmar) project bears discussion. Mae Sot is a border town directly across from the Myanmar town of Myawaddy. Prior to 2019, when a double circuit 230 kV line was brought over from Mawlamyine, Myawaddy was served by distribution lines from Thailand. Since there is a 230 kV substation nearby (Tak 2) and since Thailand appears to be planning to build a double circuit 230 kV line to Mae Sot, a project at 230 kV potentially could be feasible and relatively low cost to implement. It is not known why Thaton is listed as the Myanmar substation with which to connect, rather than at Myawaddy, as Thaton is considerably farther away, and transmission constraints are not expected between Myawaddy and Thaton.

3.3 GMS EXPANSION PLANS

Snapshot: Regional Power Master Plan. Harmonizing the Greater Mekong Sub region (GMS) Power Systems to Facilitate Regional Power Trade

Funded by: ADB

Performed by: Manitoba Hydro International

Report Date(s): June 2018, March 2019 & November 2019

Focus: GMS

Summary:

- The study developed the optimal regional generation planning scenarios for 2022-2035 and the optimal cross-border power transmission required to facilitate the generation plan.
- The study evaluated several scenarios – transmission optimized, aggressive cross-border trade, and reduced VRE cost.
- The study found that the aggressive cross-border power trade scenario delivered greatest net benefits. However, this relies on large interconnections between Myanmar-Thailand and Thailand-Cambodia-Vietnam, which are challenging for different reasons.

Background: Reviewed are three presentations by Manitoba Hydro International (MHI) to the GMS RPTCC on a technical assistance conducted over 2018 and 2019 to undertake a regional transmission master plan covering the years 2022-2035, taking into consideration and demonstrating the economic benefits of regional power trade. The November 2019 presentation (the most recent) summarized progress to date from the preliminary and interim presentations and set out the draft final study results.[120]

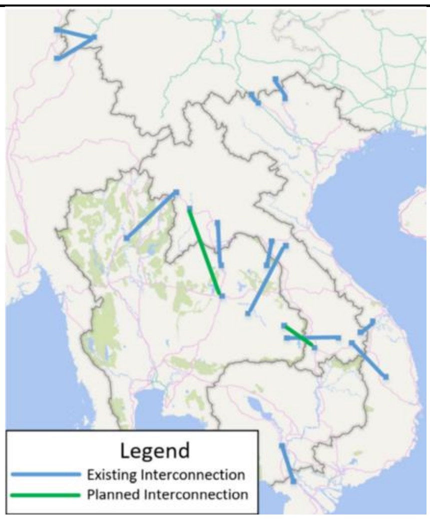
Overview: MHI used a simplified model for stochastic combined generation and transmission planning / optimization using SDDP/OPTGEN based on about 200 buses (substations) located throughout the region. MHI undertook load flow studies with PSSE based on a high-level regional network model for GMS containing more than 650 buses and 1,500 lines, comprising the actual high voltage level transmission network. The regional network model for generation planning was limited to 30 buses. MHI evaluated 33 alternative scenarios.

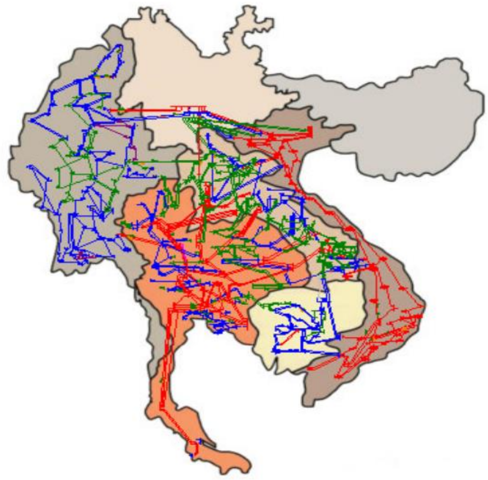
The work is a high-level optimization study, which seeks to determine optimum regional generation scenarios given certain assumptions and from those from those results, determine the necessary cross-border power flows and the optimal cross-border, "technically feasible" transmission scenarios required to make the system balance and create the maximum economic benefit to the region. The study used "medium/ high/ low" input assumptions in three areas (load growth, cost of energy resources, "technology and policy factors")[121] to define three main scenarios and a base study scenario utilizing the most likely development options based on progress on the ground so far and plans in place. With variation in the input assumptions, 33 total scenarios were modeled.

[120] The work was immediately followed by a report from the ADB in February 2020, which has a similar title; "Harmonizing Power Systems in the Greater Mekong Subregion: Regulatory and Pricing Measures to Facilitate Trade" – February 2020, but which sets out in a quite different direction (see Section 3.6.2).
[121] For example, aggressive directives for cross-border trade.

Figure 41. Summary of Manitoba Hydro's Modeling Approach

Scenario Summary												
Economic factor	Technological/Policy factor											
	Base			Solar-battery storage			Nuclear			High cross-border power trade		
Base	M	H	L	M	H	L	M	H	L	M	H	L
VRE cost reduced	M	H	L	M	H	L				M	H	L
High fossil fuel price	M	H	L				M	H	L	M	H	L
Low gas price	M	H	L									





OPTGEN™/SDDP™ Study model – Lines (220 kV & above)	Transmission power flow study model (PSSE) 110 kV – 500 kV lines are included (year 2030)

Source: Compilation from Manitoba Hydro's RPTCC presentations

Results are presented for the "medium" (6% annual) demand growth scenario over the 13-year term, together with a list of transmission links that would be required to facilitate the optimum generation dispatch in meeting the demand in each year. The scenario requires an expenditure on transmission, of US$ 2.63 Bn[122] over the eight years between 2022 and 2030.

The optimization results are that the option "High Cross-border Power Trade" outperforms all the technology / policy options regardless of the variations across the range M/H/L in the applicable economic factors.[123]

Assessment: The results of the optimization are not surprising. The ability to arbitrage resources over the widest possible set will provide least cost in all but extreme circumstances, which the GMS region certainly does not have, at least from a technical perspective (which are the confines of the study). Best of the best scenarios is reduced cost of VRE, which is also to be expected, due to the fact that temporal and geographic diversity are beneficial in firming against the intermittency of VREs.

[122] In discounted terms (NPV in 2022).
[123] Equivalent to the "Low Gas Price" option, which is really a "gas anywhere" option and would not require cross-border electricity transmission at-all.

It must be clear that it would not be feasible to implement the recommendations of the study: to build a 900 km 3,000 MW HVDC link from Gan Lan Ba in China to Tha Wung in Thailand in 2023, or even a 450 km 500 kV 1,500 MW HVAC transmission line from Mae Moh in Thailand to Yangon in Myanmar in 2022[124], or indeed any save one or two of the other proposed transmission links. A table of the actual transmission lines "committed and planned" in the near term is published in the ADB report.

The MHI work, which is in final draft form (a final report was not available for review), must be viewed as a high-level study aimed at demonstrating or promoting the economic benefits of regional power trade, using quasi-realism in the study approach to make its points. It is noted that MHI evidently found it still faced significant data gaps after two years of study, as the "final draft" submitted in November 2019 states: "Simplified transmission planning studies showed significant benefit in cross border power trade. This requires further analysis with adequate details of the regional network." As noted throughout this report, the other studies reviewed faced similar data access challenges.

[124] It seems most unsatisfactory that a two-year study the results of which are presented in late 2019, recommends the construction of major cross border transmission assets that need to be in place only three to four years later.

3.4 POWER NETWORK SYSTEM MASTER PLAN IN LAO PDR

Background

The Government of Lao PDR proposed to the Government of Japan to undertake a power system network master plan. This project was implemented by JICA in cooperation with the Ministry of Energy and Mines (MEM) and Électricité du Laos (EDL) and completed in March 2020.

The Government of Lao PDR aims to establish a "System to System" approach which will have the inter-regional grids synchronized and tied with each other rather than the present model in which there are dedicated power plants which are termed as export power plant and are directly connected to the load centers in the neighboring countries. But due to the shortcomings in the present framework, JICA recommends continuing the Generation-to-System approach until 2030, and then potentially shifting to a System-to-System approach.

Based on the geographical locations of the power plants and the interconnection transmission lines, the Lao PDR grid has been divided into 4 regions – Northern, Central 1, Central 2 and Southern, shown in Figure 42.

Snapshot: Lao PDR Master Plan

Funded by: JICA

Performed by: JICA team, comprising Tokyo Electric Power Holdings Company, TEPCO Power Grid, Nippon KOEI, and Tokyo Electric Power Services Co.

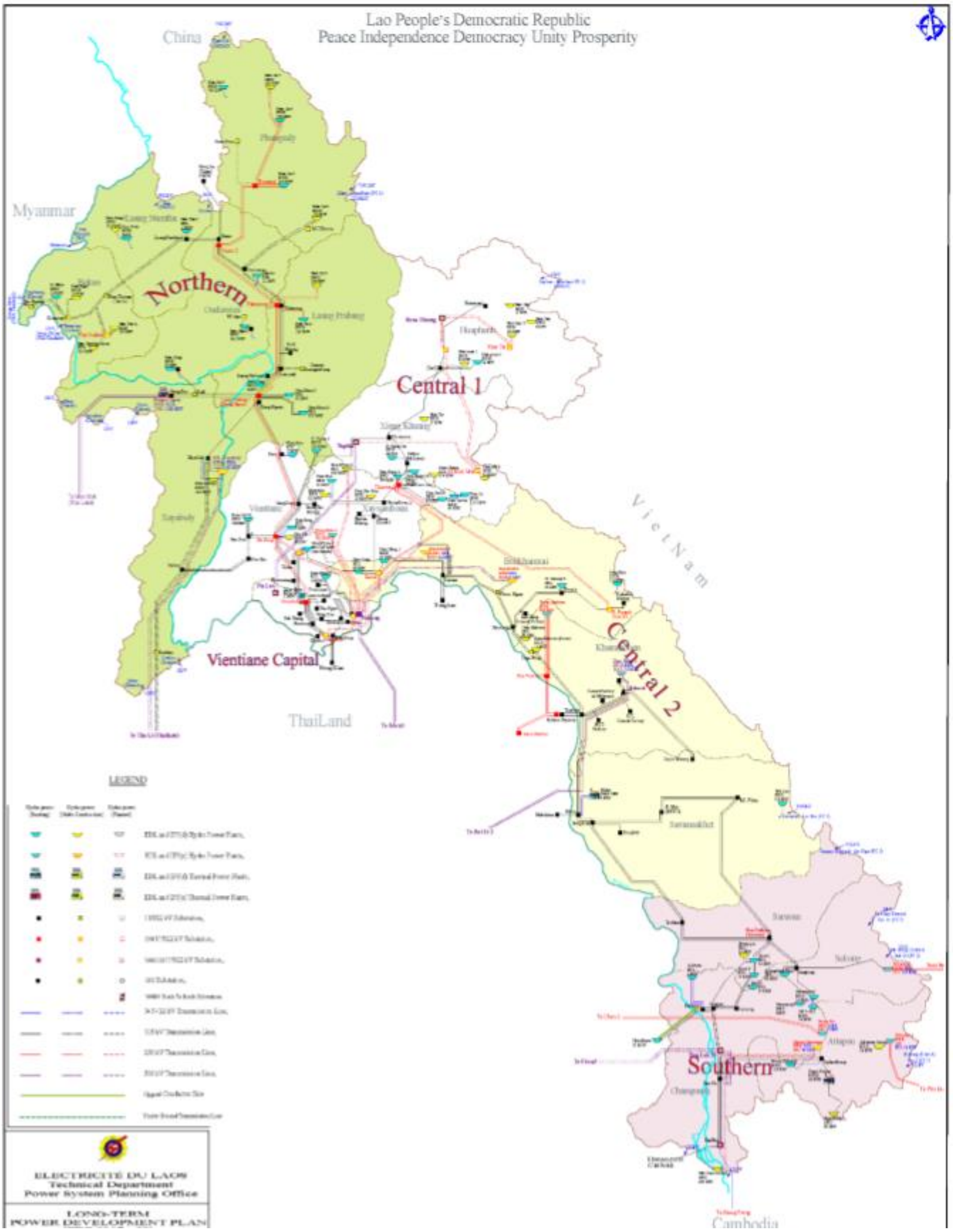
Report Date(s): February 2020

Focus: The primary scope of this report is to develop a master plan for Lao PDR's network that will facilitate power interchanges with its neighboring countries in larger scale at the same time providing stable and secure power supply to its domestic demand.

Summary:

- A framework required for a harmonized GMS grid is discussed.
- The report identifies that Lao PDR has significant potential to develop its hydroelectric power potential which will increase the export of power through proposed new transmission corridors.
- The report identifies the shortcomings in the existing operational process such as securing supply demand balance, control of generators and maintenance of domestic power system facilities.
- The existence of two synchronized blocks (Thailand – Lao PDR and Vietnam – Cambodia) is documented and explained in detail. Difficulties related to grid-to-grid connections that would link these blocks are discussed.
- The report recommends continuing with the existing model of "export power plant to load center" until at least 2030, after which a "System to System" approach can be implemented.

Figure 42. Map of Lao PDR Grid



Source: Lao PDR Power Network System Master Plan study. JICA.

The key findings by the Delphos team from the JICA report are summarized below.[125]

1. The operational aspects of Lao PDR's domestic grid (115 kV) and transmission lines (mainly 230 kV and 500 kV) connecting export IPPs to neighboring markets is discussed in detail.

[125] These key findings are summarized in greater detail in the executive summary of the JICA study.

2. The Lao PDR's domestic grid is synchronized with the Thai grid through 115 kV transmission lines. The study recommends new 230 kV and 500 kV transmission interconnections to address some drawbacks of the current cross-border grid-to-grid network, such as lower transmission capacity, higher transmission losses, and lower system stability.
3. When the study was begun, Lao PDR authorities had plans to require all new export IPPs that would sell to EGAT to connect to the Lao PDR domestic grid, such that exports would be through grid-to-grid connections, rather than via the IPP-to-foreign grid connection that have to this point. Based on findings from the study, however, it was decided to maintain IPP-to-foreign grid connections for such projects, due to "insufficient system operation functions, such as securing supply-demand balance within the power system for domestic supply in Laos, control of generators….and it being difficult for the time being to build a reliable power transmission system in combination with the power plants of power generation companies dedicated to export." The study recommends a gradual move towards increased grid-to-grid interconnections in the region, after about 2030, to allow time for domestic networks to achieve stable grid operations through optimized operation practices and grid code revisions.
4. The study includes a detailed examination of approaches to synchronize the two existing synchronized blocks (Thailand - Lao PDR and Vietnam - Cambodia) plus Myanmar, concluding that doing so would be technically complicated and risky given grid and grid control weaknesses in Lao PDR, Cambodia and Myanmar. A roadmap to greater integration, and eventual synchronization, is provided, under which steps to allow increased synchronization could begin after 2030.
5. To address the lack of frequency control mechanisms during supply-demand imbalances in several GMS countries, which is one of the main barriers to grid synchronization, the JICA study recommends implementing a governor-free mode of operations for large capacity generators. Governor-free mode will facilitate secure operation for inter-regional power transfers as it automatically makes fine adjustments of frequency fluctuations and could also serve as Frequency Containment Reserves for large and sudden drops in frequency that can occur when a large generation trips offline. The study also recommends that all major generators be equipped with an AGC function that responds to the load frequency control instructions from national control centers of individual countries for realizing power system operations that are independent from neighboring countries.
6. The study makes several recommendations to establish a harmonized GMS grid:
    - Establishment of an organization or *ad hoc* establishment within the region to share the results of studies on plans for specific projects (projects of a certain size or larger).
    - Establishment of risk assessment methods for multilateral interconnection projects.
    - Attract private capital for investment in interconnections, set up multilateral government guarantees (by financially sound countries) in GMS, and improve the business risk assessment functions of each country.
    - Establishment of a regional interconnection operation organization in GMS.
    - Development of domestic grids and domestic grid operation capabilities.

- Establishment of a regional GMS Grid Code and revisions of the grid codes of individual countries to align with the GMS Grid Code.
- Enhancement of grid operation capacity and facility functions required to comply with the Grid Codes (particularly Laos, Myanmar, and Cambodia).
- Establishment of a regional power market design, including setting of power wheeling charges.

7. China is proposing to synchronize China and Lao PDR as a single super grid under the “One Belt, One Road” initiative and export power to Thailand and Vietnam through proposed 500 kV HVAC as well HVDC transmission lines. Under this proposal, Lao PDR would import power from China through 500 kV lines to meet domestic shortfalls; these transmission corridors would continue to Thailand and Vietnam to facilitate Chinese power exports. The study notes that the Chinese proposal is at odds with many realities on the ground – supply-demand dynamics in the region, grid synchronization between Thailand and Lao PDR, EGAT’s control of the frequency on the EdL grid, among others.
8. As of December 2017, there were seven export-oriented plants in Lao PDR. Four hydropower plants (Nam Ngum 2, Nam Theun 2, Theun Hinboun, and Houay Ho) and one coal-fired thermal power plant (Hongsa Lignite) are dedicated for exports to Thailand. Two hydropower plants (Xekaman 1 and 3) export to Vietnam. EDL has ongoing plans to convert several existing and under-construction power plants intended for domestic consumption to exports, to Vietnam and Cambodia. JICA recommended an additional seven existing or under-construction projects to be converted to export-only power plants, as they are close to the neighboring grids. The study also concludes that expanding exports from Lao PDR to Vietnam by utilizing the remaining capacities of existing transmission lines from Xekaman 1 and 3 would be difficult to realize.

3.5 GMS POWER MARKET DEVELOPMENT

Background: The World Bank has supported efforts to develop power trade in the GMS, often in collaboration with the ADB, and funded the "Greater Mekong Subregion Power Market Development" study. Ricardo Energy & Environment was the lead consultant on the study, supported by Intelligent Energy Systems and Nord Pool Consulting.

The objective of the study was to identify cross-border interconnection projects that had the greatest potential to enhance power market integration in the GMS. The projects, termed business cases in the study, were ranked and prioritized in terms of benefits to create an "integrated case" – regional integration with the identified projects being prioritized and implemented in stages.

The study was carried out by the consultants over three years (2017-2019), with interim and final results presented at RPTCC meetings. In response to feedback from participants during the RPTCC meetings to align the study with ongoing efforts under the GMS framework, the World Bank consultants sourced the candidate projects primarily from previous studies conducted by the ADB.

Snapshot: World Bank Studies
Funded by: World Bank
Performed by: Ricardo Energy & Environment
Report Date(s): April 2019
Focus: GMS
Summary:

- The study modeled regional integration of power markets in the GMS and identified the cross-border interconnections to be prioritized based on the level of benefits provided. It offers a 10-year roadmap to prioritizing and developing projects.
- It compiled 14 candidate cross-border projects identified in previous country and regional reports, including studies by ADB and IEA; provided qualitative commentary on opportunities and barriers for each; and narrowed down to 10 projects (business cases) after an initial screening.
- The study summarizes the modeling results in terms of implications for generation capacity, national transmission systems, power flows, as well as impacted countries.
- The study assumes all projects identified would be grid-to-grid connections.

Methodology: The study compiled 14 candidate projects and conducted initial screening based on several criteria. Ten projects were selected for additional analysis following the initial screening, as shown in Figure 43. Modeling simulations were conducted for the selected projects individually from 2016 to 2035, with the candidate projects coming online from 2020 onwards. The models allowed intra-country transmission lines to be augmented as well, to help understand how much investments into national power systems would be required to support power trade. The study relied on the PROPHET platform for modeling in the Planning module to guide long-term system development in terms of new entrant capacity.

Figure 43. Candidate Projects Screening in the World Bank Study

No.	Candidate Transmission Project	Reasonable project cost	Dispatch benefits	Deferred gen. investment	Reserve sharing benefits	Effective resource sharing	Technical feasibility	Supports multilateral trade	Commercial arrangements	Environmental benefits	Social benefits
1	Ban Soc/Ban Hatxan (Lao-S) – Pleiku (VN-C)	✓	✓	?	✓	✓	?	✓	✓	✓	✓
2	Gan Lan Ba (PRC) – Tha Wung (TH-C) via Lao-N	X	✓	✓	✓	✓	✓	?	?	✓	?
3	Yangon area (MY) – Mae Moh (TH-N)	✓	✓	?	✓	✓	✓	✓	?	?	✓
4	Mawlamyine (MY) – Tha Tako (TH-C)	✓	✓	?	✓	✓	?	?	?	?	✓
5	Luongphabang HPP (Lao-N) - Xam Nau (Lao-N) – Nho Quan (VN-N)	✓	✓	✓	?	?	✓	?	✓	✓	✓
6	Wangnoi (TH-C) – Banteay Mean Chey – Siem Reap – Kampong Cham (CM)	?	✓	?	✓	✓	?	✓	?	?	✓
7	Kampong Cham (CM) – Tay Ninh (VN-S)	✓	✓	?	?	✓	✓	✓	✓	?	✓
8	Lower Se San 2 HPP (CM) – Pleiku (VN-C)	✓	✓	?	?	✓	✓	?	?	✓	✓
9	Yunnan (PRC) – Hiep Hoa (VN-N)	X	?	✓	✓	✓	✓	?	?	?	?
10	Mae Khot TPP (MY) – Mae Chan (TH-N)	✓	?	?	x	?	✓	?	?	?	?
11	Ban Soc/ Ban Hatxan (Lao-S) – Tay Ninh (VN-S) via Stung Treng (CM)	✓	✓	?	✓	✓	?	✓	?	✓	✓
12	Luang Prabang (Lao-N) – Yunnan (PRC)	✓	?	?	✓	✓	✓	?	?	?	?
13	Savannaket (Lao-N) – Ha Tihn (VN-C)	✓	?	?	✓	✓	✓	✓	✓	?	?
14	Mandalay (MY) – Yunnan (PRC)	✓	✓	?	✓	?	✓	?	?	?	✓

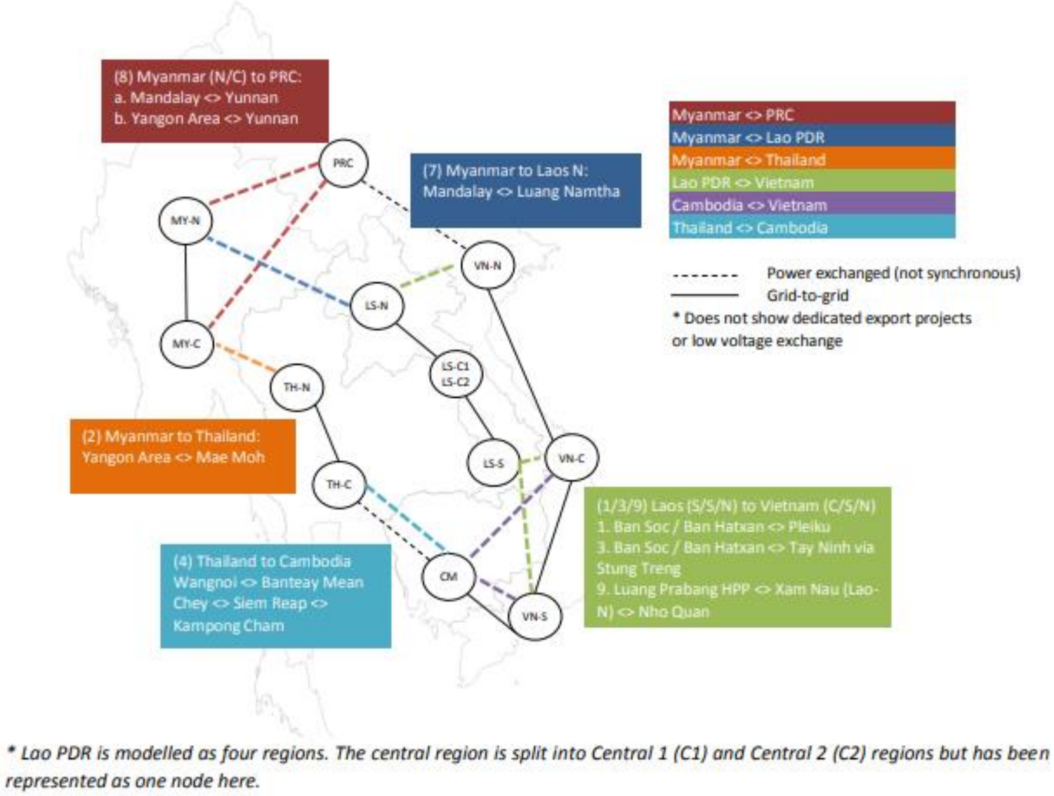
Legend: ✓ - likely, ? – doubtful, X - unlikely

Source: Greater Mekong Subregion Power Market Development.

The study was constrained by lack of granular grid data, as is typical for most such studies, and relies on a simplified network topology shown in Figure 44. The figure only shows cross-border grid-to-grid connections between Vietnam and Cambodia and no connections between Thailand and Lao PDR. The World Bank Study, in Section 4.1 of the report, mentions that there are several existing cross-border grid-to-grid connections at medium and low voltages between Thailand and Lao PDR, China and Vietnam, Vietnam and Cambodia, Thailand and Cambodia, Lao PDR and Vietnam, and China and Lao PDR. However, it asserts that only the Cambodia-Vietnam interface is a synchronized interconnection whereas the rest represent border-area load served by a foreign grid. This is incorrect since the Thailand and Lao PDR grids are synchronized, as mentioned previously in this report. Therefore, the network topology does not reflect the fact that the two grids at the center of the region are already synchronized and that expanded grid-to-grid trading is a national planning priority for Lao PDR (as described in Section 2.1.3.6).

One of projects considered but not shortlisted in the World Bank study is the Mawlamyine to Tha Tako interconnection between Myanmar and Thailand, number four in the table shown in Figure 43. This project was not shortlisted for further analysis partly because the World Bank study describes Mawlamyine as "isolated from the main grid in Myanmar" and would require substantial investment to transfer power from Mawlamyine to the Yangon region. This is simply not true, as Mawlamyine, one of Myanmar's major cities, has been on the main grid for many years.

Figure 44. Network topology in the World Bank study



Source: Greater Mekong Subregion Power Market Development.

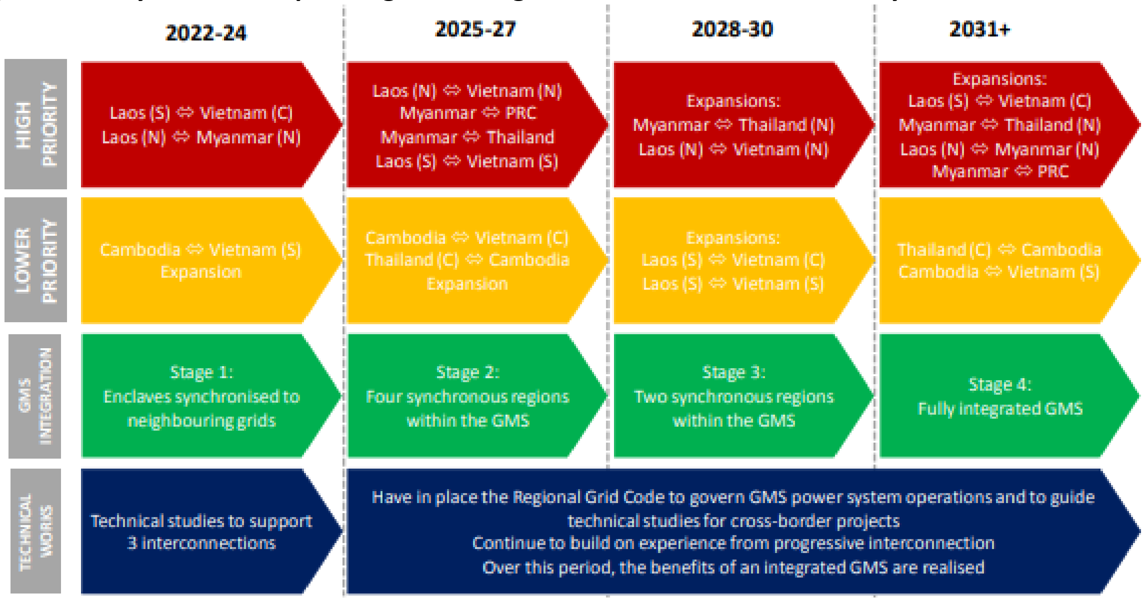
There were some assumptions that deserve closer scrutiny. The study assumes VRE development to be fixed between the base (no cross-border projects) and business cases, in other words, it does not evaluate whether the increased connections could facilitate greater VRE penetration and reduce production costs. The study also set fuel and capital costs as uniform throughout the region. This approach downplays the challenges that some countries may have in raising capital to finance planned IPP projects and therefore would overestimate the extent to which countries like Myanmar or Cambodia are able to realize their capacity expansion plans.

The study also evaluated the selected projects in a combined integrated case, in which the model would decide which cross-border connection was developed.

Findings: Unlike some of the other studies reviewed, the World Bank study provides important and relevant qualitative commentary on the pros and cons of each project, such as whether a country is likely to secure the funding necessary to carry out the necessary infrastructure upgrades to accommodate the cross-border project. This is reflected in the initial screening assessment. The insights regarding the implications for generation, transmission, power flows, and impacted countries are also well articulated. While these insights are not factored into the rankings or calculated benefits of the projects, they serve as useful reminders that projects with great "regional" benefits may not proceed if they are at odds with important stakeholders (e.g., gas generation in Thailand).

The 10-year roadmap shown in Figure 45 is again useful in determining near-term vs. longer-term priorities. However, the key assumption on grid synchronization, especially within the timeframes considered, is a shortcoming with this study and requires a potential reevaluation of the estimated benefits from the analyzed cross-border projects.

Figure 45. 10-year roadmap for regional integration in the World Bank study



Source: Greater Mekong Subregion Power Market Development.

Section 10 of the study identifies important next steps to facilitate the progression to a tightly integrated power system. The analysis assumes grid-to-grid AC interconnections but highlights the need to study HVDC interconnections as alternatives. This point is especially relevant in the context of the other next steps identified in the report: (i) a regional grid code established and adopted; (ii) adjust national planning frameworks to include cross-border projects; (iii) develop and implement wheeling charge calculation methodology; (iv) at a country level, implement the necessary policies and regulatory reforms to ensure open access to national grids; and (iv) implement trading rules and balancing arrangements. It recognizes that the modeling conducted in the study provides useful high-level cost-benefit estimates but requires additional study to ensure that the power systems can actually be operated as modeled and also highlights significant steps that must be taken to align national power system regulations and standards to realize the potential benefits identified in the study.

3.6 OTHERS

3.6.1 GREATER MEKONG SUBREGION ENERGY SECTOR ASSESSMENT, STRATEGY, AND ROAD MAP

The ADB report "Greater Mekong Subregion Energy Sector Assessment, Strategy, and Road Map" from June 2016 is an account and an assessment of the ADB's activities over 30 years, aimed at GMS market integration. The report was prepared by ADB senior energy economists attached to the SE Asian Department, with assistance from a wide range of ADB in-country advisors across the region and with input from members of the RPTCC; represented by the widest range of contributors from energy ministries, regulators, transmission planner and power utilities of the GMS countries.

Snapshot: Greater Mekong Subregion Energy Sector Assessment, Strategy, and Road Map

Funded by: ADB

Performed by: ADB

Report Date(s): June 2016

Focus: GMS

Summary:

- ADB's own assessment of 30-years of efforts in pursuit of a regional market are that they have encountered limited success.
- Regional Market in Wholesale Electricity is assessed as being 30-years in the future.
- Regional Power Trading Coordination Committee was established and meets regularly.
- Regional Power Coordination Center (proto-SO/MO) established in 2013 remains to be operationalized.
- ADB has shifted its strategic focus "from hardware to software", that is, away from funding transmission lines in favor of technical assistance.

The report recounts ADB engagement with the countries of the GMS subregion in, pursuit of a strategy of encouraging cross-border trade in electricity, with the end-goal of establishment of a multilateral unified electricity market across the region.

The instruments for enacting this strategy were:

- "…to engage with the region's governments and electricity sector representatives to further collaboration, the formation of the Regional Power Trade Coordinating Committee (RPTCC), effecting the Regional Power Trade Operating Agreement (2005) and establishment of a Regional Power Coordination Center (RPCC) for the GMS, with the work being monitored by the RPTCC."
- A Regional Master Plan for Interconnection in the GMS was prepared in 2002 under ADB's TA. [126]
- An update of the Master Plan was completed in October 2010. [127]

[126] The report addressed the requirements for a genuinely integrated power system with synchronous links existing between the two large grids in Thailand and Viet Nam, the incorporation of the Lao PDR as a main supplier, the absorption of Cambodia in the system, and linking to Myanmar.

[127] Asian Development Bank Reta No. 6440 - "Facilitating Regional Power Trading and Environmentally Sustainable Development of Electricity Infrastructure in the Greater Mekong Subregion" – Prepared by Rte International in association with EDF (France), Nord Pool Consulting AS (Norway), Power Planning Associates (UK), Franklin Société d'Avocates (France), CEERD (Thailand)

- The RPTCC is established for the purpose of monitoring and coordinating the implementation of the Master Plan. [128] [129]

Paragraph E – Lessons Learned, states that progress in achieving ADB's goals had been "slow" with only cross-border IPP links having been implemented to date, which is only the first stage of the ADB's four-stage development strategy.[130] The reasons given were:

- lack of an adequate institutional framework;
- lack of a clear identification of the benefits and beneficiaries; and
- lack of sufficient generation surpluses and transmission grid strength in some countries.

Nevertheless, the report forecasts a bright future in coming years due to the operationalization of the RPTCC as well as increasing generation surpluses (Lao PDR and South China) and the establishment of a national electricity market in Vietnam.

Table 13 of the report summarizes ADB's lending to the GMS power sector since 1992, which shows that furtherment of cross border power trading objectives formed a small proportion: less than US$ 200 M of the approximately US$ 1.0 Bn of lending undertaken by ADB to the region.

[128] The RPTCC is meant to fulfil the role of Regional Operator (somewhat in the frame of a WEM Operator undertaking financial reconciliation and clearing duties – i.e., not an ISO).
[129] The RPTCC continues to meet regularly to report on regional power sector developments and to discuss issues concerning implementation of the GMS strategy. However, the RPTCC established as an entity in 2013, is yet to be operationalized. Refer to https://www.greatermekong.org/rptcc
[130] "…a gradual approach through four successive stages (still lies ahead): Stage 1: Bilateral cross-border connections through PPAs; Stage 2: Grid-to-grid power trading between any pair of GMS countries, eventually using transmission facilities of a third regional country; Stage 3: Development of transmission links dedicated to cross-border trading; and Stage 4: Most of the GMS countries have moved to multiple sellers–buyers regulatory frameworks, so a wholly competitive regional market can be implemented."

3.6.2 HARMONIZING POWER SYSTEMS IN THE GREATER MEKONG SUBREGION: REGULATORY AND PRICING MEASURES TO FACILITATE TRADE

Background: Four years after its Assessment, Strategy, and Road Map – June 2016 (reviewed in the previous subsection), and three months after presentation of the MHI study report with a closely similar name, the ADB report "Harmonizing Power Systems in the Greater Mekong Subregion - Regulatory and Pricing Measures to Facilitate Trade" – February 2020 was published. The purpose of the study was to assess why satisfactory progress towards regional power market integration was not being achieved.

Snapshot: Harmonizing Power Systems in the Greater Mekong Subregion: Regulatory and Pricing Measures to Facilitate Trade

Funded by: ADB

Performed by: ADB

Report Date(s): February 2020

Focus: GMS

Summary:

- The study identifies barriers that are stalling progress towards regional market integration.
- It recognizes that utility-to-utility bilateral trade under PPAs must precede the development of a regional market, given that cross-border trade in energy is only 1.6% [as claimed in the report] of the total energy demand at present.
- The study lists the committed and planned future transmission interconnections in the GMS and identifies the critical features to be implemented: open access to transmission, establishment of a wheeling charge mechanism, cost recovery for transmission assets, establishment of a balancing mechanism, regulatory and contractual provisions, common trading platform, and interim and final arrangements.

Overview: The report restates and updates ADB's previous assessment of the lack of success in its efforts to date in bringing about cross-border trade and transmission connections.

The report is critical of the results achieved and identifies the following barriers to progress:

- Partial visibility of trading benefits to some or all parties, recognizing the developments needed to enable utilities to assess the scale of the benefits that could arise from importing electricity from outside their own countries.
- Regulatory and commercial issues that need to be addressed so that utilities and IPPs can gain access to a GMS power system and enter into contracts for the sale of power to neighboring utilities.
- Policy issues in areas such as power sector restructuring and regulatory reform, which have the potential to restrict regional trading.
- Training and capacity building, focusing on the most important requirements for filling any gaps in the knowledge and understanding of utility staff who are involved in the assessment, negotiation, and operation of regional trading.

The report identifies the practical steps required for future trading to come about. The first is cross-border trade with an IPP under a PPA, which is already happening. The second step is for a PPA to be concluded between utilities across their common border, possibly utilizing surplus capacity already connected to their respective networks and using the existing transmission assets of a third-party utility to wheel the power. It explains the necessary features of an electricity trading system and the steps that must be taken to implement them. It identifies that commonality and visibility of regional trades will facilitate and encourage participation. It is noted that a system of regulation and wheeling charges must be established to permit orderly access and cost recovery on investments in transmission assets.

Assessment: The report is a detailed "how to" manual on the features of a trading environment that must be implemented before development of substantially increased regional electricity trading of the sort that the ADB envisions for the region. The report does not cite any technical barriers, or any barriers arising from issues that would (or indeed, that could) be demonstrated by transmission system studies. Indeed, the report pinpoints a lack of success in achieving coordination in planning as an organizational issue which is no doubt related to poor visibility of the benefits that would accrue to some or all parties from collaboration, and from the intensive and complex effort required in reforming institutional and regulatory practices.

The report, which has been peer reviewed by the participant GMS countries, augments the list of cross-border connections, several of which are classified as "grid-to grid". In particular, the following existing and future construction are noted:

- South China – Vietnam: - 2 links at 220 kV amounting to 800 MW of capacity ("existing") and one link at either 220 kV or 500 kV "under study";
- South China – Myanmar: One 500 kV link of 3,000 MW classified as "committed";
- Vietnam – Cambodia: One 230 kV double circuit of 200 MW (existing); no future circuits planned;
- Lao PDR – Thailand: No existing grid-to-grid links (only IPP); one 500 kV link of 800 MW planned (COD 2024);
- Lao PDR – Vietnam: None existing; 2 links at 500 kV "under study";
- Lao PDR – South China: None existing; one 500 kV link of 1,000 MW "under study" (may link to Thailand and expand capacity to 3,000 MW;
- Thailand – Cambodia: One link at 115 kV of 100 MW capacity; none in planning; and
- Lao PDR – Myanmar 2 links planned; one at 230 kV and one at 115 kV (capacities not given).

The list of projects are the ones that the GMS colloquium reports as going ahead, though whether they do will depend among other things on the extent of in-country reinforcements directed at facilitating power flows across the individual national grids, which is not a given but will depend on the in-country investments being made in parallel, for grid reinforcement and the preservation/ betterment of system reliability.

ADB's analysis indicates that while a regional wholesale energy market along the lines of Europe and other Western jurisdictions may not be within reach in the near- or medium-term, there remains plenty of economic scope for expanded cross-border interconnections without full regional integration. Emphasizing an integrated regional power market as an objective may even create headwinds for expanded cross-border connections with tangible benefits. The ADB observes that:

> *"Generation in the GMS is open to IPPs from the private sector, through PPAs with a single buyer and not through competitive market."*

This is seen as counterproductive to Stage 2 development (when trading is possible between any pair of GMS countries, including through transmission network of a third country). However, there seems to be no need to implement wholesale electricity market concepts in the region when much simpler and pragmatic, grid-to-grid PPAs enacted between governments may be just as effective in supporting bilateral trade while at the same time identifying the stakeholders and the revenues necessary for grid development required to service each PPA. Furthermore, the framework of bilateral agreements has indeed led to multilateral trade in the region under the LTM-PIP project, which will also extend to Singapore from 2021.

The ADB is adhering to its vision of supporting the implementation of a market structure to stimulate trade, instead of supporting the implementation of trade to stimulate the development of a market structure. If so, it would seem to leave the door open to other development agencies to focus on bilateral projects that have direct revenues for the participants, and which will directly service the goals of both progressive interconnection of the GMS transmission systems and bilateral trade in energy that can favor the increased development and trade in large scale renewable energy. This may be possible through direct engagement with potential buyers and sellers over energy opportunities which involve grid-to-grid connections that facilitate import/ export through their national grids of surplus hydropower and of solar development.

3.6.3 THE STUDY ON POWER NETWORK SYTEM MASTER PLAN IN THAILAND – PDP 2018

The Power Development Plan (PDP 2018) for 2018 to 2037 focuses on increasing the security of the electricity system by power development and improvement of the transmission system to increase the capability of inter-regional transmission. Under Thailand's PDP 2018, 56,431 MW of new generating capacity is expected to be built over the period from 2013 through 2037, 25,310 MW of existing capacity is expected to retire, bringing Thailand's total installed capacity in 2037 to 77,211 MW.

PDP 2018 expects imports to grow to 2,357 MW by 2025 and to 5,857 MW by 2037. The report envisions four additional lines with Lao PDR (in addition to two under construction) as well as two operating lines connected to Malaysia.

Table 8. Cross-border Transmission Projects Mentioned in Thailand's PDP 2018

From		Via	To		Voltage	Capacity	Complete
Lao PDR	Xepien-Xenamnoy Hydro	Ban Lak 25	Thailand	Ubon Ratchathani 3	Double circuit 500/230 kV	354	2019
Lao PDR	Xayaburi Hydro		Thailand	Tha Li - Khon Kaen 4	Double circuit 500 kV	1220	2021
Lao PDR	Nam Theun 1 Hydro	Nabong	Thailand	Udon Thani 3		514.73	2022

The document also identifies the following in-country transmission projects that may serve to reinforce the identified cross-border transmission lines:

1. The 500 kV Nakhon Ratchasima 3 Substation was connected with the 500kV Ubon Ratchathani 3 substation, which is connected to the Xepien-Xenamnoy hydropower plant in Lao PDR via a cross-border line to the 500/230 kV Ban Lak 25 substation.
2. The 500kV Roi Ed 2 substation was connected with Nam Theun 2 hydropower plant in Lao PDR.
3. The 500 kV Udon Thani 3 substation was connected with both the 500kV Chaiyaphum 2 substation via the 500 kV Khon Kean 4 substation, as well as the 500/230 kV Nabong substation in Lao PDR which is connected to many hydropower plants.

The latest Memorandum of Understanding (MoU) between Thailand and Lao PDR in 2016 put the potential export capacity from Lao PDR at 9,000 MW until 2030 and has also introduced the concept of grid-to-grid power trade. It specifically identified three hydropower projects for export from Lao PDR: Xepien - Xenamnoy (354 MW), Xayaburi Dam (1,220 MW), and Nam Ngiep (269 MW).

Myanmar and Thailand signed an MoU in 2015 for exports from Myanmar to Thailand, although without any specific capacity stated. This MoU would have been automatically terminated in 2020 unless either party had notified the intention to renew in advance. After 2020, PPAs would be negotiated directly between EGAT and the project developer. To facilitate such projects and the PPAs, EGAT would incorporate such projects into its PDP.

Thailand and Cambodia and signed an MoU in 2000 for electricity exports from Thailand to Cambodia with no capacity limits or expiry dates. The two countries agreed to cooperate in planning and construction of the interconnection of its transmission systems as well as to set up an open access policy for future trade with other countries. There are three potential projects under Government-to-Government MoU between Thailand and Cambodia:

1. Koh Kong project with capacity of 2,000 MW, which has been under MoU negotiation process with EGAT since June 2016.

2. A second Koh Kong project with 2,600 MW capacity was submitted to Thailand's subcommittee in 2016.
3. The 94 MW Stung Mnam project which is in process of submitting to the Thai subcommittee.

There is other relevant information that can be gleaned from PDP 2018:

1) Xepien-Xenamnoy to Ubon Ratchathani 3 via Ban Lak was delayed, with a COD in 2019.
2) Connection from Xayaburi: previous ADB studies identified the plan to connect to Loie substation, whereas PDP 2018 indicates a connection to Thali instead and expected completion to be pushed back from 2019 to 2021.
3) Interconnection from Nam Theun 1 to Udon Thani 3 via Nabong had not been considered in previous ADB studies.
4) Interconnection from Paklay to Thali that had been included in prior ADB studies is no longer being implemented, according to PDP 2018.

4. COMPARISON OF TRANSMISSION PROJECTS

4.1 APPROACH AND METHODOLOGY

The terms of reference for this report requires comparison of the cross-border transmission projects proposed in several studies (see Table 3) in terms of how supportive the projects are of regional power market integration. Prior to undertaking the comparison, it was necessary to address what it means for a project to be more supportive or less supportive of regional integration, and then to formulate a methodology for the assessment. The following subsections summarize the nature of the studies reviewed, the analytical framework, and finally, the specific methodology taken to comparing individual transmission projects.

Summary of Studies: Only one of the main studies reviewed (the World Bank study) contains detailed, specific, costs and benefits for individual projects. The AIMS III study provides aggregated ASEAN-wide benefits by scenario, not by individual project. The ADB GMS Master Plan, similarly, provides aggregated GMS-wide benefits by scenario rather than for individual projects. Neither study provides a list of recommended projects.[131] The ACMECS document is not an expansion planning study and merely names several high priority projects. The JICA study names high priority projects but provides no quantitative basis for its recommendations, though it is understood that considerable modeling and other technical analysis was performed. The World Bank study provides the most project-level economic detail, with candidate project Net Present Values (NPV). However, the present report identifies various weaknesses in the modeling approach taken for that study and its assessment of the underlying projects.[132]

It is important to understand that the individual projects identified in all the different studies are conceptual; they are not specific projects with detailed analysis behind them. Interconnection substations are identified for modeling purposes that but these do not necessarily reflect input from national authorities on which substations to interconnect at or on grid considerations at the national level. Also, in most cases across the studies reviewed, the indicative timelines for project entry are notably optimistic, though the AIMS III study is more realistic in this respect. The JICA study, for its part, does not provide timelines for project entry.

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[131] The GMS Master Plan study reviewed was a series of publicly available slide decks; a final, complete, written report was not available for review (if it exists). The core AIMS III study documents reviewed did not contain any specific project recommendations, though a more recent slide deck presents a "possible prioritization" of seven projects in the LMS (the "Northern Region" of that study). Only two of the projects are ranked and no basis for the ranking is given. (The ASEAN Interconnection Masterplan Study (AIMS) III Final Project Meeting Phase I Results & Findings (Regional/Sub Regional). April 22, 2021.)

[132] The World Bank study is overall thoughtfully and professionally done. Most of the issues identified pertain to the sort of modelling simplifications made necessary by lack of time, budget, and data access. However, there are other issues, specific to certain projects, that materially affect the study's findings. See Section 3.5.

Analytical Framework: For each of the items below, an issue or challenge relevant to project evaluation is identified and then a conceptual approach is specified.

- Time dimension
  - The issue: comparing projects anticipated to be completed in different periods is "apples to oranges". The statement is true on several dimensions.
    - Even for projects that are otherwise identical in all technical ways, the underlying project value will depend on market conditions on either side of the border, which change over time. But even if the value for two projects happening in different periods could be assumed to be identical on a constant-value basis (adjusting for inflation in a common currency), the present value of the two projects would depend on a discount rate, which presumes there are specific values to discount. As discussed above, there are specific project values (as opposed to costs) to evaluate in only one of the studies reviewed.
    - Most projects in the studies are assumed to enter in different years. Within the AIMS III study, modeled new projects are shown entering in five-year blocks (e.g., 2025, 2030, etcetera). In the World Bank and GMS Master Plan, estimated "earliest" online dates are given for projects (though these dates are highly optimistic). In the other studies, dates are not given.
    - By their nature, those projects proposed for entry later rather than sooner are purely conceptual. They tend to be larger projects. Attempting to compare the relative merits of a small project that could plausibly enter within the next five years with a large project that could not plausibly enter in under ten years is fraught.
  - Conceptual approach: the emphasis is placed on near-term projects, with an implementation period stretching through 2025-30 (recall that the AIMS III first horizon is 2025). This approach captures the bulk of projects that are most plausible based on factors such as existing grid and market conditions and their likely evolution and project development timelines, while retaining a linkage to the AIMS III report.
- Interconnection Type and Project Technology
  - The issue: what bearing does the project type and technology have on the degree to which a project is supportive of regional integration? Grid-to-grid HVAC ties might be presumed to be more supportive of regional integration than HVDC ties (or HVAC with a DC back-to-back component), in the sense that synchronous ties require a high degree of coordination and trust and are more flexible in their applications. IPP-to-foreign grid or grid-to-isolated load might be presumed to be the least supportive types of projects for regional integration since, by definition, the grids of the respective countries are not integrated by these projects.[133] These presumptions are incorrect. An HVAC grid-to-grid tie that would require two asynchronous grids to

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synchronize that are not realistically capable of being safely synchronized within the project's anticipated development timeline *is not supportive* of regional integration. By contrast, a grid-to-isolated foreign load project, that could potentially become a grid-to-grid project later, *is supportive* of regional integration.

  - Conceptual approach: project type and technology must be appropriate to the setting and to the analysis period (through 2025/30) to be deemed to be supportive of regional trade.

- Project size
  - The issue: all else equal, a larger project (that is, higher voltage/more circuits) would seem to be more supportive of regional trade than a smaller project since, by definition, the larger project could accommodate more cross-border flows. Yet, clearly larger projects are not better projects if they will not be built because they are too big for the markets involved, in technical, economic, or political senses.
  - Conceptual approach: the focus is placed on the appropriateness of the project size for interconnection points and the implementation period.

- Business case / trading scenario
  - The issue: trading can occur on a continuum from centralized dispatch to opportunity trade, with the contractual basis for the trade constituting another axis of variation. Thus, within a regional market that may be centrally dispatched or locally dispatched, there could be organized short through long-term financial-only cross-border trading, combined with (or not) short through long-term physical trading. Wheeling trade is yet another aspect of potential variation. How does one rank projects based on one or another of these different modes of trading in terms of how supportive they are of regional trade?
  - Conceptual approach: All or nearly all the projects that are identified as candidate projects in the various studies were evaluated in those studies on the basis of their ability to reduce regional costs assuming centralized dispatch, which is a reasonable approach to estimating the maximum theoretical economic value of cross-border projects.[134] Within the region, however, there is an existing successful multiparty one-way wheeling arrangement in the form of the "LTM-PIP". This structure would appear to embed aspirations for expanded regional trade and is potentially replicable for other parties: for instance, a project facilitating a trade from Lao PDR through Thailand to Myanmar would appear to make at least as much economic sense as Lao PDR to Myanmar via a direct grid to grid connection between those two countries. All that is needed for the former project would be a Thailand to Myanmar interconnection and for the parties to sign up for arrangements like those in the LTM-PIP. Therefore, projects that tend to facilitate multiparty trade are deemed more supportive of regional trade than other projects.

[134] The ACMECS document does not include any modelling or other information supporting the nominated priority projects.

- “First of kind” projects
    - The issue: consider two projects that are otherwise identical, but where one would be the first cross-border project between two countries and the other would be the tenth. One might suppose the former project is more supportive of regional trade, though it might be less doable within the analysis period.
    - Conceptual approach: first of kind projects are deemed more supportive than similar projects that are not first of kind, reflecting that they ease the path to further integration.

- Other factors
    - The issue: there are a multiplicity of factors that bear on the viability of cross-border projects that are not easy to model but can be at least notionally quantified for ranking purposes and that can inform an overall evaluation. Such factors include the level of governmental support by the host countries; development partner support; the existence of supporting studies; the extent to which a project depends on another project to proceed; and the ground-level “doability” of a project.
    - Conceptual approach: These factors, and others from above, are brought into the evaluation framework as scored attributes of a project.

Methodology: Candidate projects were assessed through a multi-stage screening process, as described below.

- Candidate projects were assembled from those listed in the core studies reviewed for this report, and by others listed in the Bibliography. Several additional candidate projects were specified based on the Delphos Team’s analysis of regional needs and other factors.
- Project data were collected in as much detail for as many projects as possible. Data sought included project substations, voltage, circuits, conductor, length, technology, project type (e.g., grid-to-grid, IPP-to-grid, etcetera), capacity (MW), MVA, status, claimed entry date, cost, and the sources mentioning the project.
- A “negative screen” removed all pre-existing or in-process projects, those within-country projects not tied to a proposed cross-border project, and those projects that were projected to be unable to enter within the evaluation period (i.e., through 2025/2027).
- A “positive screen” collated scoring from 0 to 5 (higher being better) in five different categories. Those projects with a total score below a deemed cutoff score were excluded. The approach to scoring in the different categories is discussed in more detail in the next section.
- A short-list was produced, with all those projects emerging from the positive screen with a passing score.
- The shortlisted projects were examined in more detail to identify nine high priority, plausible, projects that support regional integration; these projects are discussed in section 4.3.

Figure 46 below provides a condensed version of the spreadsheet used for the steps above, covering through production of the shortlist and using fictitious projects. In the example given, Project 1 advanced through the negative screen, positive screen inputs were completed and the project received 9 points, which was set in this example as the minimum score below which projects are not selected. Projects 2 and 3 failed to advance past the negative screen stage, and hence were screened out. Project 4 nearly made the minimum score of 9 but failed to advance.

Figure 46. Sample of Project Evaluation Spreadsheet

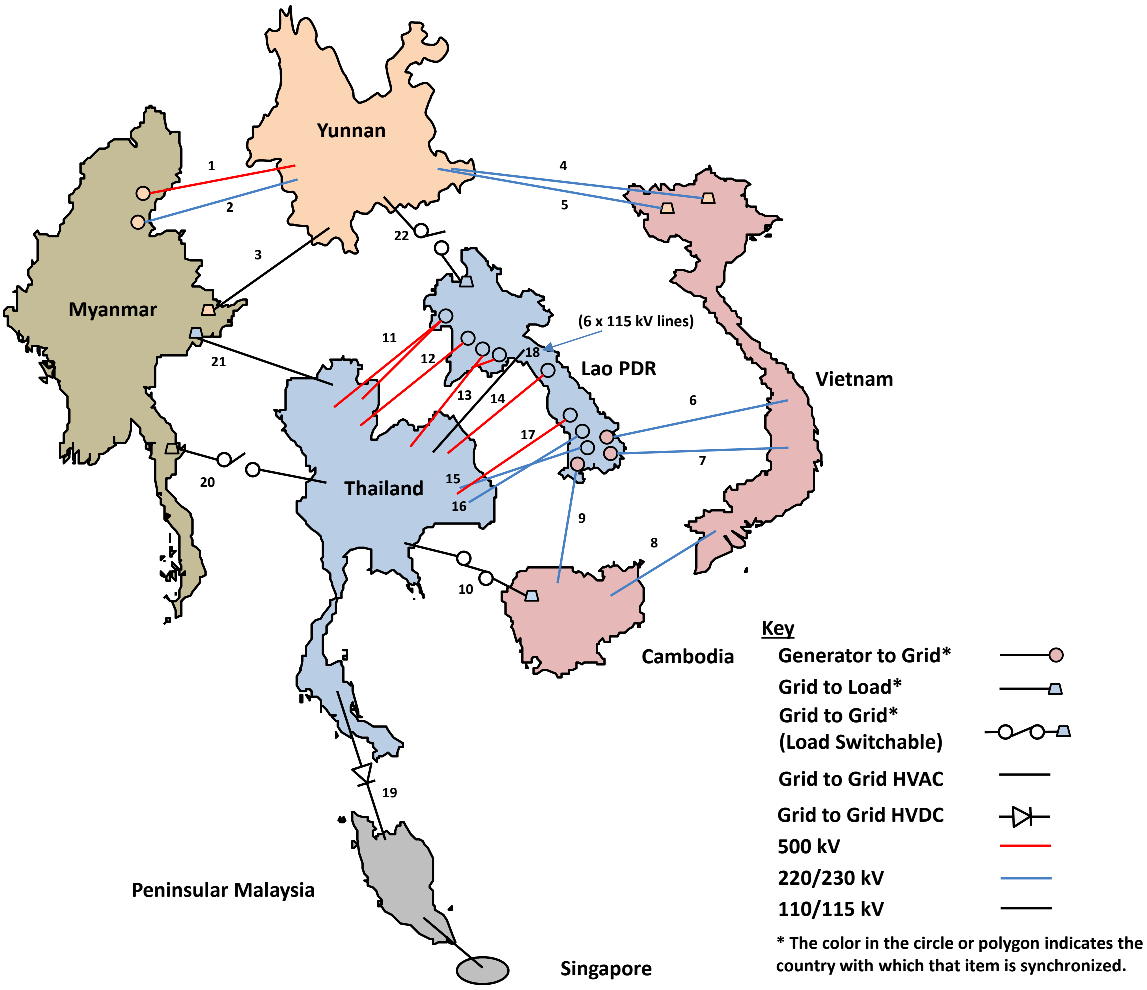
Project Name	Negative Screen Inputs?	Proceed to Positive Screens?	POSITIVE SCREENS Input Values and Explanations, as Appropriate					Positive Screen Inputs Required?	Positive Screen Inputs Complete?	Points for the Project	Project Selection Status
			Supported by Host Governments	Supported by Development Partners	Supportive of Regional Integration	Project Doability within Analysis Period	Other Factors				
Project 1	0	YES	2	1	3	3	0	YES	YES	9	✓
Project 2	1	NO: SCREENED OUT	NOT EVALUATED	NOT EVALUATED	NOT EVALUATED	NOT EVALUATED	NOT EVALUATED	NO	YES	Screened Out	×
Project 3	1	NO: SCREENED OUT	NOT EVALUATED	NOT EVALUATED	NOT EVALUATED	NOT EVALUATED	NOT EVALUATED	NO	YES	Screened Out	×
Project 4	0	YES	2	1	2	1	2	YES	YES	8	×

Source: Delphos International.

4.2 EXISTING AND IN PROGRESS PROJECTS

Figure 47 shows all existing and in progress projects in the region. The map focuses on links of 220/230 kV and above, through some of the more significant 110/115 kV interconnections are highlighted as well. Locations are indicative only. Bear in mind that the line lengths depicted relate to the separation of countries in the map rather than to the actual lengths of lines; if the countries were not separated in this way and lines were mapped to actual substations, many of the shorter line projects would not be visible or would appear only as dots. Refer to Figure 2 and Section 1.2.2 for information about the different types of interconnections depicted. Table 9 summarizes information for existing and in progress cross-border transmission projects in the region, with additional details on these projects provided in Annex B: Existing and In Progress Projects.

Figure 47. Map of Existing and In Progress Projects



Source: Delphos International

Table 9. Existing and In Progress Transmission Projects in the GMS

SN	Project Name	From Country	To Country	From Substation	To Substation	Voltage (kV)	Ckts	Project Type	Existing Rated or Planned Capacity (MW)
1	Myanmar - China Project	Myanmar	China	Dapein 1	Dayingjiang /Dehong	500	1	Generator to Foreign Grid	880
2	Myanmar - China Project	Myanmar	China	Shweli 1	Dehong /Hannong	220	2	Generator to Foreign Grid	600
3	China - Myanmar Project 3	China	Myanmar	Menglong	Jingyang	110	1	Grid to Grid	
4	Vietnam - China Project	Vietnam (North)	China	Ha Giang	Maguan (Malutang)	220	1	Grid to Grid	350
5	Vietnam - China Project	Vietnam (North)	China	Lao Cai	Xinqiao (Guman)	220	2	Grid to Grid	450
6	Vietnam - Laos Project	Laos	Vietnam (central)	Xekaman 3	Thanh My	220	2	Generator to Foreign Grid	250
7	Vietnam - Laos Project	Laos	Vietnam (central)	Xekaman 1	Pleiku	220	2	Generator to Foreign Grid	320
8	Vietnam - Cambodia Project	Vietnam (South)	Cambodia	Chau Doc	Takeo - Phnom Penh	230	2	Grid to Grid	200

9	Laos - Cambodia Project	Laos (South)	Cambodia	Ban Hat	Stung Treng	230		Grid to Grid	145
10	Thailand - Cambodia Project	Thailand	Cambodia	Wathana Nakhon substation (EGAT) via Aranyaprathet 2 substation (PEA)	Banteay Meanchey -Siem Reap	115	1	Grid to Isolated Load	180
11	Thailand - Laos Transmission line 5	Laos	Thailand	Hong Sa	Nan	500	2	Generator to Foreign Grid	1473
11	Laos North - Thailand Project	Laos (North)	Thailand	Hong Sa	Mae Moh 3	500	2	Generator to Foreign Grid	
12	Thailand - Laos Transmission line 7	Thailand	Laos	Thali	Xayaburi	500	2	Generator to Foreign Grid	
13	Laos North - Thailand Project	Laos (North)	Thailand	Nam Ngum 2 - Nabong (Ban Na Bong)	Udon Thani 3	500	2	Generator to Foreign Grid	596.6
14	Laos - Thailand Project	Laos	Thailand	Nam Theun 2	Roi Et 2	500	2	Generator to Foreign Grid	948
15	Thailand - Laos Transmission line 6	Thailand	Laos	Ubon Ratchathani 3	Xe-Pain Xe-Namnoy	230	2	Generator to Foreign Grid	390
16	Laos - Thailand Transmission Line 2	Thailand	Laos	Ubon Ratchathani 2	Houay Ho	230	2	Generator to Foreign Grid	145/500
17	Laos – Thailand Project	Laos	Thailand	Pak Xe (Ban Lak 25)	Ubon Ratchathani 3	500		Generator to Foreign Grid	1300
18	Laos - Thailand Project	Laos (north)	Thailand	Paklay/Paklai	Thali	115	1	Grid to Grid	
18	Thailand - Laos Project	Thailand	Laos	Nong Khai	Thanaleng (Vientiane)	115	1	Grid to Grid	75
18	Thailand - Laos Project	Thailand	Laos	Nong Khai	Phon Tong	115	2	Grid to Grid	
18	Thailand - Laos Project	Thailand	Laos	Bung Kan	Pakxan	115	1	Grid to Grid	
18	Laos - Thailand Project	Laos	Thailand	Bang Yo	Sirindhorn 2	115	1	Generator to Foreign Grid	36
18	Bangyo -Sirindhon 2 Transmission Line	Laos	Thailand	Bang Yo	Sirindhorn 2	115	1	Grid to Grid	
19	Thailand - Malaysia Transmission line	Thailand	Malaysia	Khlong Ngae	Gurun	300	1	Grid to Grid	300
19	Thailand - Malaysia	Thailand	Malaysia	Sadao	Chuping	115/132	1	Grid to Grid	80
20	Thailand – Myanmar (Myawaddy) Line	Thailand	Myanmar	Mae Sot	Myawaddy	115		Grid to Isolated Load	
21	Thailand - Myanmar Project	Thailand	Myanmar	Chiang Rai	Tachileck	110		Grid to Isolated Load	75
Not Shown on Map									
22	Laos - Thailand Project 4	Laos	Thailand	Pakbo / Savannakhet	Mukdahan 2	115	1	Grid to Grid	75
23	Lao PDR - Thailand Project	Laos	Thailand	Theun Hinboun-Thakhek	Nakhon Phanom 2	230	2	Generator to Foreign Grid	440
24	Thailand - Laos Transmission line 1	Thailand	Laos	Nakhon Phanom	Thakhek	115	2	Grid to Grid	75
25	China - Vietnam Project	China	Vietnam	Hekou	Lao Cai	110	1	Grid to Grid	70
26	China - Vietnam Project	China	Vietnam	Maomaotiao	HaGiang	110	2	Grid to Grid	110
27	China - Laos Project	China	Laos	Mengla	Namo (Oudomxai)	115	1	Grid to Grid	60
28	Laos - Cambodia Project	Laos	Cambodia	Ban Hat	Khamponsalao	115	1	Grid to Grid	
29	Vietnam - China Transmission Line	Vietnam	China	Mong Cai	Shengou	110	1	Grid to Grid	75
30	Laos North - Thailand Project	Laos (North)	Thailand	Xayaburi	Loei 2- Khon Kaen 4	500		Generator to Foreign Grid	1220

31	Thailand - Laos Project	Thailand	Laos	Udon Thani 3	Ban Na Bong - Nam Theun 1	500	2	Generator to Foreign Grid	523
32	Laos - Thailand Project	Laos	Thailand	Luang Prabang	Nan	500	2	Generator to Foreign Grid	1400
33	500kV Phayargyi - Hlaingthayar Transmission Line	Myanmar	Myanmar	Phayargyi	Hlaingthayar	500		Internal	
34	230kV Mawlamyine-Ye-Dawei Transmission Line	Myanmar	Myanmar	Mawlamyine	Dawei	500		Internal	
35	500kV Taungoo to Phayargyi	Myanmar	Myanmar	Sabakywe	Karmanat / Phayargyi	500		Internal	

Source: Delphos International

4.3 COMPARISON OF PROPOSED PROJECTS

The Delphos Team compiled a database in Microsoft Excel of cross-border projects (and projects potentially related to cross-border projects) in the region. Projects were identified from the core studies reviewed for this report as well as from other sources, such as studies and reports prepared by development banks, documents posted on the RPTCC website, materials and information acquired from regional utilities, and press reports. In addition, some projects were identified based on the Delphos Team's own analysis.

In assembling the database, it was decided to combine various versions of projects to account for different spellings of substations, different conductors, or other details.

Table 10 shows key project details of shortlisted projects; more information can be found in Annex A: ALL Shortlisted Projects. As described in Section 4.1, projects on the shortlist were screened to ensure that only projects meeting basic criteria (such as being plausibly achievable within the evaluation period) were selected. Then, these projects were scored on a variety of attributes. In Table 10, the highest ranked projects are grouped at the top. Of these, the top nine are mapped in Figure 49 (showing expected average net power flow direction) and discussed individually later in this section. Note that project scores are intentionally not reported here, as doing so might leave the incorrect impression that there is sufficient information available to make fine-tuned comparisons across projects. Rather, the intent is to identify projects that merit further discussion and potentially further study.

Table 10. Shortlist of Planned/Proposed Projects after Initial Screening

SN	Project Name	From Country	To Country	From Substation	To Substation	Voltage (kV)	Ckts	Project Type	Existing Rated or Planned Capacity (MW)
1	Lao North - Thailand Project	Laos (North)	Thailand	Muang Houn	Nan 2	500		Grid to Grid	800
2	Thabok-Bung Kan Transmission Line	Laos	Thailand	Thabok-Pakxan	Bung Kan	115	1	Grid to Grid	
3	Mae Sot-Myawaddy Transmission Line	Thailand	Myanmar	Mae Sot	Myawaddy	230	2	Grid to Grid	300
4	Lao PDR-Myanmar Power Interconnection	Laos	Myanmar	M. Long	Keng Tung	230/500	2	Grid to Grid	300
5	Thailand - Malaysia Transmission line	Thailand	Malaysia	Khlong Ngae	Gurun	300	1	Grid to Grid	300
6	Thailand - Myanmar (Tanintharyi) Transmission Line	Thailand	Myanmar	Tha Tako	New Substation	500	2	Grid to Isolated Load	

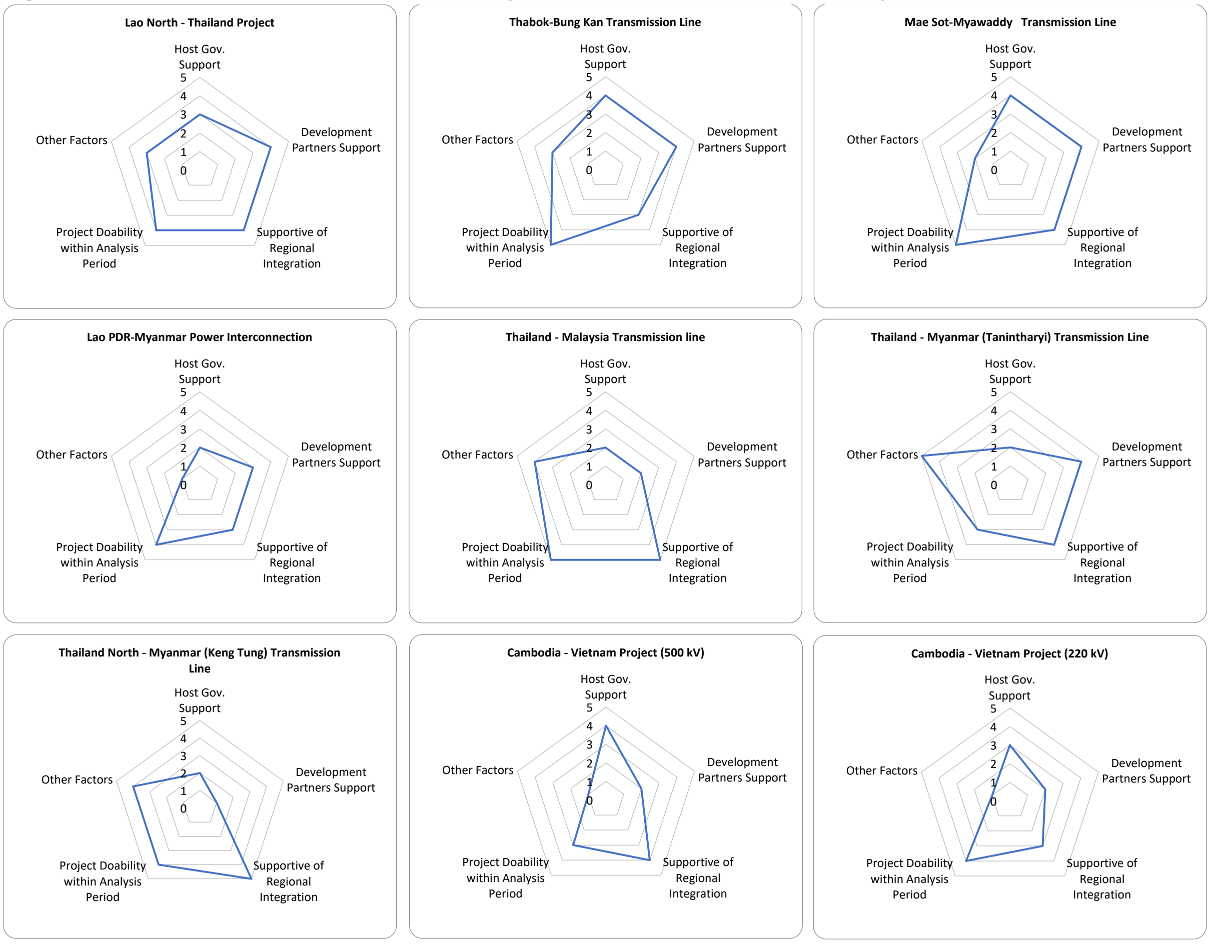
7	Thailand North - Myanmar (Keng Tung) Transmission Line	Thailand	Myanmar	Chiang Rai	Keng Tung	230	1	Grid to Grid	
8	Cambodia - Vietnam Project	Cambodia	Vietnam	Kampong Cham	Tay Ninh	500	2	Grid to Grid	400
9	Cambodia - Vietnam Project	Cambodia	Vietnam (South)	Stung Treng	Tay Ninh	220		Grid to Grid	207
10	Thailand - Cambodia	Thailand	Cambodia	Wang Noi	Banteay Meanchey - Siem Reap - Kampong Cham	500	2	Grid to Grid	300
11	Myanmar - Thailand Project	Myanmar	Thailand	Yangon area	Mae Moh	500		Grid to Grid	1500
12	Laos (South) - Vietnam (Central) Project	Laos	Vietnam	Savannakhet - Mahaxai	Ha Tihn	500		Grid to Grid	600
13	Laos - Thailand Project	Laos (North)	Thailand	Pak Beng / M.Houn (Pak Nguyen)	Tha Wang Pha	500		Grid to Grid	800
14	China - Laos - Thailand Project	China	Thailand	Ban Na - Pak Beng	Tha Wang Pha	500		Grid to Grid	3000
15	Laos - Vietnam Project	Laos (North)	Vietnam (North)	Luang Prabang-Xam Nau (Lao-N)	Nho Quan	500	2	Generator to Foreign Grid	1500/2500/3500
16	Laos - Myanmar Project	Laos (North)	Myanmar	Luang Namtha	Mandalay	230/500	2	Grid to Grid	1000
17	Cambodia - Vietnam Central Project	Cambodia	Vietnam	Lower Se San 2	Pleiku	230	2	Generator to Foreign Grid	250
18	Laos - Vietnam Power Transmission Interconnection 2	Laos (South)	Vietnam (centre)	Hatxan	Pleiku	500	2	Grid to Grid	1000
19	Laos - Cambodia - Vietnam Project	Laos (South)	Vietnam (South)	Ban Soc (Ban Hatxan)	Tay Ninh via Stung Treng	500		Grid to Grid	1700
20	Laos-China Project	Laos (north)	China	Na Mo	Ban Na	500		Grid to Grid	1000/3000
21	Myanmar - Thailand Project	Myanmar	Thailand	Mae Khot	Mae Chan	230		Generator to Foreign Grid	250
22	Laos PDR to Thailand Transmission Interconnection Project	Laos	Thailand	Ton Pheng	Mae Chan	115		Grid to Grid	300
23	Laos - Cambodia Project	Laos (south)	Cambodia	Xekong	Phanom Peng	500		Generator to Foreign Grid	
24	East - West Energy Corridor to Mawlamyine	Myanmar	Thailand	Mawlamyine	Mae Sot	230		Grid to Grid	
25	Laos North - Thailand Project	Laos (North)	Thailand	Nam Ngum 3-Nabong (Ban Na Bong)	Udon Thani 3	500	2	Generator to Foreign Grid	440
26	Thailand - Cambodia	Thailand	Cambodia	Prachin Buri	Battambang	230	2	Grid to Grid	500
27	Myanmar - Thailand Project	Myanmar	Thailand	Hutgyi	Phitsanulok 3	500		Generator to Foreign Grid	920
28	Myanmar - Thailand Project	Myanmar	Thailand	Ta Sang	Mae Moh 3	500		Generator to Foreign Grid	3000
29	Myanmar - Thailand Project	Myanmar	Thailand	Mong Ton	Sai Noi 2	500		Generator to Foreign Grid	3000
30	Laos - Laos Project	Laos	Laos	Muang Houn	Napia	500	2	Grid to Grid	
31	Laos - Laos Project	Laos	Laos	Napia	Houa Phan Thermal	500	2	Grid to Grid	

Source: Delphos International

Figure 48 provides radar chart summaries of the evaluation of the nine projects that were shortlisted for possible further analysis. As mentioned above, projects were scored in five categories. It is important to understand the heavy dose of judgement involved in scoring, considering both the inherent subjectivity of the scoring itself and the large number of individual scores that needed to be produced for over a hundred candidate projects in five scored categories. Scoring was approached as follows in the Excel spreadsheet used for the evaluation:

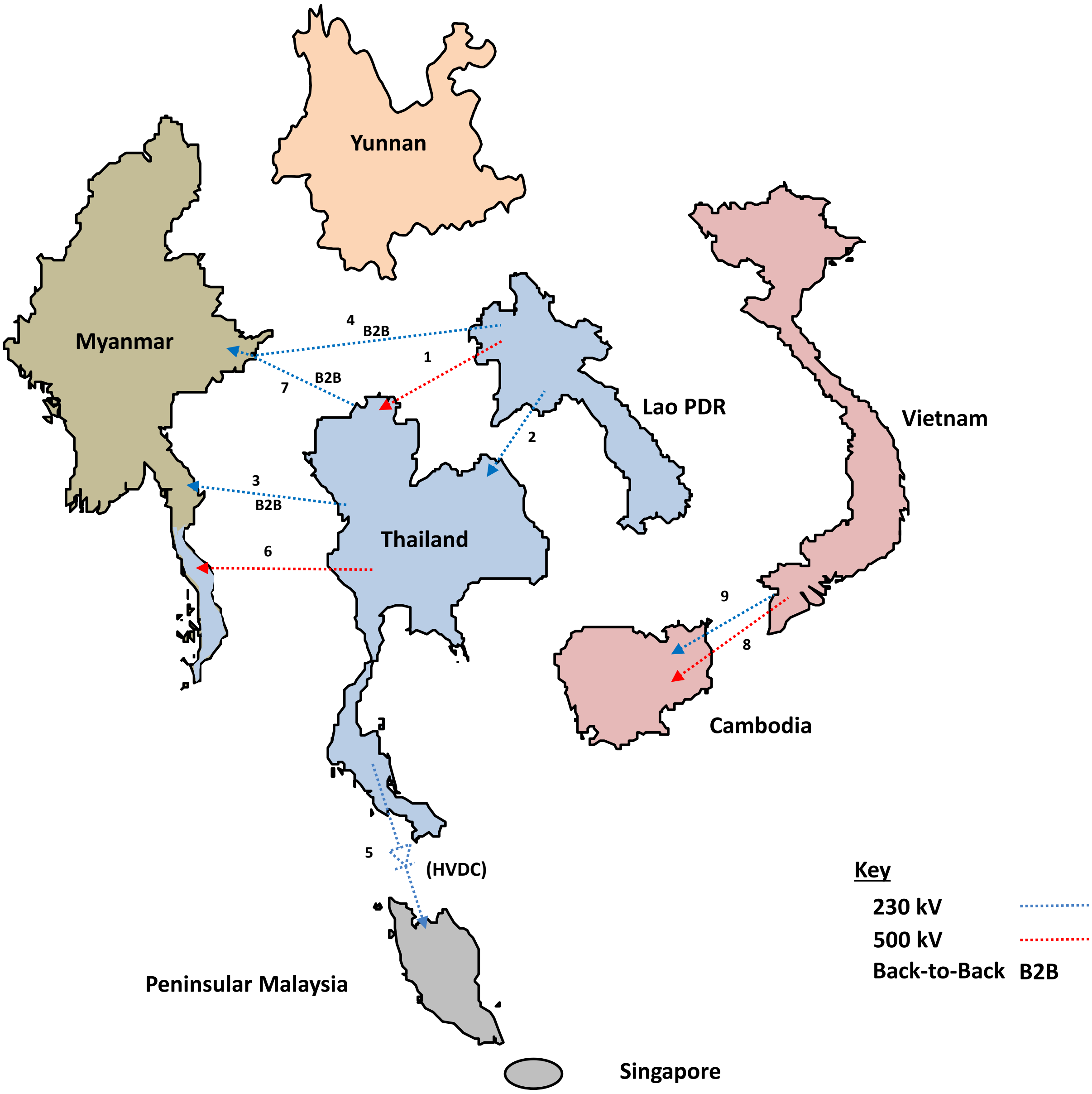
- Host Governments Support: Input sum of: A) 0 for no known government support; 1 for one country's known support; 2 for two or more countries' known support, and B) 0 to 3 for degree of support (higher is more support).
- Development Partner Support: Input sum of: A) 0 for no known development partner support; 1 for one development partner's known support; 2 for two or more development partner's known support, and B) 0 to 3 for degree of support (higher is more support).
- Supportive of Regional Integration: Input sum of A) 0 for not supportive (e.g., internal line not related to interconnectivity); 1 for generator to foreign grid projects; 2 for two country grid to grid projects; 3 for grid to grid plus wheeling; and, B) 0 to 2 for level of support.
- Project Doability within Analysis Period: Input value from 0 to 5 (higher is better) for project doability within the analysis period.
- Other Factors: Input value from 0 to 5 (higher is better) for other factors not covered in other categories.

Figure 48. Radar Charts of Shortlisted Projects for Possible Further Analysis



As an example of the sort of assessment that was done, the three "high priority" projects recommended in the JICA study (projects 1 – 3) were judged to be supported by only one development partner (JICA itself) but were awarded 3 points for the degree of support (since there were only three high priority projects recommended in the entire study, which was itself found to be highly credible. By contrast, the Lao PDR – Myanmar Power Interconnection Project was found to be supported (in the sense of studied) by multiple development partners, but without strong positive endorsement by any of them or by the underlying studies.

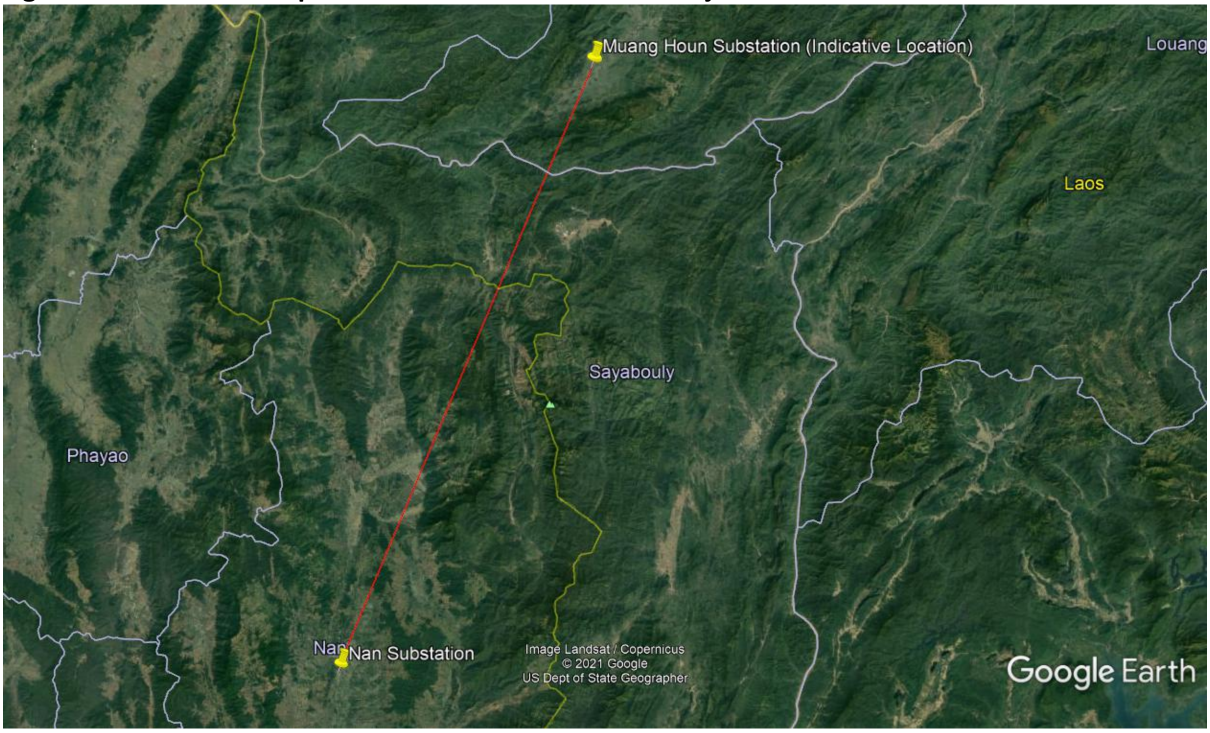
Figure 49. Map of Proposed Projects Shortlisted for Possible Further Analysis



Source: Delphos International

Lao PDR North (Houn) to Thailand (Nan) Project (1): This 500 kV project of about 150 kms is explained most compellingly and completely in the JICA study (section 20.3). It is also listed as a planned project in Lao PDR's "Country Presentation" at the 27th Meeting of the Regional Power Trade Coordination Committee (RPTCC-27), as well as in other sources. Rationales given for the project in the JICA report include that Lao PDR (in the north, especially) is and will remain for a considerable period very long on power supply, mostly hydropower. It makes sense to use this excess hydro to reduce the cost of meeting demand in Thailand and potentially to meet demand in Myanmar through new connections to that country from Thailand. Figure 50 depicts the project conceptually.

Figure 50. Indicative Map of Lao PDR North - Thailand Project



Source: Delphos International

Lao PDR (Thabok-Paksan) to Thailand (BungKan) Transmission Project (2): This is an approximately 60 kms long 230 kV project, whose business case is explained in the JICA study (section 20.3). The project would take the same route as an existing 115 kV grid-to-grid line. While the project is not mentioned in other studies, the fact that it is listed as one of three high priority projects in the JICA report, which the Delphos Team found to be authoritative, suggests strongly that the project has merit. Its short distance on an existing transmission corridor implies the project could be completely relatively quickly.

Figure 51. Thabok-BungKan Transmission Project

Source: Delphos International

Thailand (Mae Sot) - Myanmar (Myawaddy) Project (3): As with the two projects above, this one is also listed as one of the three high priority projects in the JICA study. Myawaddy, a city of over 200,000 inhabitants, with peak demand of around 30 MW, was served as isolated load by Thailand until March 2019, when the city was connected to the main Myanmar grid. The new transmission project involved a double circuit 230 kV line from Mawlamyine, Myanmar, plus a new 100 MVA transformer with six 66 kV bays, of which four are currently used for service to the city. The project was originally conceived to facilitate a cross-border connection with Thailand, via 115 kV connecting at the 115 kV Mae Sot substation or at a new 230 kV substation in the area.

It is believed, but has not been confirmed, that the 230 kV lines are operated at 115 kV currently. Certainly, double circuit 230 kV would appear excessively sized for service to a relatively small domestic load.

There appears to be ample support on both the Myanmar and Thailand sides for a potential 230 kV interconnection at this point. For instance:

- A 5 November 2019 Bangkok Post article, "EGAT talks power trade with Cambodia, Myanmar", quotes a government source as saying that EGAT had been "ordered by the Energy Minister to talk with the two governments (Myanmar and Cambodia) about future power trading," and that "EGAT's preliminary study found Thailand can trade electricity to Myanmar through the immigration checkpoint at Mae Sot, Tak."
- In a 31 March 2020 post on its website "EGAT TODAY", EGAT stated it has planned to construct a 230 kV double circuit transmission line between Mae Sot and Tak 2 substations in order to supply more electricity to the special economic zone (SEZ 1) in the area, to enhance the system

security in the long run, and to increase the capability in connecting with the electricity system of the neighboring countries. The post states that the project shall be completed in 2025.

- As noted, the double circuit 230 kV line on the Myanmar side is understood to have been built to facilitate a cross-border interconnection.

The project (see Figure 52) is anticipated to provide important system benefits to Myanmar, given that it would inject power on the southern portion of the grid, which suffers from inadequate supply (most supply is to the north of a major north/south transmission congestion interface).

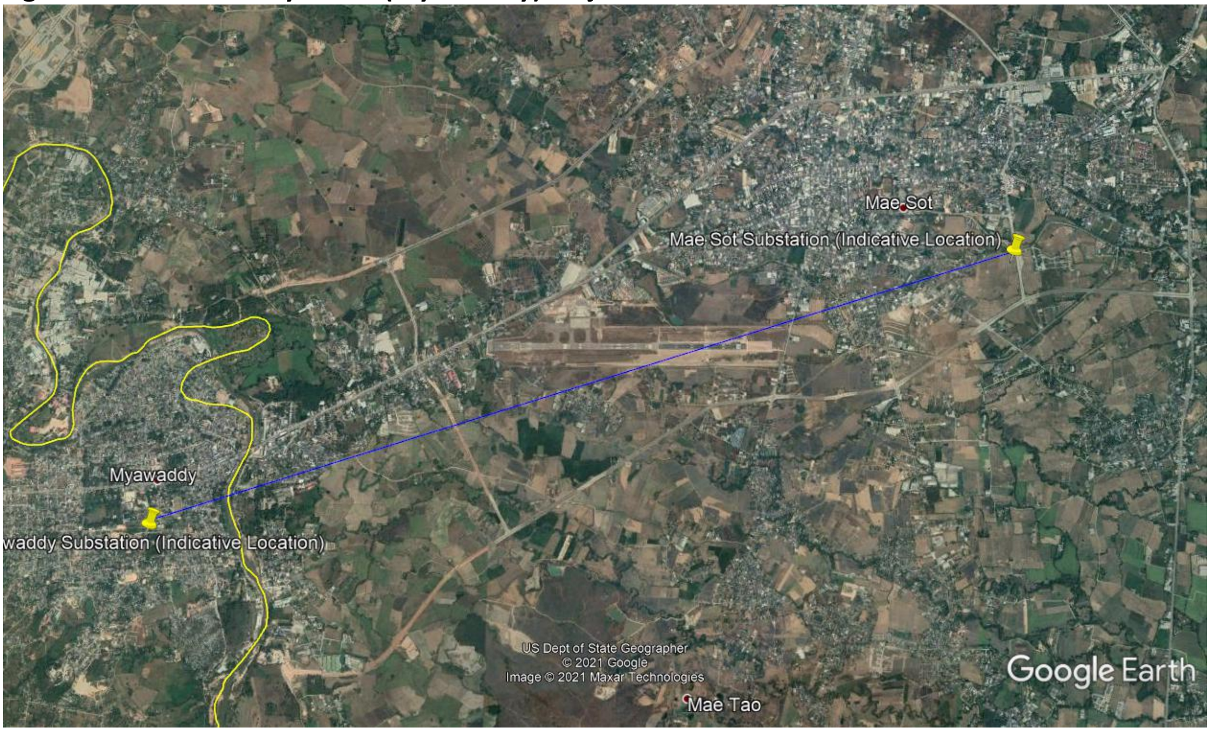
Of all the projects evaluated, this one would appear to be the simplest to execute. The distance is very short (approximately 10 kms). There are presumably existing transmission corridors/rights of way from the pre-existing service by Thailand to Myawaddy which potentially would be sufficient for the new project. One would expect that an AC/DC/AC back-to-back facility would be required.

What is not known is whether the two sides have initiated the details of a specific cross-border link.

It is not clear to the Delphos Team why so few sources other than the JICA study (and the Delphos Team itself, independently)[135] see potential in this project. The few other sources that mention the project have it connecting on the Myanmar side at Mawlamyine, a city of about 450,000 that has been on the Myanmar grid (and host to a power station) for many years. Several sources propose 230 kV or 500 kV links to Mawlamyine but discount the idea on the incorrect grounds that the city is not connected to the Myanmar grid.[136] One can only imagine that someone at some point confused Myawaddy (which was not on the main grid until March 2019, as noted early) and Mawlamyine, and subsequently that regional power planning studies, including some reviewed in this report, did not pick up on the original error.

[135] Eric Shumway (Delphos) and Nasser Faarooqui (AECOM), who separately spent long periods working within Myanmar on energy sector projects, have significant knowledge of the Myanmar grid and institutions.
[136] For instance: "Annex to the Regional Investment Framework 2022: Project Pipeline September 2017", page 41; and World Bank: GMS Power Market Development". Intelligent Energy Systems, June 2018, page 58.

Figure 52. Thailand - Myanmar (Myawaddy) Project



Source: Delphos International

Lao PDR (Muong Long) to Myanmar (Keng Tung) Power Interconnection Project (4): This project, which is among the best-documented of all the projects reviewed, would involve a double-circuit 230 kV line from Muong Long substation in northern Lao PDR to a new substation in Keng Tung completed in 2020, a distance of about 200 kms. The AIMS III Phase II modeling assumes this project would be completed by 2025.

Regarding the Keng Tung substation, the Myanmar President at the time (U Win Myint) was quoted as saying, "By using the 230 kV electrical substation of Shan State (East) which we have opened today as centre [sic], we will work to build more electric power supply lines to the Tachileik-Maingkhoke-Maingsat-Maingwa regions in order to connect the whole of Shan State to the electric power grid." [137] (Most of eastern Shan State is currently not on the Myanmar grid).

The project would involve construction of a new substation at Tachileik, a Myanmar city on the border of Thailand, with approximately 50,000 inhabitants, and is expected to include an AC/DC/AC back-to-back element.

The business case for the project is simple: Myanmar needs power and Lao PDR (especially northern Lao PDR) has excess power. An MOU between the governments in support of studies for the project has been signed.

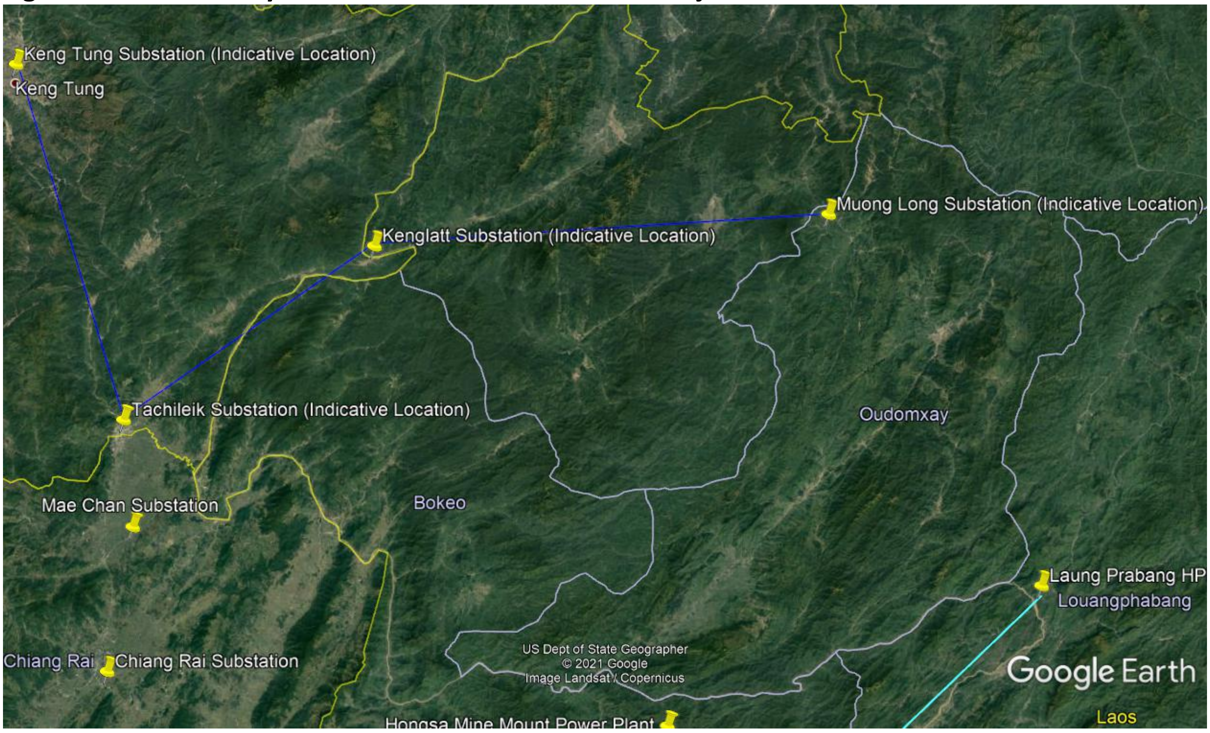
The project is best discussed in tandem with the Thailand - Myanmar (Keng Tung) Project (7), discussed later in this section. Briefly, this other project would involve the same elements on the Myanmar side,

[137] Myanmar News Agency reporting, "President connects Shan State (East) to National Grid", *The Global New Light of Myanmar*, August 9, 2020.

but would interconnect over a much shorter distance to Thailand at the Mae Chan substation. Below are several observations about the two projects.

- Project 4 would interconnect with the Lao PDR grid, which is already effectively synchronized with, and controlled by, Thailand.[138] One could say, therefore, that Project 4 connects at a weaker portion of the Thai grid than Project 7. Provided Lao PDR's business objectives could be addressed through other means, it is unclear what technical or strategic advantage would be gained by Lao PDR by undertaking Project 4 rather than by supporting Project 7.
- Project 7 could accomplish Project 4's business objective by pairing Project 7 with an LTM-PIP-style arrangement, whereby Lao PDR sells the power to Myanmar, wheeling through Thailand.
- Of course, Thailand might prefer to sell its own excess power to Myanmar via Project 7. The business arrangements would need to be worked out. It is worth noting that Delphos Team contacts at Myanmar's MOEE indicated that there appeared to be little interest in Project 4 at MOEE.

Figure 53. Lao PDR-Myanmar Power Interconnection Project



Source: Delphos International

Thailand (Khlong Ngae) to Malaysia (Grun) Transmission Project (5): This 230 kV HVDC project is assumed to proceed in 2025 in the AIMS III Phase II study (see Figure 54 below), and different versions of the project have been mentioned elsewhere. It would take the same route as the existing 230 kV HVDC link (shown in the figure as entering in 2020, meaning only that it is in the system at that point).

The business case is that Thailand and Lao PDR have low-cost power to sell and Malaysia and Singapore have documented an ongoing interest in buying under the LTM-PIP structure, which could be

[138] See section 2.1.3.3.

expanded. Since Thailand is not a seller under the LTM-PIP structure (it only provides wheeling service) an expanded connection with Peninsular Malaysia would facilitate its own sales to Malaysia and potentially to Singapore. Given the pre-existing path, the strong and well-managed grids on either side of the border, and the HVDC nature of the project, there would appear to be few developmental or technical obstacles to the project.

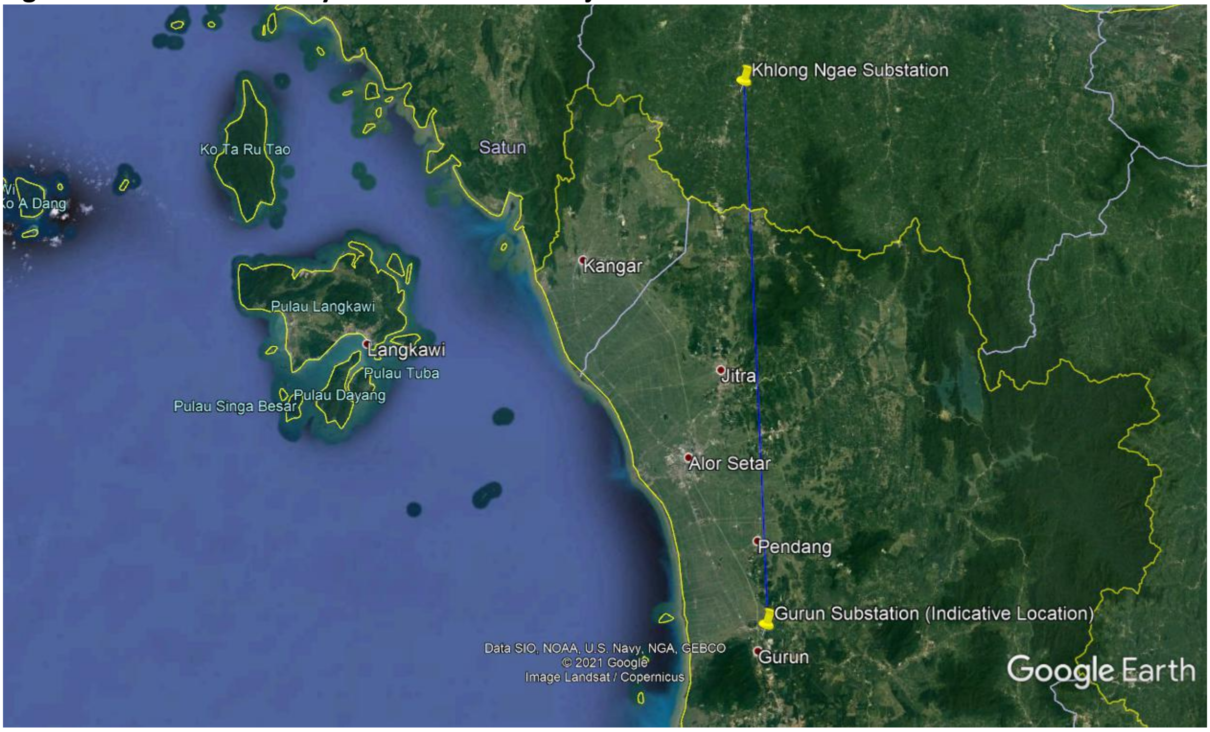
Figure 54. Thailand - Malaysia Project in AIMS III

Table 2-43: Summary of ASEAN Region Interconnections (FY 2020-2040)

Year	Interconnection	From S/S AMS	To S/S AMS	Voltage Level (kV)	Line Length (km)	Technology	Conductor Size	Capacity planned as per CEP (MW)	Thermal Capacity in MVA/ckt
2020	Thailand – Malaysia	Khlong Ngae(Eq) Thailand	61214 P. Malaysia	230	120	HVDC (Mono-pole)	ACSR cardinal (546sqmm)	300	-
2025	Thailand – Malaysia	Khlong Ngae(Eq) Thailand	61214 P. Malaysia	230	120	HVDC (Bi-pole)	ACSR cardinal (546sqmm)	600	-
2035	Thailand – P Malaysia	Hat Yai Thailand	61523 P. Malaysia	500	185	HVAC	Twin – 795MCM	600	1500

Source: AIMS III, Phase II, page 126.

Figure 55. Thailand - Malaysia Transmission Project



Source: Delphos International

Project 6: Thailand (Tha Tako) to Myanmar (Tanintharyi) Project (6): The Tanintharyi region in Myanmar, a strip approximately the length of Portugal and with a population of 1.5 million, is islanded from the main Myanmar grid. The region is served by several mini-grids, the largest of which serves the city of Dawei (population of about 150,000) and the nearby Dawei special economic zone[139].

[139] The Dawei SEZ is supported by Japan and Thailand, among others.

Various large coal and gas-fired power projects in the region have been proposed over the years and advanced through discussions with MOEE. All these projects would have involved construction of 230 kV / 500 kV lines up to the national grid around Mawlamyine. The ADB is studying a 500 kV transmission project on this path, but with no associated power project.

The underlying assumption for Project 6 is that the 500 kV Mawlamyine to Tanintharyi transmission line does not get built for a considerable period. Indeed, it would appear difficult to justify such a large, expensive project without a significant source of power injection in Tanintharyi – be it from a new power project or imports – since Myanmar is already drastically short of power and particularly in the southern portion of the country. In Figure 56, Mawlamyine is located just below the word "Martaban". One can see that the Thai substation assumed here (Tha Tako) and Mawlamyine would be approximately equidistant from Dawei.

In the view of the Delphos Team, it could make more sense to supply the Tanintharyi region from Thailand. In such a case, the entire region would be synchronized with the Thai system, though Myanmar would own the assets on its side of the border. In the longer term, the region could be connected to the Myanmar national grid.

Buildout of regional transmission trunk lines, sub-transmission and distribution could be carried out by distribution companies operating under concession[140]. MOEE already has issued concessions to the larger mini-grid companies in the region. Those concessions could be expanded/re-negotiated or complemented by new concessions to electrify the region using reliable power from Thailand. The existence of Dawei city and the Dawei SEZ would provide credible anchor off-takers with good prospects of substantial growth. (In fact, lack of low-cost and reliable power at the Dawei SEZ has been a major deterrent for investment there; with reliable power, higher levels of investment would be expected).

Provision of reliable power to the region would have important environmental benefits, by displacing the inefficient and polluting diesel gensets that dominate regional mini-grids.

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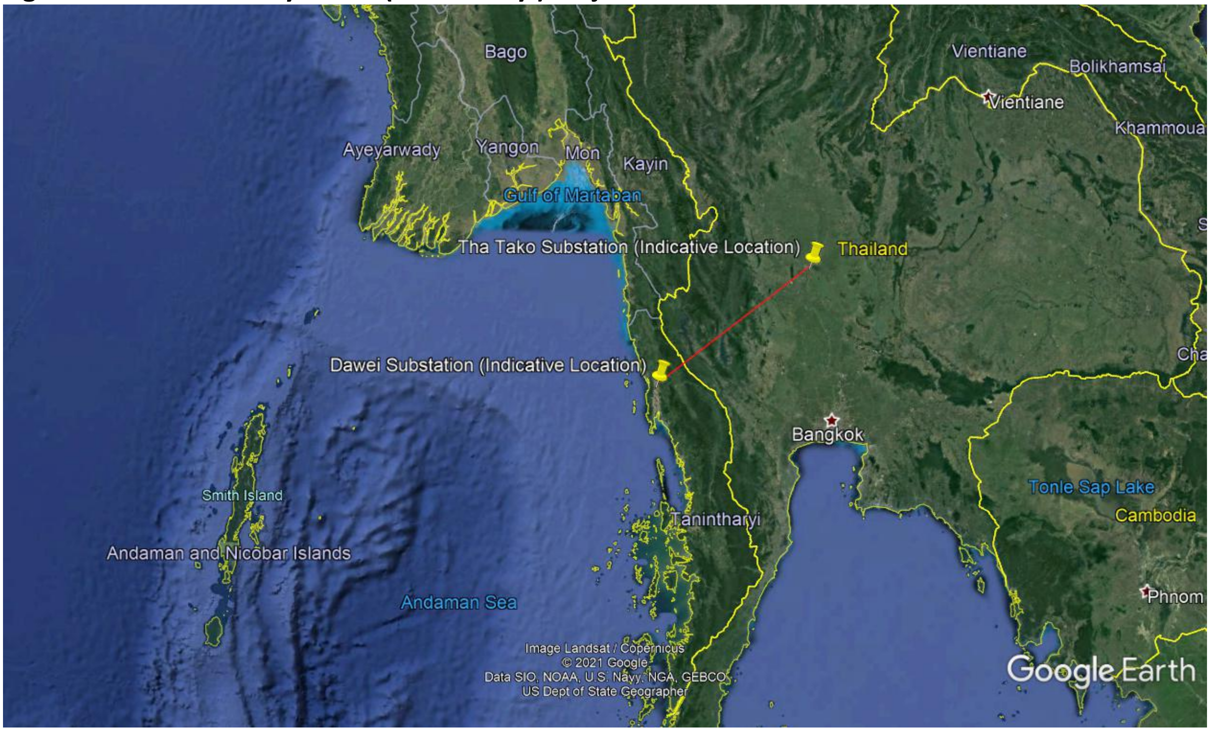
[140] Myanmar's electricity law would require transfer of transmission assets, when completed, to MOEE. It is believed that the law would allow MOEE to pay for the assets upon transfer.

Figure 56. Thailand - Myanmar (Tanintharyi) Project



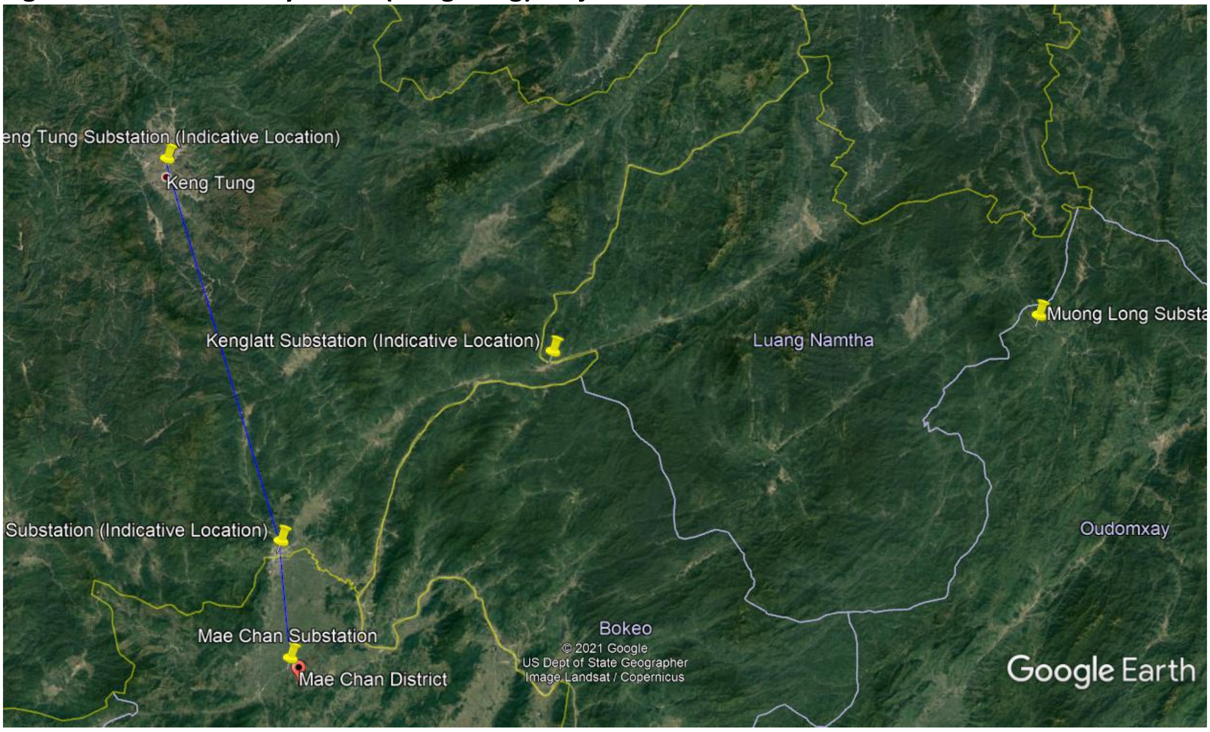
Source: Delphos International

Thailand (Mae Chan / Chiang Rai) to Myanmar (Keng Tung) Project (7): This 230 kV project is a variation on Project 4 and is discussed in that section.

Project 7 would connect on the Thailand side to the Mae Chan substation, as shown in Figure 57. While none of the studies reviewed have mentioned this project, EGAT apparently plans to advance studies on the project, based on “EGAT Today” postings on its website.

The business case for this project, as noted for Project 4, is for either or both Thailand or Lao PDR to sell to Thailand.

Figure 57. Thailand - Myanmar (Keng Tung) Project



Source: Delphos International

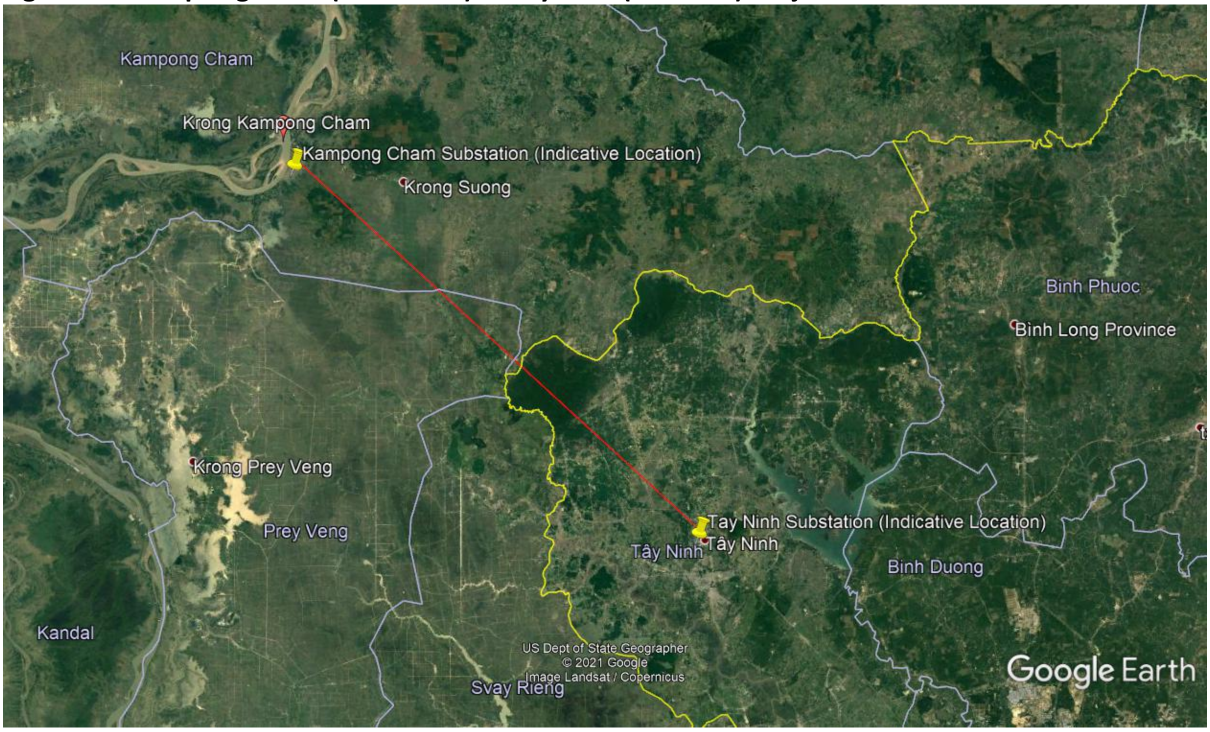
Cambodia (Kampong Cham) to Vietnam (Tay Ninh) Project (8): This is currently envisioned as a 500 kV double-circuit transmission line with 400 MW of capacity. It was initially planned to be online in 2022, though it has been pushed back now to 2030. It has been evaluated in the ADB funded Regional Power Master Plan study by Manitoba Hydro International as well as the World Bank study. Figure 58 depicts the project conceptually.

The distance is relatively short (100 km), which makes the project more doable. Due to the shorter distance, the estimated investment amount required for the project is moderate – USD 78 million. There is already an existing 230 kV grid-to-grid connection between Vietnam and Cambodia; the precedence can facilitate the necessary bilateral agreements, regulatory approvals, commercial arrangements, and operational guidelines for this project. The project would help address Cambodia's power shortage and improve utilization rates for Vietnam's planned new generation capacity.

The project is supported by the governments of both Cambodia and Vietnam and has been studied as a candidate project by both ADB, in the Regional Power Master Plan study carried out by Manitoba Hydro, and the World Bank. It ties strongly with Cambodia's approach to expand interconnections with neighboring countries to import power since Cambodia has not been able to increase generation capacity relative to demand growth.

This project also has long-term strategic value for regional integration, as it could facilitate Vietnam's import of cheap hydropower from Lao PDR into the southern part of the Vietnamese grid. Together with Project 10 and Cambodia's existing connections with Laos and Thailand, this project could form the basis of multilateral power trade in the region – between Thailand and Vietnam or Lao PDR and Vietnam. While these require significant improvements to Cambodia's grid (particularly to realize multilateral trade) and grid codes, increased connection to the stronger EVN grid (which is being further strengthened with numerous transmission upgrade projects) could provide additional reliability benefits for Cambodia.

Figure 58. Kampong Cham (Cambodia) to Tay Ninh (Vietnam) Project



Source: Delphos International

Cambodia (Stung Treng) to Vietnam (Tay Ninh) Project (9): This would be a 230 kV transmission line with 207 MW of capacity extending 250 km. It has been evaluated in the ADB funded Regional Power Master Plan study by Manitoba Hydro International, ADB's Harmonizing Power System in the Greater Mekong Subregion report from February 2020, as well as the World Bank study. Figure 59 depicts the project conceptually.

The benefits and challenges of Project 9 would be similar to those of Project 8. This project is evaluated in the World Bank study as part of a Lao PDR – Cambodia – Vietnam project, or Project 9 extending from Stung Treng to Ban Hat in Lao PDR. This would fit with the objectives of both Lao PDR and Vietnam – Lao PDR has approved plans to develop its abundant hydro resources in southern Lao PDR for export to both Vietnam and Cambodia, whereas Vietnam is seeking to import cheap hydropower from Lao PDR to meet its rapid demand growth.

Figure 59. Stung Treng (Cambodia) to Tay Ninh (Vietnam) Project

Source: Delphos International

4.4 BARRIERS AND AIDS TO REGIONAL INTEGRATION

There is a perception prevalent among donors that progress towards regional market integration in the LMS has been slow. While it is beyond the scope of this report to compare the pace of integration in the LMS to that in other regional markets[141], it is worth taking stock of the current level of integration. In some respects, there already exists substantial regional integration and there are underlying market features that should impel expanded regional trading, as summarized below.

- A central spine of existing grid-to-grid connections links Lao PDR, Thailand, Peninsular Malaysia, and Singapore. Thus, any country adding grid-to-grid links to the central spine would become a member of a five-country regional market, which in terms of the number of countries involved, would place that market among the largest internationally.
- There are extremely high levels of IPP-to-foreign-grid participation across the region (mainly based in Lao PDR), which constitutes real cross-border trade and lays the physical infrastructure foundation for other types of links. Moreover, the existence of such IPP-to-foreign-grid projects bespeaks an easier path for other types of cross-border transmission projects since a common minimum set of legal, regulatory, and institutional matters need to be addressed for all types of cross-border projects.

[141] Based on the Delphos Team's experience, the pace of integration within the region of interest is not slow by comparison to that of other regional markets.

- There are multiple, significant, grid-to-isolated load and grid-to-grid (load switchable) connections in the region, including especially across interfaces that do not have direct grid-to-grid connections. These existing projects can facilitate subsequent direct grid-to-grid linkages and, as with IPP-to-foreign grid projects, they pave the way for more ambitious projects.
- The LTM-PIP project, recently expanded to include Singapore, is an important proof-of-concept involving wheeling through Thailand. Given the regional geography, Thailand is likely to remain the main country across which wheeling might realistically be expected.
- Market fundamentals suggest ongoing trade opportunities. In the short and medium term (through 2030 or so), likely buyers include Vietnam, Cambodia, Myanmar, Malaysia, and Singapore, with likely suppliers being Lao PDR and Thailand. In the longer term, there are (and will be) large bankable potential off-takers in Vietnam, Thailand, Malaysia, and Singapore for potential cross-border PPAs selling grid-to-grid. Lao PDR (hydro potential) and Myanmar (hydro, solar, wind and gas potential) would appear to be the natural suppliers over the longer term.
- Concerted years'-long efforts by the RPTCC to develop a regional grid code and planning for permanent "brick and mortar" regional market institutions have created a foundation for increasing regional integration.

Below, barriers to achieving greater regional market integration are presented and then potential solutions are discussed.

Barriers:

- Unrealistic ambitions for the regional market and timelines to achieve those ambitions push integration efforts in unproductive directions. Some of the grander visions for regional integration involve multi-directional trade in a meshed grid across numerous interfaces, with open access to a regional grid, standing wheeling arrangements across the different markets, and regional system operational and market institutions. These visions are unrealistic over the period of analysis (through 2030) and most likely through 2040. (To be clear, this is not to say that striving in this direction is fruitless, just that policy makers must be aware of the time required to achieve such a goal). The underlying reality is that only two countries in the LMS are likely exporters (Lao PDR and Thailand) for at least the next ten years. Each of these two countries can export on existing and new dedicated lines to their own most likely customers within the LMS. Lao PDR can also export to Malaysia and Singapore under LTM-PIP arrangements, which could be expanded. It is difficult to imagine that trading patterns would be much different in a fully meshed regional grid with advanced market structural elements.

  In other words, the underlying economics would tend to support mainly bilateral initiatives, often involving one-way trade not necessarily requiring grid-to-grid connections, plus expansion of the LTM-PIP framework. There would seem to be limited need over the period of analysis for a regional grid code or regional market institutions (though these are worthy objectives).
- The regional market's core members have been mis-conceived. For historical and institutional reasons, much of the focus has been on the LMS / GMS, whereas the LTM-PIP + Singapore

structure would appear to constitute a more natural core regional market. Three of the four countries involved have robust and well-managed national grids while Lao PDR's national grid is already synchronized with Thailand. There are two natural buyers and two natural sellers. Given weak grids and institutions in Myanmar and Cambodia, is it worthwhile to struggle to implement an organized regional market in which those countries could participate from Day 1 on an equal footing? As regards Vietnam, as noted above, its most natural trading partners are Lao PDR and Cambodia. As documented in JICA's study, grid-to-grid connection with Lao PDR could be challenging, but in any case, could be pursued bilaterally. For these reasons, it is not clear what Vietnam would gain by its active participation in an organized regional market during the analysis period.

- Grid-to-grid projects are treated incorrectly by some donors and regional forums as being the only type of projects that is supportive of regional trade.[142] As argued throughout the present report, other types of connections are highly supportive of regional trade as well and can be much easier to implement. For instance, grid-to-isolated load or grid-to-grid (load switchable) can make a great deal of sense economically and operationally when a sizeable load in one country is far from generation resources (and especially when supply to the area is inadequate) and relatively near to the grid of another country. There are many cases internationally, including portions of the US served by Canada and portions of Mexico served by the USA. Within the region of interest, as discussed earlier in the present report, there already exist major projects of this type, with China supplying northern Vietnam and Thailand supplying western Cambodia. Smaller examples include Thailand supplying Tachileik, Myanmar and until recently, supplying Myawaddy, Myanmar.

  Apart from the underlying economic benefits of such projects, there can be other important benefits as well. For instance, isolated or poorly served loads tend to be reliant on inefficient and polluting diesel gensets. Interconnecting such regions to a larger grid displaces those gensets, resulting in reduced emissions. Such projects also smooth the path for more direct market integration between the two countries later by facilitating build out of transmission and distribution infrastructure in the importing region and establishing the rights of way that could potentially allow for additional lines or uprating of existing lines.

- There are a variety of technical and institutional/regulatory barriers to implementation of an advanced market that have been well-documented by the World Bank and JICA studies, as well as several ADB reports, including lack of sufficient cross-border transmission facilities; grid and system operational weakness in Lao PDR, Cambodia and Myanmar; missing,

[142] The ADB and World Bank have played leading roles in efforts to develop a regional market in the GMS. The high esteem accorded to grid-to-grid projects is evident from structural features of technical assistances sponsored by these institutions over the years as well as by the approach taken to assessing progress and conducting master plans. Examples are given here for each. (1) The ADB's framework for GMS market development has been organized since the beginning around the goal of development an advanced regional market, with (disappointing) progress measured periodically against that (unrealistic) goal. See the executive summary of the "Harmonizing Power Systems in the Greater Mekong Subregion: Regulatory and Pricing Measures to Facilitate Trade" study reviewed in the present report. The following source provides an incisive review of the ADB's approach to regional trade from nearly a decade earlier: "Review of the Greater Mekong Sub-Region Regional Power Trade Final Report", SIDA, December 2011. (2) The World Bank study reviewed in the present report notes: "At present, dedicated transmission lines do not permit third party access as a result of restrictions in the project's PPAs, even though in many instances the transmission lines would be physically capable of accommodating additional power flow. Such restrictions are viewed to be a significant barrier to higher levels of integration in GMS power markets." The World Bank study, like the ADB-sponsored GMS Master Plan, also includes only grid-to-grid projects in its list of candidate projects.

inadequate and/or unenforced grid codes in Lao PDR, Cambodia, and Myanmar; lack of regional market and system operating institutions; and lack of coordinated planning. To the extent that ambitions for the market could be made more modest, some of these challenges would be more tractable.

- The ongoing attempt to create a GMS or LMS-wide power market involving robust grid-to-grid connections has been paired with efforts to create a GMS-wide grid code. What has resulted is a proposed regional grid code that may be appropriate to the vision of such a market, but prospects for adoption and enforcement of the GMS grid code across the region are low for quite some time, certainly through 2030 or so, in part because of the deficiencies mentioned above. In other words, envisioning a simpler, smaller, regional market allows for a simpler and more implementable grid code for that market.
    - The market that the GMS grid code is designed to accommodate would include features such as: third party access to the regional grid; pre-set wheeling arrangements that would allow any member to sell power to any other member, provided available transmission capacity (ATC) could be assigned; an approach to identifying and allocating ATC; as well as regional system and market institutions that would coordinate regional dispatch and operate the regional market. This is complicated.
    - By contrast, the LTM-PIP + Singapore project involves one-way trade from Lao PDR to Malaysia and Singapore. Power flows perfectly match contractual flows and these flows perfectly match the underlying economics. There is no need to deal with third party access, market institutions, ATC allocation or other such complications. This market structure could be built upon easily, for example by adding features that would allow Thailand to sell to Malaysia and Singapore as well, and by adding Myanmar or Cambodia under parallel one-way market arrangements. Transmission capacity could be built that would specifically support this market. There is no need for a full-blown grid code for such a market structure; operational requirements could be contained within the contractual arrangements for the market itself. Over time, this market structure could become more permanently established. One could imagine donor funding for transmission infrastructure for this market paired with development of a dedicated institution whose aim would be to expand the market.
- Economic and financing barriers to the building of new cross border transmission lines are significant. For bilateral projects, typically, the two countries agree to fund construction on their own sides of the border, and split funding for related infrastructure. Fiscal limits on the part of the poorer countries in the region are the constraint in this case. Funding for common-use market infrastructure is a much larger challenge; fortunately, none of the projects considered in the studies reviewed would constitute investments in common-use infrastructure, and such investments do not appear necessary for the foreseeable future.

Solutions:

- De-emphasize the consensus-driven GMS RPTCC approach, which attempts to build an advanced regional market that could accommodate all GMS member states.
- Adopt more realistic ambitions for the regional market over the next ten to twenty years, focused on establishing a core market in the LTM-PIP + Singapore group of countries. The LTM-PIP structure reflects the existing and expected future natural trading flows, that is, from Lao PDR and Thailand towards the south. There is no need to undertake in the near term the extremely complicated task of transforming this simple structure into a more flexible wheeling arrangement allowing reverse flow trades, given that south (Singapore and Malaysia) to north (Thailand and Lao PDR) flows are highly unlikely for at least the next ten years based on existing and committed oversupply in the north. This market could potentially be expanded to include Myanmar under similar arrangements, with Lao PDR selling to Myanmar, wheeling across Thailand, over new ties between Thailand and Myanmar. Again, these wheeling arrangements can be unidirectional initially since Myanmar will be short on capacity for many years. Note that there is also no need to develop a common grid code to support these trading arrangements, evidenced by the fact that the LTM-PIP was successful, has been extended and expanded, all without a common grid code. If a version of LTM-PIP involving Myanmar were to be formed, it would only need to involve Lao PDR, Thailand and Myanmar, not the other countries. In such a scenario, if the connection were to be grid-to-grid (presumably involving a DC back-to-back element), then the relevant system operational requirements and procedures could be included in the contract. It would be much easier, however, for the arrangement to provide power as a grid-to-grid (load switchable) project, as has been done successfully in various locations throughout the region.
- Approach grid-to-isolated load and grid to grid load switchable as worthy projects, rather than as something shameful and inadequate. It is worth noting here that an independent 2013 evaluation of the ADB’s 2008 loan for the 115 kV Thailand to Cambodia grid-to-grid (load switchable) project found the project’s development impact and outcome to have been “excellent”.[143] This project has enabled further potential connections on this interface, including one proposed by the Delphos Team in the present report.
- Continue work on “no regrets” objectives:
    - Focus on improvement at the national level on grid control for Lao PDR, Myanmar and Cambodia.
    - Improve grid codes and grid code enforcement in the same countries.
    - Improve sectoral planning throughout the region.
    - Examine technical approaches to grid-to-grid linkages across the currently unsynchronized interfaces: Thailand to Myanmar; Lao PDR to Myanmar; Lao PDR to Vietnam/Cambodia; and Thailand to Cambodia. Such approaches might involve HVAC plus back-to-back facilities, HVDC, and creation of subregions within national markets that are synchronized with a neighboring market.

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[143] “Cambodia Power Transmission Lines Co., Ltd., Power Transmission Project, Performance Evaluation Report”. ADB. December 2013.

- Funding
  - Development partners should support specific project feasibility studies on projects of bilateral interest. These studies should cover technical, economic, funding, operational, legal, and regulatory aspects.
  - Development partners could provide debt financing to specific projects.
  - Development partners should engage the larger/wealthier countries in structuring arrangements – essentially, loans – involving the large/wealthier countries financing both sides' capital contributions, in exchange for regular payments for the assets by the smaller/less developed partner.
  - If the technical need for common market infrastructure is identified, development partners could consider funding the structuring work. Such work could cover establishment of the ownership vehicle, shareholder arrangements and debt financing.

ANNEX A: ALL SHORTLISTED PROJECTS

SN	Project Name	From Country	To Country	From Substation	To Substation	Voltage (kV)	Ckts	Project Type	Existing Rated or Planned Capacity (MW)	Technology	Distance (km)	Entry Date	Sources
1	Lao North - Thailand Project	Laos (North)	Thailand	Muang Houn	Nan 2	500		Grid to Grid	800	HVAC	150	2024	ADB (Manitoba Hydro, June 2018) RPTCC-25 (Lao PDR) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) ADB (Harmonizing Power Systems in GMS, February 2020)
2	Thabok - BungKan Transmission Line	Laos	Thailand	Thabok - Pakxan	Bung Kan	115	1	Grid to Grid			58		JICA Study Lao PDR
3	Mae Sot-Myawaddy Transmission Line	Thailand	Myanmar	Mae Sot	Myawaddy	230	2	Grid to Grid	300	HVAC	29	2025	ADB (GMS RIF 2022, October 2020) ADB (GMS LT Strategic Framework 2030, November 2019) JICA Study Lao PDR
4	Lao PDR-Myanmar Power Interconnection	Laos	Myanmar	M. Long	Keng Tung	230/500	2	Grid to Grid	300		200	2025	RPTCC-26 (Lao PDR) ADB (GMS LT Strategic Framework 2030, November 2019) ADB (GMS RIF 2022, October 2020) ADB (EDF, November 2019) RPTCC-27 (Lao PDR) ADB (GMS RIF 2022 Annex, November 2020)
5	Thailand - Malaysia Transmission line	Thailand	Malaysia	KhlongNgae	Gurun	300	1	Grid to Grid	300	HVDC	110	2002	EGAT September 2015
6	Thailand - Myanmar (Tanintaryi) Transmission Line	Thailand	Myanmar	Tha Tako	New Substation	500	2	Grid to Isolated Load					Delphos Team
7	Thailand North - Myanmar (Keng Tung) Transmission Line	Thailand	Myanmar	Chiang Rai	Keng Tung	230	1	Grid to Grid					Delphos Team
8	Cambodia - Vietnam Project	Cambodia	Vietnam	Kampong Cham	Tay Ninh	500	2	Grid to Grid	400		100	2030	ADB (Manitoba Hydro, November 2019) World Bank (June 2018) World Bank (March 2019)
9	Cambodia - Vietnam Project	Cambodia	Vietnam (South)	Stung Treng	Tay Ninh	220		Grid to Grid	207	HVAC	250		ADB (Manitoba Hydro, June 2018) ADB (February 2020)
10	Thailand - Cambodia	Thailand	Cambodia	Wangnoi	Banteay Meanchey - Siem Reap - Kampong Cham	500	2	Grid to Grid	300		500	2030	ADB (Manitoba Hydro, November 2019) World Bank (June 2018) World Bank (March 2019)

11	Myanmar - Thailand Project	Myanmar	Thailand	Yangon area	Mae Moh	500		Grid to Grid	1500	HVAC	350	2030	ADB (Manitoba Hydro, November 2019) World Bank (June 2018) World Bank (March 2019) JICA Study Lao PDR
12	Laos (South) - Vietnam (Central) Project	Laos	Vietnam	Savannakhet-Mahaxai	Ha Tihn	500		Grid to Grid	600		200	2027	ADB (Manitoba Hydro, November 2019) World Bank (March 2019) ADB (September 2012)
13	Laos - Thailand Project	Laos (North)	Thailand	Pak Beng / M.Houn (Pak Nguyen)	Tha Wang Pha	500		Grid to Grid	800	HVAC	120		ADB (Manitoba Hydro, June 2018) ADB (GMS RIF 2022, October 2020) JICA Study Lao PDR ADB (GMS RIF 2022 Annex, November 2020) ACMECS Master Plan
14	China - Laos - Thailand Project	China	Thailand	Ban Na - Pak Beng	Tha Wang Pha	500		Grid to Grid	3000	HVAC	380		ADB (Manitoba Hydro, June 2018) World Bank (March 2019) JICA Study Lao PDR
15	Laos - Vietnam Project	Laos (North)	Vietnam (North)	Luang Prabang-Xam Nau (Lao-N)	Nho Quan	500	2	Generator to Foreign Grid	1500 / 2500 / 3500	HVAC	400	2029	ADB (Manitoba Hydro, June 2018) ADB (Manitoba Hydro, November 2019) World Bank (June 2018) World Bank (March 2019) ADB (February 2020)
16	Laos - Myanmar Project	Laos (North)	Myanmar	Luang Namtha	Mandalay	230/500	2	Grid to Grid	1000	HVAC	600	2025	ADB (Manitoba Hydro, June 2018) World Bank (June 2018) World Bank (March 2019) ADB (NSEC-5 Power Myanmar) ADB (GMS RIF 2022, September 2017) ADB (GMS RIF 2022 Annex, September 2017) ACMECS Master Plan
17	Cambodia - Vietnam Central Project	Cambodia	Vietnam	Lower Se San 2	Pleiku	230	2	Generator to Foreign Grid	250		230		World Bank (June 2018) World Bank (March 2019)
18	Laos - Vietnam Power Transmission Interconnection 2	Laos (South)	Vietnam (centre)	Hatxan	Pleiku	500	2	Grid to Grid	1000	HVAC	154	2027	ADB (Manitoba Hydro, June 2018) World Bank (June 2018) World Bank (March 2019) RPTCC-25 (Lao PDR) RPTCC-26 (Lao PDR) ADB (GMS LT Strategic Framework 2030, November 2019) RPTCC-27 (Lao PDR) ADB (GMS RIF 2022 Annex, March 2019) ADB (GMS RIF 2022, November 2019) ADB (GMS RIF 2022 Annex, November 2019) ADB (GMS RIF 2022 Annex, November 2020) ADB (February 2020)
19	Laos - Cambodia - Vietnam Project	Laos (South)	Vietnam (South)	Ban Soc (Ban Hatxan)	Tay Ninh via Stung Treng	500		Grid to Grid	1700		320	2027	ADB (Manitoba Hydro, November 2019) World Bank (June 2018) World Bank (March 2019)

20	Laos-China Project	Laos (north)	China	Na Mo	Ban Na	500		Grid to Grid	1000 / 3000			2021	RPTCC-25 (Lao PDR) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) ADB (February 2020)
21	Myanmar - Thailand Project	Myanmar	Thailand	Mae Khot	Mae Chan	230		Generator to Foreign Grid	250		115	2025	ADB (Manitoba Hydro, November 2019) World Bank (March 2019)
22	Laos PDR to Thailand Transmission Interconnection Project	Laos	Thailand	Ton Pheng	Mae Chan	115		Grid to Grid	300		60	2024	ADB (GMS RIF 2022, September 2017) ADB (GMS RIF 2022 Annex, September 2017) ADB (February 2020) ACMECS Master Plan
23	Laos - Cambodia Project	Laos (south)	Cambodia	Xekong	Phanompeng	500		Generator to Foreign Grid				2025	RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Cambodia) ADB GMS Update JICA Study Lao PDR
24	East - West Energy Corridor to Mawlamyine (as part of a concerted and planned)	Myanmar	Thailand	Mawlamyine	Mae Sot	230		Grid to Grid					ADB (GMS RIF 2022, September 2017) ADB (GMS RIF 2022 Annex, September 2017) JICA Study Lao PDR
25	Laos North - Thailand Project	Laos (North)	Thailand	Nam Ngum 3-Nabong (Ban Na Bong)	Udon Thani 3	500	2	Generator to Foreign Grid	440	HVAC	200.5	2026	RPTCC-27 (Thailand) PGI ACMECS Master Plan
26	Thailand - Cambodia	Thailand	Cambodia	Prachin Buri	Battambang	230	2	Grid to Grid	500	HVAC	240	2030	AIMS III Phase 1 Energy Foundation China (November 2020)
27	Myanmar - Thailand Project	Myanmar	Thailand	Hutgyi	Phitsanulok 3	500		Generator to Foreign Grid	920	HVAC	370	2030	AIMS III Phase 1 Energy Foundation China (November 2020) PGI
28	Myanmar - Thailand Project	Myanmar	Thailand	Ta Sang	Mae Moh 3	500		Generator to Foreign Grid	3000	HVAC			Energy Foundation China (November 2020) PGI
29	Myanmar - Thailand Project	Myanmar	Thailand	Mong Ton	Sai Noi 2	500		Generator to Foreign Grid	3000	HVDC			Energy Foundation China (November 2020) PGI
30	Laos - Laos Project	Laos	Laos	Muang Houn	Napia	500	2	Grid to Grid		HVAC	240		JICA Study Lao PDR
31	Laos - Laos Project	Laos	Laos	Napia	Houa Phan Thermal	500	2	Grid to Grid		HVAC	170		JICA Study Lao PDR

ANNEX B: EXISTING AND IN PROGRESS PROJECTS

SN	Project Name	From Country	To Country	From Substation	To Substation	Voltage (kV)	Ckts	Project Type	Existing Rated or Planned Capacity (MW)	Technology	Distance (km)	Entry Date	Sources
1	Myanmar - China Project	Myanmar	China	Dapein 1	Dayingjiang /Dehong	500	1	Generator to Foreign Grid	880		120	2011	ADB (Manitoba Hydro, June 2018) RPTCC-25 (China) RPTCC-26 (China) ADB (GMS ASR, June 2016) ADB (GMS: 2 Decades of Cooperation) ADB (Harmonizing Power Systems in GMS, February 2020)
2	Myanmar - China Project	Myanmar	China	Shweli 1	Dehong /Hannong	220	2	Generator to Foreign Grid	600		120	2009	ADB (Manitoba Hydro, June 2018) RPTCC-25 (China) RPTCC-26 (China) ADB (GMS ASR, June 2016) ADB (GMS: 2 Decades of Cooperation) ADB (Harmonizing Power Systems in GMS, February 2020)
3	China - Myanmar Project 3	China	Myanmar	Menglong	Jingyang	110	1	Grid to Grid				2015	RPTCC-26 (China) RPTCC-25 (China) ADB (Harmonizing Power Systems in GMS, February 2020)
4	Vietnam - China Project	Vietnam (North)	China	Ha Giang	Maguan (Malutang)	220	1	Grid to Grid	350		320	2007	ADB (Manitoba Hydro, June 2018) RPTCC-25 (China) RPTCC-26 (China) ADB (Harmonizing Power Systems in GMS, February 2020)
5	Vietnam - China Project	Vietnam (North)	China	Lao Cai	Xinqiao (Guman)	220	2	Grid to Grid	450	HVAC	350	2006	ADB (Manitoba Hydro, June 2018) RPTCC-25 (China) RPTCC-26 (China) ADB (GMS: 2 Decades of Cooperation) ADB (Harmonizing Power Systems in GMS, February 2020)
6	Vietnam - Laos Project	Laos	Vietnam (central)	Xekaman 3	Thanh My	220	2	Generator to Foreign Grid	250		250		ADB (Manitoba Hydro, June 2018) RPTCC-25 (Lao PDR) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR)
7	Vietnam - Laos Project	Laos	Vietnam (central)	Xekaman 1	Pleiku	220	2	Generator to Foreign Grid	320	HVAC	250		ADB (Manitoba Hydro, June 2018) ADB (Manitoba Hydro, November 2019) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR)
8	Vietnam - Cambodia Project	Vietnam (South)	Cambodia	Chau Doc	Takeo - Phnom Penh	230	2	Grid to Grid	200	HVAC	200	2009	ADB (Manitoba Hydro, June 2018) ADB (Manitoba Hydro, November 2019)

													RPTCC-26 (Cambodia) ADB (Harmonizing Power Systems in GMS, February 2020)
9	Laos - Cambodia Project	Laos (South)	Cambodia	Ban Hat	Stung Treng	230		Grid to Grid	145	HVAC	200		ADB (Manitoba Hydro, June 2018) RPTCC-25 (Lao PDR) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) ADB (Harmonizing Power Systems in GMS, February 2020)
10	Thailand - Cambodia Project	Thailand	Cambodia	Wathana Nakhon substation (EGAT) via Aranyaprathet 2 substation (PEA)	Banteay Meanchey - Siem Reap	115	1	Grid to Isolated Load	180	HVAC	221	2007	RPTCC-25 (Thailand) RPTCC-26 (Cambodia) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (Harmonizing Power Systems in GMS, February 2020)
11	Thailand - Laos Transmission line 5	Laos	Thailand	Hong Sa	Nan	500	2	Generator to Foreign Grid	1473	HVAC	324	2015	RPTCC-25 (Thailand) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (Harmonizing Power Systems in GMS, February 2020)
11	Laos North - Thailand Project	Laos (North)	Thailand	Hong Sa	Mae Moh 3	500	2	Generator to Foreign Grid		HVAC			ADB (Manitoba Hydro, June 2018) ADB (Manitoba Hydro, November 2019) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR)
12	Thailand - Laos Transmission line 7	Thailand	Laos	Thali	Xayaburi	500	2	Generator to Foreign Grid		HVAC		2019	RPTCC-25 (Thailand) RPTCC-26 (Thailand) RPTCC-27 (Thailand) RPTCC-27 (Lao PDR)
13	Laos North - Thailand Project	Laos (North)	Thailand	Nam Ngum 2 - Nabong (Ban Na Bong)	Udon Thani 3	500	2	Generator to Foreign Grid	596.6	HVAC	171.5	2017	ADB (Manitoba Hydro, June 2018) RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (GMS ASR, June 2016) ADB (Harmonizing Power Systems in GMS, February 2020)
14	Laos - Thailand Project	Laos	Thailand	Nam Theun 2	Roi Et 2	500	2	Generator to Foreign Grid	948		304	2009	ADB (Manitoba Hydro, November 2019) RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (GMS ASR, June 2016) ADB (GMS: 2 Decades of Cooperation)
15	Thailand - Laos Transmission line 6	Thailand	Laos	Ubon Ratchathani 3	Xe-Pain Xe-Namnoy	230	2	Generator to Foreign Grid	390	HVAC		2019	RPTCC-25 (Thailand) RPTCC-26 (Thailand) RPTCC-27 (Thailand)

16	Laos - Thailand Transmission Line 2	Thailand	Laos	Ubon Ratchathani 2	Houay Ho	230	2	Generator to Foreign Grid	145/500		250	1999	ADB (Manitoba Hydro, June 2018) ADB (Manitoba Hydro, November 2019) RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (GMS ASR, June 2016) ADB (GMS: 2 Decades of Cooperation)
17	Laos – Thailand Project	Laos	Thailand	Pak Xe (Ban Lak 25)	Ubon Ratchathani 3	500		Generator to Foreign Grid	1300	HVAC	150	2019	ADB (Manitoba Hydro, June 2018) ADB (Manitoba Hydro, November 2019) RPTCC-25 (Lao PDR) RPTCC-26 (Lao PDR) ADB (RIF 2022 Progress Report, October 2020) RPTCC-27 (Lao PDR) ADB (Harmonizing Power Systems in GMS, February 2020)
18	Laos - Thailand Project	Laos (north)	Thailand	Paklay/Paklai	Thali	115	1	Grid to Grid		HVAC		2020	RPTCC-25 (Lao PDR) RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (Harmonizing Power Systems in GMS, February 2020)
18	Thailand - Laos Project	Thailand	Laos	Nong Khai	Thanaleng (Vientiane)	115	1	Grid to Grid	75	HVAC	50		ADB (Manitoba Hydro, June 2018) RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (Harmonizing Power Systems in GMS, February 2020)
18	Thailand - Laos Project	Thailand	Laos	Nong Khai	Phon Tong	115	2	Grid to Grid		HVAC	0		RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (Harmonizing Power Systems in GMS, February 2020)
18	Thailand - Laos Project	Thailand	Laos	Bung Kan	Pakxan	115	1	Grid to Grid			0		RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand) ADB (Harmonizing Power Systems in GMS, February 2020)
18	Laos - Thailand Project	Laos	Thailand	Bang Yo	Sirindhorn 2	115	1	Generator to Foreign Grid	36		100		RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand)

													RPTCC-27 (Thailand) ADB (Harmonizing Power Systems in GMS, February 2020)
18	Bangyo -Sirindhon 2 Transmission Line	Laos	Thailand	Bang Yo	Sirindhorn 2	115	1	Grid to Grid			42	2020	JICA Lao PDR study
19	Thailand - Malaysia Transmission line	Thailand	Malaysia	Khlong Ngae	Gurun	300	1	Grid to Grid	300	HVDC	110	2002	RPTCC-25 (Thailand) RPTCC-26 (Thailand) RPTCC-27 (Thailand)
19	Thailand - Malaysia	Thailand	Malaysia	Sadao	Chuping	115/132	1	Grid to Grid	80	HVAC	24.5	1981	Powergrid International Limited
20	Thailand – Myanmar (Myawaddy) Line	Thailand	Myanmar	Mae Sot	Myawaddy	115		Grid to Isolated Load					
21	Thailand - Myanmar Project	Thailand	Myanmar	Chiang Rai	Tachileck	110		Grid to Isolated Load	75		50		ADB (Manitoba Hydro, June 2018)
22	Laos - Thailand Project 4	Laos	Thailand	Pakbo / Savannakhet	Mukdahan 2	115	1	Grid to Grid	75	HVAC	30		ADB (Manitoba Hydro, June 2018) RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand)
23	Lao PDR - Thailand Project	Laos	Thailand	Theun Hinboun-Thakhek	Nakhon Phanom 2	230	2	Generator to Foreign Grid	440		176	1998	ADB (Manitoba Hydro, June 2018) ADB (Manitoba Hydro, November 2019) RPTCC-25 (Thailand) RPTCC-27 (Lao PDR) RPTCC-27 (Thailand) ADB (GMS ASR, June 2016) ADB (GMS: 2 Decades of Cooperation) ADB (Harmonizing Power Systems in GMS, February 2020)
24	Thailand - Laos Transmission line 1	Thailand	Laos	Nakhon Phanom	Thakhek	115	2	Grid to Grid	75		70		ADB (Manitoba Hydro, June 2018) RPTCC-25 (Thailand) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Thailand) RPTCC-27 (Thailand)
25	China - Vietnam Project	China	Vietnam	Hekou	Lao Cai	110	1	Grid to Grid	70	HVAC	300	2004	ADB (Manitoba Hydro, June 2018) RPTCC-25 (China) RPTCC-26 (China) ADB (Harmonizing Power Systems in GMS, February 2020)
26	China - Vietnam Project	China	Vietnam	Maomaotiao	HaGiang	110	2	Grid to Grid	110		300	2005	ADB (Manitoba Hydro, June 2018) RPTCC-26 (China) RPTCC-25 (China) ADB (Harmonizing Power Systems in GMS, February 2020)
27	China - Laos Project	China	Laos	Mengla	Namo (Oudomxai)	115	1	Grid to Grid	60	HVAC		2009	RPTCC-25 (China) RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR)

													RPTCC-26 (China) ADB (Harmonizing Power Systems in GMS, February 2020)
28	Laos - Cambodia Project	Laos	Cambodia	Ban Hat	Khamponsalao	115	1	Grid to Grid					RPTCC-26 (Lao PDR) RPTCC-27 (Lao PDR) RPTCC-26 (Cambodia)
29	Vietnam - China Transmission Line	Vietnam	China	Mong Cai	Shengou	110	1	Grid to Grid	75		300	2023	ADB (Manitoba Hydro, June 2018) RPTCC-25 (China) ADB (Harmonizing Power Systems in GMS, February 2020)
30	Laos North - Thailand Project	Laos (North)	Thailand	Xayaburi	Loei 2- Khon Kaen 4	500		Generator to Foreign Grid	1220	HVAC	300	2019	ADB (Manitoba Hydro, June 2018) RPTCC-25 (Lao PDR) ADB (Harmonizing Power Systems in GMS, February 2020)
31	Thailand - Laos Project	Thailand	Laos	Udon Thani 3	Ban Na Bong - Nam Theun 1	500	2	Generator to Foreign Grid	523	HVAC	254	2022	ADB (Manitoba Hydro, June 2018) RPTCC-25 (Thailand) RPTCC-27 (Thailand)
32	Laos - Thailand Project	Laos	Thailand	Luang Prabang	Nan	500	2	Generator to Foreign Grid	1400	HVAC	185	2028	Powergrid International Limited
33	500kV Phayargyi - Hlaingthayar Transmission Line	Myanmar	Myanmar	Phayargyi	Hlaingthayar	500		Internal		HVAC	97	2020	RPTCC-26 (Myanmar)
34	230kV Mawlamyine-Ye-Dawei Transmission Line	Myanmar	Myanmar	Mawlamyine	Dawei	500		Internal		HVAC	290	2020	RPTCC-26 (Myanmar)
35	500kV Taungoo to Phayargyi	Myanmar	Myanmar	Sabakywe	Karmanat / Phayargyi	500		Internal		HVAC	200	2021	ADB (Pilot study on section-specific planning for the GMS North-South Economic Corridor in Myanmar, 2020) RPTCC-26 (Myanmar)

ANNEX C: REFERENCES

1. **ACMECS Master Plan (2019 – 2023). Concept Document.** The concept document shows actions plans under three goals of building ACMECS CONNECTS by 2023: seamless connectivity; synchronized ACMECS; and smart and sustainable ACMECS. The "Energy Infrastructure and Connectivity" section lists four projects – (i) Na Bong (Lao PDR) to Udon Thani 3 (Thailand); (ii) Ban Lak 25 (Lao PDR) to Ubon Ratchathani 3 (Thailand); (iii) Pak Beng or Pak Nguyen (Lao PDR) to Tha Wang Pha (Thailand); and (iv) Mae Sot (Thailand) to Thaton (Myanmar). It lists other priority projects as well sources from the Greater Mekong Subregion Regional Investment Framework.

2. **"AIMS III Final Interim & Phase I Report." GE Energy Consulting, November 2020.** The report covers all tasks under Phase I of the AIMS III study: (i) Task 1 – Data Collection and Gap Analysis; (ii) Task 2 – RE Resource Assessment; (iii) Task 3 – Capacity Expansion Planning; (iv) Task 4a – Socio-Environmental Assessment; (v) Task 4b – Economic Analysis; (vi) Task 5 – Production Simulation Analysis. The report includes a background of the AIMS III study and the consultants' approach to each task under Phase I. Potential sites for solar and wind projects were identified and narrowed under Task 2 (20 from 47 for wind; 40 from 91 for solar), and LCOEs for wind and solar calculated for each ASEAN member state for 5-year increments from 2020 to 2040. These and other capacity plans derived from country-specific PDPs were evaluated with a PLEXOS model, and further social, environmental, and economic analysis conducted.

   The results of the study include modeled cross-border interconnections (Table 3-1); interconnection capacity between countries in 2025 (base: Figure 4-3) and 2040 (base: Figure 4-4); modeled utilization rates for cross-border interconnections under base and different alternate scenarios of RE penetration.

   The report also includes, for each country, the data used: techno-economic parameters of power plants, interconnection capacity, and reliability parameters; and the results (for each country and region) of the simulations under the different scenarios in terms of installed capacity, generation costs, and interconnection capacity.

3. **"AIMS III Preliminary Phase II Report." ASEAN Centre for Energy/GE Energy Consulting, December 2020.** The report covers the following task under Phase II of the AIMS III study: Task 7a: Grid Analysis, with the following deliverables: (i) country-level, sub-regional, and integrated ASEAN grid models in PSS/e format for the study horizon 2020-2040 in 5 year increments; (ii) results of power flow and contingency analysis; (iii) results of short circuit analysis; (iv) results of dynamic modeling and stability analysis; and (v) recommendations on mitigating identified constraints in proposed interconnections.

   The preliminary report contains a very useful data gap analysis summarized in a table (Table 2-1) with the information that is available and missing, as well as the resolution for modeling purposes to account for missing information, for each country. The grid modeling approach combined three modeling approaches depending on the grid density and data availability for different

countries/regions: (i) reduced transmission equivalent model (peninsular Malaysia, Myanmar, Lao PDR, Java & Sumatra); (ii) nodal equivalent model (Singapore, Cambodia, Sabah, Sarawak, Brunei, and Kalimantan); and (iii) regional equivalent model (Thailand and Vietnam).

Additional useful data shared in the report includes grid models in PSS/E format; sources of references for future transmission expansion; lists of planned transmission line additions; and technical details on various cross-border interconnections.

The results of analysis are summarized for interconnection flows, contingency flows, short-circuit levels by cross-border interfaces and scenarios.

4. **"Analysis of China's Power Market Structure and Market Entities' Business Interface under the Reform of Electric Power System." W. Chen, P. Zhou, M. Fan and M. Zeng. 2017.** http://dpi-proceedings.com/index.php/dtssehs/article/viewFile/15437/14949. The paper summarizes China's power market structure following reforms implemented under the No.9 document issued by the State Council. It provides an overview of the business interfaces of power generation, transmission, and trading entities.

5. **"ASEAN Renewable Grid Integration Analysis." International Energy Agency, October 2019.** IEA conducted a study to assess the value of cross-border power trade in integrating and accommodating the growing VRE generation. Compared to other studies, this study relies upon a more simplistic regional transmission model for the analysis.

6. **"Burma: Energy Project Development and Technology Advisory Services." Delphos International, September 2017.** https://drive.google.com/file/d/1o7MrpqrVAGWnehWOfXUWcBPMh30FxmRq/view?usp=sharing The report includes maps of Myanmar's grid, identifies binding constraints, and analyses of the impact of different scenarios (both static and dynamic analysis) of renewable energy expansion on the grid including hosting capacity estimates at different high-voltage nodes on the grid.

7. **"Cambodia Approves Two 500 kV Transmission Line Projects." GMS, November 2020.** https://www.greatermekong.org/cambodia-approves-two-500-kv-transmission-line-projects#:~:text=The%20Government%20of%20Cambodia's%20Council,import%20electricity%20from%20its%20neighbors. The Government of Cambodia's Council of Ministers approved two 500 kilovolt (kV) transmission line investment projects in (i) Phnom Penh to the Cambodia-Lao PDR border, and (ii) Battambang to the Cambodia-Thailand border, to prepare to import electricity from its neighbors. Construction of both lines are expected to start in 2021 and last for 3 years and 4 years respectively.

8. **"Cambodia: Energy Sector Strategy, Assessment, and Road Map." ADB, December 2018.** https://www.adb.org/sites/default/files/institutional-document/479941/cambodia-energy-assessment-road-map.pdf The report has a comprehensive overview and discussion on Cambodia's energy sector. Relevant information is also provided, including: institutional framework governing the sector; generation capacity mix with planned development and available resources; demand growth; and planned grid development for electrification, including cross-border imports.

9. **“Cambodia Turns to Other Sources of Energy.” GMS, May 2020.** https://greatermekong.org/cambodia-turns-other-sources-energy The 10-year plan of the Government of Cambodia will defer the development of new hydropower dams in 2020-2030 and seek to focus instead on other energy sources and imports. The revision in plans is related to an energy cooperation development agreement signed between Cambodia and Lao PDR for 6 GW by 2030.

10. **“China Trading Power: Improving Environmental and Economic Efficiency of Yunnan’s Electricity Market.” Harvard Kennedy School Belfer Center for Science and International Affairs, February 2021.** https://www.belfercenter.org/sites/default/files/2021-03/YunnanMarketReform.pdf The paper discusses potential reforms of the electricity market in China’s Yunnan province. It includes an overview of the current electricity system in the province, sourced from provincial government data.

11. **“Chinese Electricity: Blessing or Curse for Myanmar?” The Irrawaddy, March 2020.** https://www.irrawaddy.com/opinion/analysis/chinese-electricity-blessing-curse-myanmar.html The article discusses the evolution of power trade discussions between China and Myanmar, from when China sought to import hydroelectricity from Myanmar, to developing dedicated hydropower plants in Myanmar for import into China, to now exporting surplus power to Myanmar. It discusses the progress of several interconnection projects and associated infrastructure.

12. **“Deals and dams on the Salween: How China, Thailand and Myanmar shut local communities out.” ASEAN Today, March 2020.** https://www.aseantoday.com/2020/03/dams-on-the-salween-china-thailand-and-myanmar-shut-communities-out/ The article covers reports of negotiations with Chinese state-owned corporations to build three damns (hydropower projects) on the Salween river along the Thai-Myanmar border, including local resistance to the projects and the key stakeholders backing the projects. An illustrative maps depicts the sites for the proposed dams (Ywathit, Wei Gyi, and Dagwin) as well as those under construction (Kunlong, Nong Pha, Mongton, and Hatgyi).

13. **“Establishing Multilateral Power Trade in ASEAN.” IEA, August 2019.** https://asean.org/storage/2020/02/Establishing_Multilateral_Power_Trade_in_ASEAN.pdf The study evaluates different models of multilateral power trading for the ASEAN region. The analysis includes eight international case studies; minimum political, technical, and institutional requirements for multilateral power trade; and implications for key stakeholders such as utilities, regulators, investors, and consumers.

14. **Existing Power Grid and Under Construction Projects. Myanmar MOEE, August 2019.** https://www.moee.gov.mm/en/ignite/page/641 Map of Myanmar’s grid (existing and under-construction) including details on transmission lines and substations by voltage, as well as power plants by type (hydro/gas/steam).

15. **“Facilitating Regional Power Trading and Environmentally Sustainable Development of Electricity Infrastructure in the Greater Mekong Subregion: The Case of ADB/GMS RETA No. 6440 – GMS Power Master Plan.” Prof. Thierry Lefevre, October 2012.** https://www.iitk.ac.in/ime/anoops/for12/photos/PPTs/13%20-%20Prof.%20Thierry%20Lefevre%20-%20OERC-%20Presentation%20GMS%20RETA%206440%20REG%20-%2022%20October2012.pdf
The slides from the presentation includes several prior maps of the planned GMS cross-border interconnects in 2012. An comparison of more recent cross-border interconnection plans can be compared against this slide for an indication of the evolution of GMS priorities as well as the practical feasibility of some long-planned but as-yet unrealized lines.

16. **GMS Draft Grid Code.** https://greatermekong.org/greater-mekong-subregion-regional-grid-code

17. **Greater Mekong Subregion Economic Cooperation Program, Regional Power Trade Coordinating Committee (RPTCC) meetings.** https://www.greatermekong.org/rptcc RPTCC comprises of officials from the energy departments and ministries of the six GMS states. It convenes stakeholders in periodic meetings, facilitating exchange of information on energy sector plans and projects, as well as providing policy recommendations regarding regional power trade. RPTCC meetings are numbered, and presentations made at each meeting are shared as attachments.

    i. **24th Meeting of the Regional Power Trade Coordination Committee (RPTCC-24).** RPTCC-24 was held in Nay Pyi Taw, Myanmar on June 18-20, 2018.

        a. **“Harmonizing the Greater Mekong Sub region (GMS) Power Systems to Facilitate Regional Power Trade – Transmission Master Plan Study.” Manitoba Hydro International, June 2018.** [Attachment 6 – Regional Master Plan] Manitoba Hydro International (MHI), a consultant engaged by the ADB, presented an update on the regional generation and transmission master plan covering 2022-2035 for power trade in the GMS region. The presentation included simple maps and tables of existing, under-construction, planned, and proposed cross-border transmission interconnections with details on: (i) source/sink location (not sub-station level), (ii) voltage, (iii) technology, (iv) capacity, and (v) length. References for the country-level data and assumptions driving the models are provided.

        MHI presented results of four scenarios, with different combinations of planned and proposed transmission lines included, in terms of regional operational costs and impacts on each country.

        b. **Working Group on Regulatory Issues (WGRI) meeting.** [Attachment 10 – WGRI Meeting] The notes on the WGRI meeting summarizes the current transmission charge approach used in each GMS country, as well as priorities for further refinements. Additional details from country presentations and international case studies on transmission charge approaches can be found in Attachment 11 – WGRI Presentation.

c. **"World Bank: GMS Power Market Development." Intelligent Energy Systems, June 2018.** [Attachment 16 – GMS Power Market] Dr. Stuart Thorncraft, a consultant engaged by the World Bank, presented on an assessment of business cases to support GMS power market integration. The presentation included: (i) maps of cross-border projects compiled from previous studies conducted by ADB, APERC, IEA, and others; and (ii) maps of the power systems of Vietnam, Myanmar, Laos, and Cambodia showing transmission network, load centers, and generation resources. The results cover implications for generation and national transmission. Vietnam noted inconsistency in business cases selected for this study with other ongoing ADB master plan studies and projects proposed by GMS Secretariat.

ii. **25th Meeting of the Regional Power Trade Coordination Committee (RPTCC-25).** RPTCC-25 was held in Bangkok, Thailand on March 20-22, 2019.

a. **Country Presentations**

- Cambodia
  Includes aggregate information on 2018 energy mix, existing substations and transmission lines, and planned generation and transmission projects in table form. [Attachment 11.1 Cambodia]

- Lao PDR: Includes map of grid system by control area with cross-border interconnection; breakdown of energy supply and consumption by sector; aggregate level information on transmission lines and substations; maps (somewhat unclear) and project details on power trade with Thailand, Vietnam, Cambodia, and Myanmar (no map); and long-term PDP with generation and transmission projects (maps and tables) under construction. [Attachment 11.2 Lao PDR]

- Myanmar: Includes chart on energy sector organization structure; power supply mix (current and projected); existing transmission networks. [Attachment 11.3 Myanmar]

- People's Republic of China: Includes information on generation mix, transmission lines and substations (aggregate level), current power trade on China-Vietnam and China-Lao interfaces, and simple map of current and planned cross-border interconnections. [Attachment 11.4 PRC]

- Thailand: Includes information on capacity and generation mix, transmission lines and substation by voltage (aggregate level), map of electric power system with a list of existing foreign generation and interconnection projects (in table form) – both current and planned. [Attachment 11.5 Thailand]

- Vietnam: Includes information on capacity and generation mix, transmission lines and substation by voltage (aggregate level), map of electric power system, current plans and policies regarding RE development, status update on ongoing move to competitive power market. [Attachment 11.6 Vietnam]

b. **"Feasibility Studies – GMS Interconnections. Status." ADB, March 2019.** [Attachment 5 – GMS Power Interconnection Pre-Feasibility Study] Electricity de France (EDF) was engaged to conduct feasibility assessments of short-term regional power projects. The presentation includes 4 proposed high-priority projects from Lao PDR to Myanmar, Cambodia, Thailand, and Vietnam. They require decisions on the locations of the project (for Lao-Thailand and Lao-Vietnam interconnections) and scope of the study.

c. **"Harmonizing the Greater Mekong Sub region (GMS) Power Systems to Facilitate Regional Power Trade – Transmission Master Plan Study." Manitoba Hydro International, March 2019.** [Attachment 7 – GMS Transmission Master Plan] Manitoba Hydro International (MHI), a consultant engaged by the ADB, presented an update on the regional generation and transmission master plan covering 2022-2035 for power trade. MHI used (i) a regional network model for GMS with more than 650 buses, 1,500 lines, and a complete load flow model (PSSE); (ii) a simplified model for stochastic transmission planning (SDDP/OPTNET) with about 200 buses; and (iii) a regional network model for generation planning with about 30 buses. MHI evaluated two alternate scenarios involving high cross-border transfer and low cost of RE.

d. **"Regional Investment Framework (RIF) 2022. Monitoring and Progress." ADB, March 2019.** [Attachment 10 – Regional Investment Framework 2022 Monitoring and Progress] ADB presented updates and revisions to energy sector projects in the RIF (a pipeline of 247 projects worth $81 billion to support the Hanoi Action Plan). Projects are categorized as investment or technical assistance. There were 11 energy investment projects worth $2.3 billion and 9 energy technical assistance projects worth $16.2 million. Information is provided in tables on these projects, including project title, country, description, year of approval, cost estimates, potential funding sources, and project contact.

e. **"World Bank: GMS Power Market Development." Intelligent Energy Systems, March 2019.** [Attachment 6 – GMS Power Market Development – Business Cases Final Report] Dr. Stuart Thorncraft, a consultant engaged by the World Bank, presented on the final results of greater power market integration in GMS. Analysis evaluated 14 reference candidate cross-border projects (provided in a table) with details on: connection points, type, length, capacity, and source for the projects. All 14 projects overlapped with ADB's work. The analysis includes proposed timing of expansion, and prioritization based on timing, size, costs, and benefits. In discussions, when Vietnam queried evaluating a case accounting for increased RE in most countries, the consultant responded that the effect of RE is minimal on the modeling results.

iii. **26th Meeting of the Regional Power Trade Coordination Committee (RPTCC-26).** RPTCC-26 was held in Hanoi, Vietnam on November 26-27, 2019.

a. **Country Presentations**

- Cambodia: The update includes information on lines and substations at both transmission and distribution levels at an aggregate level from 2011-2019. It includes lists and maps of power trade (current and expected future) with its neighbors: Thailand, Vietnam, and Lao PDR. In the discussions, Cambodia confirmed that EDC signed a PPA with EDL for 500 MW, with TSBP Sekong Power and Mineral Company for 600 MW, and with Xekong Thermal Power Plant Company for 1,800 MW. [Attachment 11.1: Cambodia Power Situation]

- Lao PDR: First, JICA briefed RPTCC on the Power Network System Master Plan in Lao PDR study. The presentation includes several maps of Laos' power system, a map of hydro resources in the region, and maps of potential system configuration for power export in the future under a more system-to-system grid integration scenario. The study highlights potential reliability issues arising from synchronous interconnections around Lao (besides Thailand) without the addition of more transmission and generation assets. JICA also presented a roadmap to a system-to-system synchronization future. In the discussions, participants commented that Lao PDR exports even during dry season due to growing demand abroad and that Lao would be both importer and exporter in the future. [Attachment 9: Lao Master Plan]

  In a subsequent country presentation by Lao PDR, it presented an updated version of the current grid (maps with interconnections, list of transmission projects); the status of trade with Thailand, Vietnam, Myanmar, and Cambodia (MOUs signed, existing interfaces and trade, projects planned or under construction); status on multilateral power trade via the LTM-PIP project; and the long-term PDP (planned additions of generators, transmission lines, substations with maps). In the discussions, (i) Lao PDR agreed to isolate/dedicate the load area to connect with China Southern Power Grid; (ii) confirmed its separate grids/systems (?) to meet PPA and domestic requirements; (iii) acknowledged the delay in planned 500 kV backbone connecting the four regions (instead of current 230 kV) due to costs; and (iv) confirmed that it is synchronized with Thailand and is currently exporting 600 MW. [Attachment 11.4: Country Report: Lao PDR]

- Myanmar: The update included a summary of the power sector structures, a list of transmission projects in its master plan, and new renewable energy development in the country. [Attachment 11.3: Country Presentation: Myanmar]

- People's Republic of China: CSG briefed RPTCC on the 8 transmission lines (110 kV and above) linking CSG with GMS. Detailed maps were not provided. CSG has made several cross-border greenfield and M&A investments in power. It also confirmed that there are four cross-border projects in the planning stage with the long-term goal of both import/export: (i) China-Laos-Thailand; (ii) China-Vietnam; (iii) Myanmar-China; and (iv) Bangladesh-Myanmar-China. [Attachment 11.2: Country Presentation by CSG]

- Thailand: The update included a list of existing transmission assets at an aggregate level (by voltage); lists of existing and planned cross-border generation, interconnection, and transmission; information on Thailand's national grid code (as well as low-res maps); and updates on a new initiative for RE, EE, DSM (Thailand is starting a forecast center for RE generation for system generation planning and power system control). [Attachment 11.5: Country Update: Thailand]

- Vietnam: Includes information on capacity and generation mix, solar PV development, and a simplified overview of the transmission system. Vietnam also briefed RPTCC that its National Grid Codes were being amended to account for the rapid growth of RE, smart grid technologies, and the move to implementing a competitive wholesale power market. It is also considering DSM/DR as a solution to provide ancillary service and help reduce transmission losses on the North-Central-South grid. [Attachment 11.6: Country Update: Viet Nam]

b. **"GMS RPTCC #26 Meeting." ADB, November 2019.** [Attachment 4: Enforcement Grid Code]: The ADB consultant conducted a gap assessment of the national grid codes of Cambodia, Laos, Thailand, and Vietnam vis-à-vis the GMS Grid Code Technical Requirements. The presentation provides solutions to address gaps, many of which are related to the ongoing restructuring process in the power sector in these countries. Next steps for the tasks related to operation and strategic planning are listed. These include several Technical Assistance projects on grid code compliance requiring 90-day or even 270-day levels of effort, highlighting the level of cost/detail required to move things forward.

c. **"Greater Mekong Subregional Program: Long Term Strategic Framework 2030." ADB, November 2019.** [Attachment 10: RIF 2022]: This document lists the energy projects in the RIF pipeline along with their cost estimates. Projects in this pipeline are more likely to be realized due to multi-institution consensus on their priority.

d. **"Laos-Myanmar Interconnection – Interim Report # 1." EDF, November 2019.** [Attachment 5: Laos-Myanmar Interconnection Interim Report] The ADB consultant briefed RPTCC on the Lao PDR – Myanmar Interconnection sharing the initial results of the pre-feasibility studies of the Tachileik-Kengtun line (in Myanmar) and the Tachileik-Kenglat (Lao border) line to be commissioned in 2023. The presentation includes maps of Myanmar main grid and Laos Northern main grid depicting the interconnect, technical information of the projects (including those confirmed by MOEE and MEM), and the single line diagram.

   The presentation also introduced a study of high voltage transmission systems in Myanmar and Lao PDR to interconnect the two systems at 230 kV and 66 kV (with future 500 kV), assessing future power exchanges at various combinations of voltage levels and technology. It lists the data collected by Myanmar and Laos Task Forces including grid maps, generations sites, single line diagrams, and PSS/e data, JICA reports, and MHI's GMS Transmission Master Plan.

   Finally, the presentation briefly assessed the current technical gaps and recommended options to synchronize Myanmar's grid with Lao and Thailand grids, listing the key criteria, policies to be harmonized, and the main activities necessary to achieve harmonization.

e. **"Regional Power Master Plan. Harmonizing the Greater Mekong Sub region (GMS) Power Systems to Facilitate Regional Power Trade." Manitoba Hydro International, November 2019.** [Attachment 6: Regional Master Plan]: MHI provided an updated on the studies to develop a regional generation and transmission master plan. It evaluated a variety of scenarios of load growth, energy economics, and technological/policy factors. The presentation includes basic maps of cross-border transmission lines under the OPTGEN/SDDP and PSSE models, lists the regional transmission plans considered, and offers a summary of key outcomes on generation development and cross-border interconnections in different countries. In the discussion, participants raised the issue of enhancing stability of a regional system while keeping costs under control.

f. **"WGRI Consolidation Workshop – Summary." ADB, November 2019.** [Attachment 12.1: WGRI Summary]: WGRI provided an update on key developments (new bilateral controls, national power markets, unbundling). The presentation included a discussion of potential options to make additional progress towards multilateral/regional power trading (including the step-by-step system synchronization suggested in the World Bank study) and proposed next steps to develop a pilot study for grid-to-grid interconnection of 3 countries.

g. **"Working Group for Planning and Operation. Summary Discussions." ADB, November 2019.** [Attachment 12.2: WGPO Summary]: WGPO provided a work plan for the next two years on tasks on (i) operationalizing the regional GMS Grid Code and (ii) strategic planning.

iv. 27th Meeting of the Regional Power Trade Coordination Committee (RPTCC-27).
RPTCC-27 was held via web-conference on October 15, 2020.

a. **Country Presentations**

- Lao PDR: Updated version of the current grid (maps with interconnections, list of transmission projects); the status of trade with Thailand, Vietnam, Myanmar, and Cambodia (MOUs signed, existing interfaces and trade, projects planned or under construction); status on multilateral power trade via the LTM-PIP project; and the long-term PDP (planned additions of generators, transmission lines, substations with maps). [Attachment 5: Country Presentation: Lao PDR]

- Myanmar: Updated information on supply mix, existing transmission lines and substations, a map of transmission network, projects under construction (generation and transmission), and future plans for transmission lines. [Attachment 5.3: Country Presentation: Myanmar]

- People's Republic of China

- Thailand: Updated information on supply mix, EGAT's transmission assets, existing cross-border interconnection projects (with map) and planned foreign generation, interconnection and transmission plan (list and map). [Attachment 5.4: Country Update: Thailand]

- Vietnam: Includes information on capacity and generation mix, Vietnam's transmission system with a map, and the 2021 renewable energy pipeline. Vietnam also briefed RPTCC on its Master Plan VIII – incorporating detailed planning for 2021-2030, with vision to 2045. The expected execution time was 10/2019 – 10/2020 and no projects would be approved until Master Plan VIII is published. Vietnam also updated the RPTCC that the pilot for the wholesale market would be implemented next year (2021) with a smaller scope, and full implementation of the electricity market in 2024. [Attachment 5.5: Country Presentation: Viet Nam]

b. **"GMS Regional Investment Framework 2022." ADB, October 2020.** [Attachment 4 – GMS RIF 2022]: There are a total of 11 energy sector investment projects, totaling $4.1 billion in financing. Of these, 4 were completed, 3 are ongoing, and 4 are proposed. On the Technical Assistance category, there are 4 projects with $6.5 million in financing – 3 are ongoing and 1 is proposed. The completed projects include: (i) Lao PDR – Thailand Nabong 500 kV transmission substation, (ii) transmission interconnect project in the same location, and (iii(the 230 kV Mae Sot – Myawaddy transmission line. Dropped projects relevant to the GMS RPTCC include (i) extension of energy access in Myanmar from nodes in Thailand and PRC and (ii) development of GMS Coordination Center for Regional Power Trade. Additional details are available on the most recent update report and accompanying annex from November 2020.

c. **"Greater Mekong Subregion. Laos-Myanmar Interconnection. Milestone 2: System Study." EDF, October 2020.** [Attachment 6: Myanmar-Lao PDR Interconnection]: EDF, the consultant engaged by ADB, briefed RPTCC on the progress of the Lao PDR–Myanmar Power Interconnection Project study. Task 1 – the feasibility of Tachileik-Kengtung transmission line and substation, and Tachileik-Kenglatt transmission line (Lao-Myanmar Interconnection line) – has been completed including an economic study and system study. The draft final report was presented to MOEE in March 2020 by video conference. On the second task, the system study of high voltage power transmission systems in Myanmar and Lao PDR to interconnect the two systems, EDF concluded that transmission line from Lao adds an extra cost compared to Myanmar hydro, but would still be cheaper to import 300 MW of Lao hydro vs Myanmar coal or gas since the two countries are similar in terms of generation costs, load patterns. The similarity may drive investment to Laos instead of Myanmar. EDF provided contacts and Myanmar and Lao PDR for data collection, cost assumptions on the interconnect, economic generation assumptions, weekly load pattern data, regional supply-demand analysis conducted in both Myanmar and Laos, and diagrams on substations, line routing, and interconnection area.

18. **"Greater Mekong Subregion Energy Sector Assessment, Strategy, and Road Map." ADB. June 2016.** https://www.greatermekong.org/sites/default/files/gms-energy-asr.pdf. Provides a useful regional overview of power systems, interconnections, a summary of development partners engaged in energy in the region, and ADB's GMS funding priorities.

19. **“Greater Mekong Subregion Power Market Development – All Business Cases including the Integrated GMS Case. Final Report for the World Bank.” Ricardo Energy & Environment. April 2019.** http://documents1.worldbank.org/curated/en/541551554971088114/pdf/Greater-Mekong-Subregion-Power-Market-Development-All-Business-Cases-including-the-Integrated-GMS-Case.pdf The World Bank study sought to establish the business cases to enhance power market integration in the region. The business cases studied assumed system-to-system connections. The report provides an overview of the current status of the power system and development plans for Cambodia, Lao PDR, Myanmar, Thailand, Vietnam, and Guangxi and Yunnan provinces in China. There is a discussion of the current cross-border interconnections and trade along with a list of possible future cross-border projects.

20. **gridfinder – Global Energy Infrastructure** https://gridfinder.org/ The website contains an open-source mapping of electricity network lines, developed based on night-time satellite imagery and OpenStreetMap data. It was created to demonstrate the research conducted for the paper Predictive mapping of the global power system using open data. The data is available for download.

21. **“Harmonizing Power Systems in the Greater Mekong Subregion (GMS): Regulatory and Pricing Measures to Facilitate Trade.” ADB, February 2020.** https://www.adb.org/publications/harmonizing-power-systems-gms-facilitate-trade Tables 1 and 2 summarize existing and planned cross border transmission projects; regional regulatory bodies are summarized; aims and obstacles of increased regional trade are explored. Note that, while the report was published in 2020, most of the underlying information appears to have been compiled by 2017.

22. **“Hydropower Politics and Conflict on the Salween River.” [Book Chapter] Carl Middleton, Alec Scott, & Vanessa Lamb. August 2019.** https://link.springer.com/chapter/10.1007/978-3-319-77440-4_3#Sec4
The chapter examines Myanmar’s proposed hydropower projects on the Salween River in the context of regional politics and power trade with China and Thailand. They are helpful for tracing the history of discussions on cross-border power trade to the 1990s, predating the GMS framework for regional cooperation, as well as identifying the most influential state and private institutions on this issue.

23. **“Implications of a Crowded Field: Sub-regional architecture in ACMECS Member States.” Benjamin Zawacki (The Asia Foundation), June 2019.** https://asiafoundation.org/wp-content/uploads/2019/06/Implications-of-a-Crowded-Field_whitePaper.pdf
The white paper from The Asia Foundation compares 13 different Mekong-related frameworks in terms of their agendas, members, backers (donors), and partners. The report includes charts mapping the relationships between the different frameworks, as well as lists of funding and expenditures.

24. **“Japan's Ongoing or Possible Cooperation Projects related to ANNEX A and B of ACMECS Master Plan.” MoFA, Japan.** https://www.mofa.go.jp/files/000406737.pdf

This document contains a list of prioritized projects to be implemented under "ACMECS Master Plan (2019-20)" with status and potential financing scheme.

25. **"Karen Villagers Protest Hatgyi Dam, Other Projects on Salween River." The Irrawaddy, March 2018.** https://www.irrawaddy.com/news/karen-villagers-protest-hatgyi-dam-projects-salween-river.html
The article covers reports of local resistance to the Hatgyi dam and describes the access road to the dam as nearly complete and the construction on the dam itself to be complete in 2020-2021.

26. **"Lao People's Democratic Republic: Energy Sector Strategy, Assessment, and Road Map." ADB, November 2019.** https://www.adb.org/sites/default/files/institutional-document/547396/lao-pdr-energy-assessment-2019.pdf
The report has a comprehensive overview and discussion on Lao PDR's energy sector. Relevant information is also provided, including: a clear transmission network map; institutional framework governing the sector; generation capacity mix with planned development and available resources; demand growth; and cross-border connections.

27. **"Learning from Power Sector Reform Experiences – The Case of Vietnam." World Bank, March 2020.** http://documents1.worldbank.org/curated/en/757761583166223011/pdf/Learning-from-Power-Sector-Reform-Experiences-The-Case-of-Vietnam.pdf
This policy research working paper contains a discussion of the energy sector reforms in Vietnam, including the Vietnam Competitive Generation Market and the transition to the Vietnam Wholesale Electricity Market. It provides a summary of the institutional framework of the sector, and evaluates the performance of the sector in achieving security of supply; affordability; technical efficiencies in generation, transmission, and distribution; and financial viability of EVN.

28. **"Myanmar: Power Transmission Improvement Project. Project No.46390-002." MOEE/DPTSC/ADB, 2013-2020.** https://www.adb.org/projects/46390-002/main#project
The ADB project was conducted in collaboration with Myanmar's government bodies (namely MOEE and DPTSC) to complete the 230 kV transmission ring for Yangon by building the transmission line linking the Thida, Thaketa, and Kyaikasan substations, as well as building and upgrading other substations. Several reports have been prepared for this project, including environmental monitoring reports, loan agreement, procurement plan, and a project administration manual. The environmental monitoring reports contain detailed technical information of the primary infrastructures pertaining to the project and feedback from key stakeholders on this project. The project administration manual includes detailed cost estimates of the components of the project.

29. **"Pilot Study on Section-Specific Planning for the GMS North-South Economic Corridor in Myanmar and the People's Republic of China: Electric Power in the Myanmar Component." ADB (Draft Report), 2020.**
The report focuses on a portion of the North-South Economic Corridor (NSEC) within Myanmar, specifically on NSEC 5 (a portion linking Myanmar with China), and includes recommended power and transmission investments.

[Main document, PDF 31, shows no currently planned 500 kV lines. PDF 32 shows 500 kV Shan, Kayah, Bago, Myanmar line at prefeasibility stage. "This will bring the 500 kV Myanmar system closer to the PRC grid for future interconnection." PDF 33 shows other 500 kV potential projects.

Appendix 1, PDF 2, describes an ADB-funded project involving interconnecting Tanintari at 230 kV with Myanmar main grid, estimated complete in 2025. PDF 3-4, Hatgyi not listed as in table of projects with MOUs/MOAs. PDF 4-6 describes a 500 kV line from Yunnan to Muse area and related 500 kV project within Myanmar, and other PRC-Myanmar transmission projects.

Appendix 2 lists proposed projects.]

30. **"Power Interconnection in ASEAN Region. Lessons Learned from International Experiences." Energy Studies Institute (National University of Singapore), 2019.** https://www.kas.de/c/document_library/get_file?uuid=ba461b31-2a92-0a91-e7ac-a48a87cca3a9&groupId=265079
This book evaluates three pathways to cross-border power trade: (i) multilateral trade of excess power via long-term contracts; (ii) multilateral power trade with spot exchanges; and (iii) fully competitive power markets. For each option, it evaluates an international example as a case study, steps required to move to that model, and pros and cons. The book contains information on supply-demand, power trade and interconnection projects in the region though the majority of the data is derived from studies from 2016 or earlier.

31. **"Report on ASEAN Grid Code Comparison Review." ASEAN Centre for Energy, October 2018.** https://aseanenergy.org/report-on-asean-grid-code-comparison-review/
The report contains background on the importance of grid codes to project development and international standards on grid code harmonization. It includes an overview of the grid codes of all ASEAN member states, and recommendations on updating grid codes vis-à-vis VRE based on in-depth reviews of the grid codes of Indonesia, Malaysia, and Thailand, and comparison against international best practices.

32. **"Report on Power Sector of the Kingdom of Cambodia; Compiled by Electricity Authority of Cambodia from Data for the Year 2019." Electricity Authority of Cambodia, 2020.** https://www.eac.gov.kh/site/viewfile?param=annual_report%2Fenglish%2FAnnual-Report-2019-en.pdf&lang=en
The annual report on the power sector from Cambodia's regulator provides updates on the developments in the sector in 2019. It also includes an overview of Cambodia's electricity laws and the institutional arrangement in the sector. The report contains important information regarding different types of generation and transmission license holders, current imports, planned projects, and details on the transmission network.

33. **"Technical Standards Framework Review Report. Myanmar Renewable Energy: On-Grid Solar Technical Assistance." AECOM New Zealand Limited, August 2020.**
The report evaluated the technical framework of Myanmar's power system planning and operations and recommended technical requirements to inform the planning, procurement, and operations of grid-connected inverter-based generation. In developing its recommendations, the

consultant analyzed the existing technical framework, including the grid code and other national guidelines, on several parameters (voltage variation range, frequency variation range, fault current) and conducted a gap analysis with respect to international standards. The recommendations include: (i) data requirements from both developers and the government during the planning stage; (ii) monitoring and control capability requirements during the operations period; (iii) technical requirements for solar plants to adhere to during operations; and (iv) technical requirements for all major solar plant equipment during procurement.

34. **"Thailand Electricity Security Assessment." OECD, April 2016.** http://www.oecd.org/publications/thailand-electricity-security-assessment-9789264255852-en.htm
TBD

35. **"Thailand plans to dust off Hatgyi Dam; EGATi awaits Myanmar Govt to negotiate with ethnic group." Mekong Eye, September 2016.** https://www.mekongeye.com/2016/09/14/thailand-plans-to-dust-off-hatgyi-dam-egati-awaits-myanmar-govt-to-negotiate-with-ethnic-group/
The article covers Thailand's interest in reviving the proposed development of the Hatgyi hydro project in Myanmar for consumption in Thailand.

36. **"Thailand Renewable Grid Integration Assessment." International Energy Agency, October 2018.**
The report contains the results of power system modeling for 2036 under high wind and solar penetration scenarios, and assessments of potential improvements to power system planning practices. The report contains assumptions of rooftop solar, EV charging; background on Thailand's power sector, including contractual arrangements, supply-demand balances, transmission system, tariff schedule, power plan economics, grid connection codes; and recommendations on integrating VRE into Thailand's grid and the power system planning process.

37. **"The role of cross-border power trade in meeting demand: a win-win story. Regional power market and cross-border interconnection training." EGAT, September 2016.** http://www.bigconnectivity.org/beta/sites/default/files/2017-03/01-Session%201.5-Thailand%20Case.pdf
The (slightly dated) slides from the presentation includes detail on electricity consumption by region (including cross-border connections); EGAT's transmission map; projected changes in generation, demand, and transmission system (for 2024) based on the then PDP; and detailed grid maps around the existing (then) cross-border interconnections with Laos.

38. **"The Study on Power Network System Master Plan in Lao People's Democratic Republic." JICA February 2020.** https://libopac.jica.go.jp/images/report/P1000042609.html The study was conducted by Japan International Cooperation Agency (JICA), Tokyo Electric Power Company Holdings, TEPCO Power Grid, NIPPON KOEI, and Tokyo Electric Power Services. The study contains an overviews of: the energy sector in Laos; its power plan; its plans for interconnections with Thailand; a list of distribution lines near the border for power trading with neighboring countries; maps on Laos' power network (for 2030) with details including power plants; existing and under

construction power plants; review of limits of transmission capability; analyses of power supply with planned changes in supply and export/import, assumptions of demand growth, future developments; reviews of the PDPs of neighboring countries (Thailand, Vietnam, Myanmar, Cambodia, Southern China), including maps of power networks, import/export plans, cross-border trade; a review of a study of Laos' power network system by China (Electric Power Planning & Engineering Institute); a review of regional interconnection plans from ADB and World Bank studies including lists of candidate and prioritized interconnection projects; analysis of power trade under different scenarios and requirements for individual projects; cost estimates for planned transmission lines and substations; expanding from current grid code and power system operations to a GMS-wide system-to-system integration and challenges of getting there.