Greater Mekong Subregion Power Market Development

All Business Cases including the Integrated GMS Case

Final Report for The World Bank
Contract No. 7179685

In association with Intelligent Energy Systems and Nord Pool Consulting

IES Intelligent Energy Systems

NORD POOL

ED 62052 | Issue Number 3 | Date 02/04/2019

Customer:

The World Bank

Customer reference:

Contract No. 7179685

Confidentiality, copyright and reproduction:

Contact:

Jonathan Hedgecock
Ricardo Energy and Environment
Gemini Building, Harwell, Didcot, OX11 0QR, United Kingdom

t: +44 (0) 1483 544951
e: jonathan.hedgecock@ricardo.com

Ricardo-AEA Ltd is certificated to ISO9001 and ISO14001

Author:

Stuart Thorncraft

Approved By:

Jonathan Hedgecock

Date:

2 April 2019

Ricardo Energy and Environment reference:

Ref: ED62052- Issue Number 3

Table of contents

Executive Summary

Overview

The objective of Task 1 was to establish business cases that enhance power market integration in the Greater Mekong Subregion (GMS) and to provide motivate discussions within the Regional Power Trade Coordination Committee (RPTCC) on the opportunities and challenges that specific businesses cases (cross-border interconnection projects) face as part of a strategy to enhance power market integration.

Presently, within the GMS most instances of cross-border trade relate to the direct connection of power stations in one country that are largely dedicated to exporting power to a neighbouring jurisdiction. The importing system retains isolation from the exporting power system and the associated transmission lines do not permit third party access as a result of restrictions in the project's power purchase agreements (PPAs). Such restrictions are viewed to be a significant barrier in the quest for higher levels of power system integration in the GMS.

The objective of Task 1 was originally to analyse ten (10) business cases with each to be discussed and analysed with the RPTCC stakeholders (consisting of energy policy makers, regulators, utilities and potential investors). Having completed nine (9) such business cases, it was decided to focus Task 1's remaining work on the analysis of an integrated transmission plan to understand the sequencing and prioritisation of the business cases. This in turn will enable the consultant to rank and prioritise the businesses cases that have the highest potential to not only accelerate power trade within the GMS, but to also focus on projects that are most likely to be of commercial interest to prospective project investors.

It should be noted that all business cases studied were assumed to be system-to-system connections and were studied based on the results of least cost generation and transmission modelling for a period of 19 years from 2017-35.

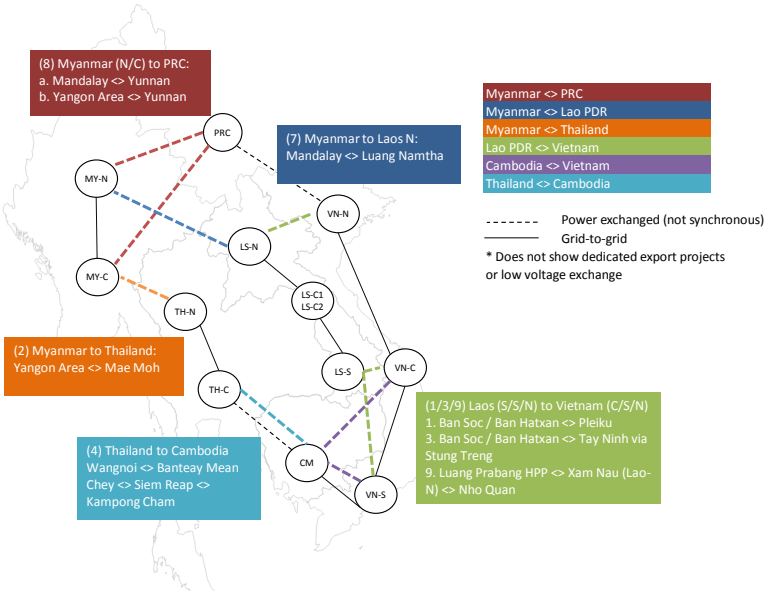
Candidate Cross-border Interconnection Projects

A list of candidate cross-border interconnection projects has been compiled based upon various country and regional reports and studies conducted by a number of organisations including ADB, APERC, ECA and IEA. For each of the fourteen (14) cross-border interconnections, a preliminary qualitative assessment identified potential benefits and drawbacks. Further analysis, based on an assessment framework covering economics, technical, commercial and environmental factors, provided a platform to filter down to nine (9) business cases to perform a holistic assessment of the benefits of these transmission projects and the extent to which they could accelerate cross border trade in Task 1[1].

The majority of these interconnections (below) are to support large-scale hydro generation export, which is being viewed as the main mechanism for power exchange in the GMS over the short to medium term. In addition to connections linking Northern and Southern Lao PDR (which is not considered as a business case in this project), connections between Viet Nam and Thailand (via Lao PDR and/or Cambodia) have been viewed as an essential step in establishing the regional power market given they are two of the largest grids in the GMS (besides the CSG in PRC given its different context). This viewpoint has been taken into consideration when identifying business cases. The business cases and network topology is shown in Figure 1 and summarised in Table 1.

[1] Screening criteria includes reasonable project cost, dispatch benefits, avoided/deferred generation investment, reserve sharing benefits, effective resource sharing, technical feasibility, supports multilateral trade, achievable commercial arrangements, environmental benefits and social benefits.

Figure 1 Network Topology*



** Lao PDR is modelled as four regions. The central region is split into Central 1 (C1) and Central 2 (C2) regions but has been represented as one node here.*

Table 1 Summary of all Business Cases and the Integrated Case

No.	Region (From)	Region (To)	Connection Points (From – To)	Assumed Length (km)	Sizing Options (MW)	Project Cost (US $m)
1	Lao PDR (South)	Viet Nam (Central)	Ban Soc / Ban Hatxan ⇔ Pleiku	190	500, 1000, 2000	162, 207, 266
2	Myanmar	Thailand (North)	Yangon area ⇔ Moe Moh	350	500, 1000, 2000	298, 382, 490
3	Lao PDR (South)	Viet Nam (South)	Ban Soc / Ban Hatxan ⇔ Tay Ninh via Stung Treng	320	500, 1000, 2000	272, 349, 448
4	Thailand (Central)	Cambodia	Wangnoi ⇔ Banteay Mean Chey ⇔Siem Reap ⇔ Kampong Cham	500	200, 400, 800	187, 374, 480
5	Cambodia	Viet Nam (South)	Kampong Cham ⇔ Tay Ninh	100	200, 400, 600	68, 78, 87
6	Cambodia	Viet Nam (Central)	Lower Se San 2 (HPP) ⇔ Pleiku	230	200. 400, 800	78, 156, 201
7	Lao PDR (North)	Myanmar	Luang Namtha ⇔ Northern Myanmar	150	500, 1000, 2000	510, 654, 840
8a	Myanmar	PRC	Mandalay ⇔ Yunnan	500	Only 1000	872
8b	Myanmar	PRC	Yangon ⇔ Yunnan	350	Only 1000	327
9	Lao PDR (North)	Viet Nam (North)	Luang Prabang (HPP) ⇔ Xam Nau (Lao-N) ⇔ Nho Quan	400	1500, 2500, 3500	420, 640, 896
10	Integrated case: Optimised timing and sizing of all business cases 1-9				Dynamic	As per above

Laos ⇔ Viet Nam	**Cambodia ⇔ Viet Nam or Thailand**	**Myanmar ⇔ Lao PDR, PRC or Thailand**

Modelling Approach

The Base case assumes the GMS countries continue to develop projects as per their power development plans (generally standalone with limited connectivity with neighbouring countries) based on a medium demand growth outlook. The business cases were modelled one at a time, with the business case (transmission project) assumed to be in operation from the year 2020. Intra-country transmission lines were allowed to be augmented in the model on a least cost basis[2]. This enables us to understand how national power systems may need to be expanded in support of cross-border power trade.

The optimised cross-border transmission plan (Integrated Case) follows that of the Base case and individual business case studies with differences listed below. This provides insight into optimal development of generation and transmission in the region, including the prioritisation of the transmission projects.

- All candidate cross-border transmission projects are available as options that the model could develop and let it decide which business case projects to build with the earliest commissioning date set for each business case link;
- Allow all national transmission links to be upgraded as required to support regional trade; and
- All cross-border transmission projects are modelled as continuous i.e. no lumpy investment – this is to understand the "optimal" sizes.

Cost and Benefits

GMS integration will benefit all countries within the region in the form of avoiding additional generation investments, deferring the need for national transmission upgrades, and avoiding higher power generation (Figure 5).

There are clear diversification benefits that in a number of countries provide relief from under-investment in generation. Other identified benefits include being able to deploy higher levels of renewable energy in the region and better utilisation of hydro resources as a consequence of diversification in hydrological conditions and diversification in demand profiles of the interconnected countries.

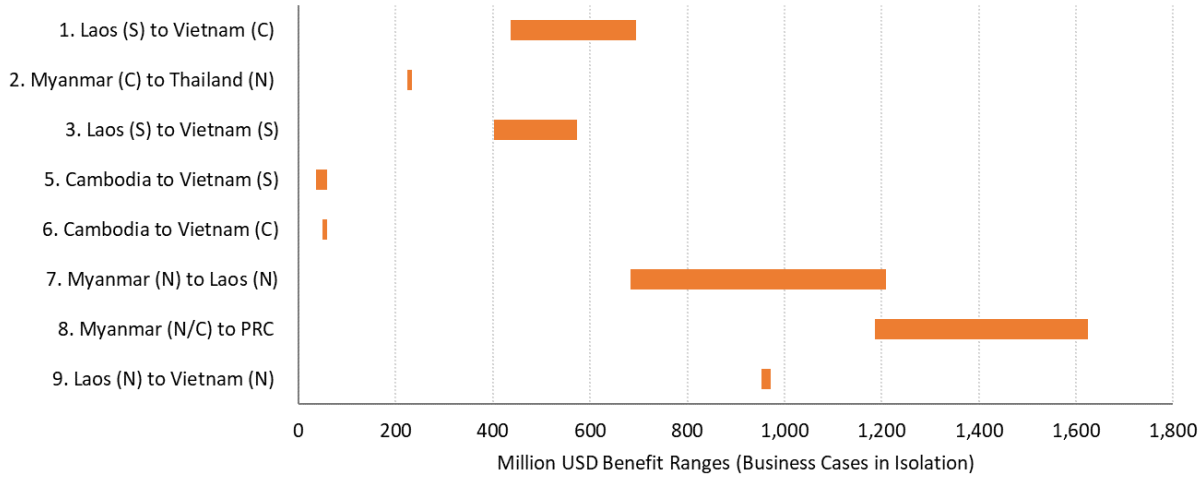
The modelling carried out in this study also shows that there are significant benefits from greater integration of Laos with its neighbouring countries. In the near-term, Laos could play a role in terms of providing additional power supplies to Myanmar and Vietnam with immediate short-term cost reductions, and over the longer-term for Thailand. Most of the benefits associated with the Integrated Case are the result of alleviation of Myanmar's short to medium term tightness in supply, use of surplus power from PRC, and use of hydro resources in Laos for exports to Vietnam and Myanmar. These benefits arise from only a limited number of interconnections that were studied, specifically the Myanmar to PRC and Laos, and Laos to Vietnam business cases.

Each business case, when modelled in isolation resulted in positive net present values (NPV) ranging from US$36 million to US$1.6 billion) arising from a deferral or avoidance of generation investment, and highly significant reductions in power generation costs. However, the results show that there is a subset of the individual business cases that show significantly higher benefits as a consequence of hydro displacing coal and gas generation. The benefits for the Integrated case reinforces these findings as an overall integrated case tends to prioritise the same business cases: in general, power systems with dominant hydro or relatively low-cost exports (particularly Laos and PRC) are able to offset more expensive generation sources and reduce the system costs in Myanmar, Thailand and Vietnam.

[2] Includes Myanmar, Vietnam and Laos national transmission system.

Figure 2 plots the NPV ranges for the individually modelled business case sizing options and Figure 3 plots the highest NPV ranges per business case along with the NPV result from the Integrated case[3].

Figure 2 Business Case NPV Ranges



Case 4 not shown as it was not modelled separately

Figure 3 Optimal Business Case NPVs with Integrated Case

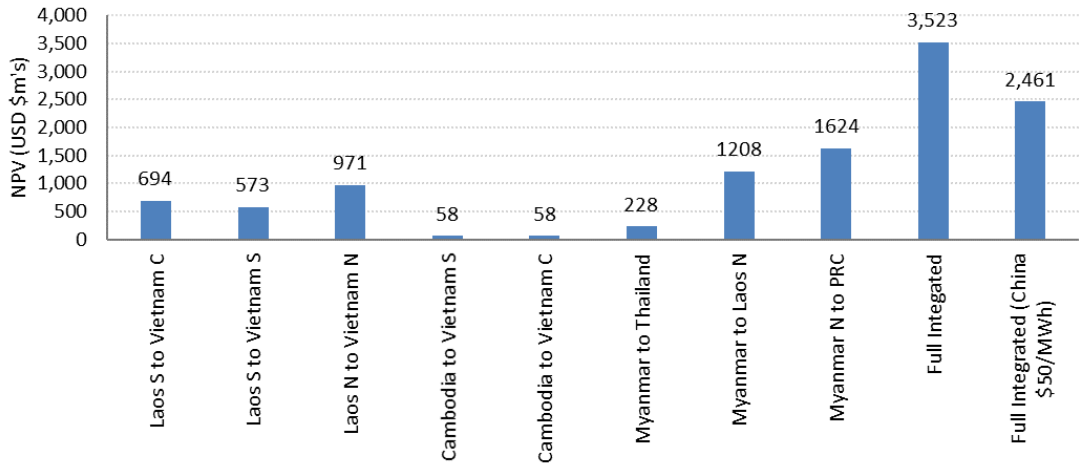


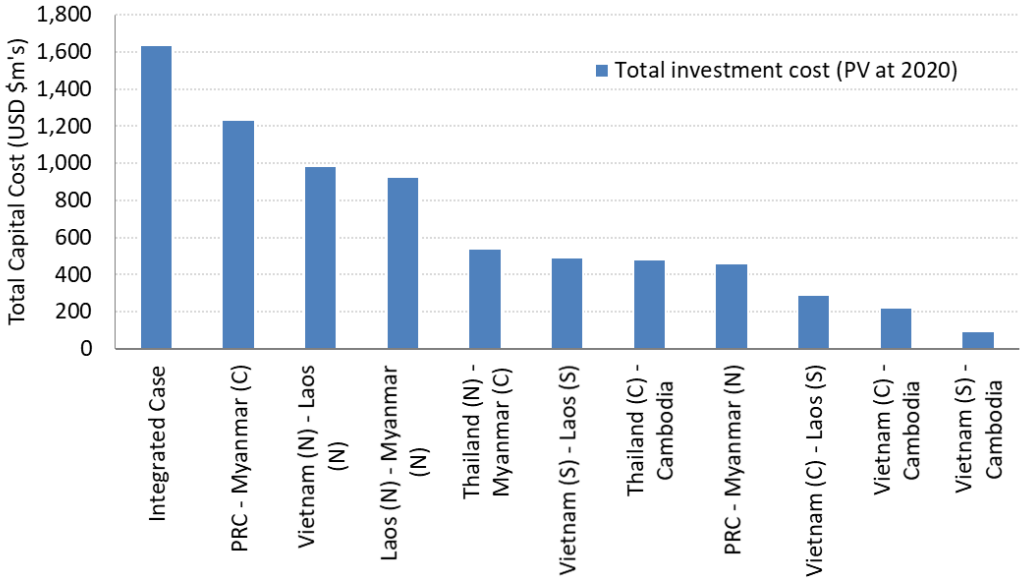
Figure 4 compares the total transmission investment cost (excluding national transmission augmentations) across the individual business case links and the Integrated case on a present value basis. The Integrated case is based on developing the optimal business case link capacities incrementally over time compared to the individual cases which were assumed to be in place at their full sizing at 2020 – the cost of the Integrated case is much smaller than the sum of the individual business case link investment costs, supporting the notion that prioritisation will be key in maximising the benefit across the GMS.

[3] Note that the Integrated Case was evaluated based on a cost for imported energy from PRC ranging from zero to USD 50/MWh – based on considerations of generation oversupply in PRC.

Figure 5 plots the total costs and benefits in the Integrated case by country whereby significant developments (investments) in Lao PDR drive a lot of the generation cost reductions (benefits) in Vietnam and Thailand. The cost of national grid transmission augmentations would relieve the total investment required to augment the Myanmar and Vietnam grids, but increase the importance of the Laos network in connecting the region. The net benefit is approximately $440m by 2035.

Carbon emissions, in Figure 6, are also lower than that of the Base case by approximately 7% from 2020 to 2035 with a reduction in coal fired generation across the GMS. By 2035, the Integrated case results in 670 million tons of carbon dioxide equivalent emissions, down from 730 million tons in the Base case. On a standalone basis individual business cases reduce carbon emissions by up to 2.7% over the period from 2020 to 2035. Most of the emissions reductions in the Integrated case arise from Laos hydro displacing thermal generation located in Vietnam, benefits of which have not been quantified in addition to the reduction in generation costs.

Figure 4 Total Transmission Investment Cost (Ordered)



Individual business case links were based on sizes with the highest NPV

Figure 5 Total Generation Cost Difference by Country

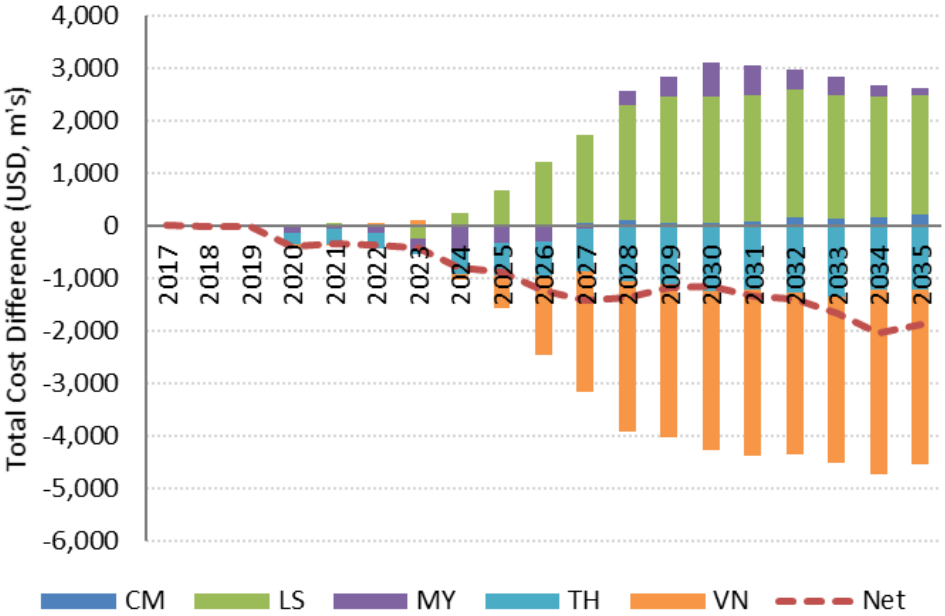
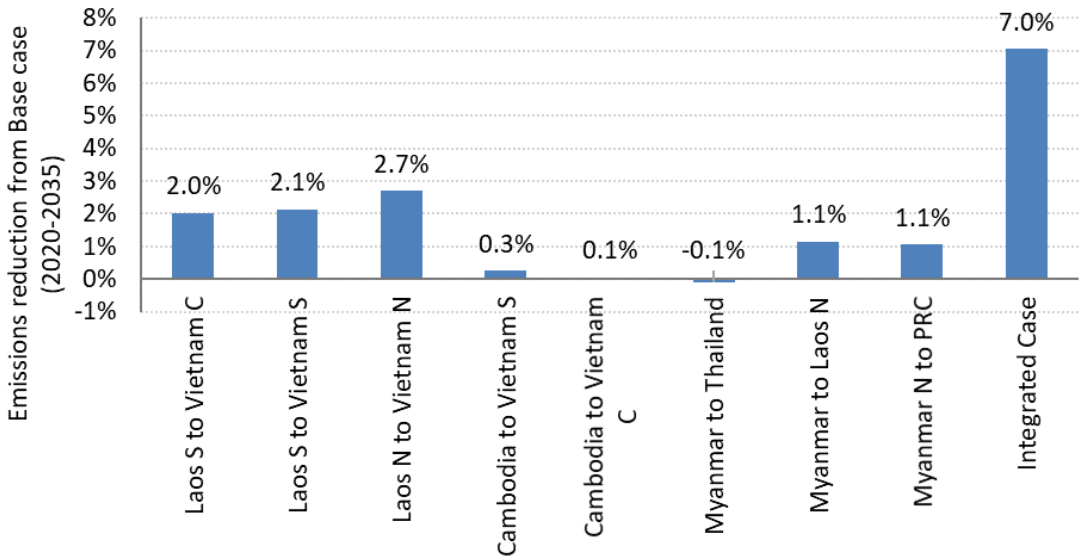


Figure 6 Carbon Emissions Reduction (Optimal Business Cases and Integrated Case against Base Case)



Integrated Case Regional Transmission Expansion

Table 2 summarises the business case expansion limits that resulted from the Integrated Case modelling. The table shows for each period the business cases (defined by "From Region" and "To Region") the resulting capacity expansion for the cross-border link, and prioritisation of the business case links in an integrated GMS context. The prioritisation was based on least-cost modelling across the GMS with business cases, generation and national transmission augmentations optimised to deliver the lowest GMS-wide system cost.

Table 3 shows the same information, but has rearranged the cross-border expansions by chronological order to form a possible strategy for enhancing cross-border trade over time. The priority projects and augmentation timings, based on size and benefit of the business case

augmentation, and estimated augmentation costs are also noted in the table. Figure 7 plots the corresponding investment cost requirements for the prioritised interconnection projects in the Integrated case which gradually increases to $3.4 billion by 2035 and is driven by the interconnection projects involving Laos and Myanmar.

An integrated GMS will allow greater potential for further cross-border trading opportunities which will benefit and open up power planning options. This would include the potential for reducing overall reserve requirements in the region through the utilisation of interconnector capacity. Lao PDR plays a very vital role in integrating the GMS, and in effect would become counterparty to all of the GMS countries, however, coordination is required in relation to grid-to-grid operations between country networks and also in delivering a national transmission grid to support cross-border trading.

Table 2 Business Case Link Timing and Expansion Summary (Integrated Case)

BC No.	Region (From)	Region (To)	Regional Transmission Expansion	Earliest Year Allowed
1	Lao PDR (South)	Viet Nam (Central)	• 1200 MW developed in 2022 • 1200 MW => 1400 MW by 2030 • 1400 MW => 2000 MW by 2035	2022
2	Myanmar	Thailand (North)	• 550 MW in 2025 • 1550 MW developed by 2030 • 2000 MW developed by 2035	2025
3	Lao PDR (South)	Viet Nam (South)	• 800 MW in 2025 • 800 MW => 2000 by 2028	2025
4	Thailand (Central)	Cambodia	• 100 MW => 300 MW in 2027 • 300 MW => 700 MW in 2032	2025
5	Cambodia	Viet Nam (South)	• 200 MW => 470 MW in 2023 • 470 MW => 600 MW by 2033	2022
6	Cambodia	Viet Nam (Central)	• 250 MW by 2026/27	2025
7	Lao PDR (North)	Myanmar (North)	• 1100 MW in 2023 • 1100 MW => 2000 MW by 2033	2022
8a	Myanmar (Mandalay)	PRC	• 800 MW developed from 2025 • Expanded to 1000 MW in the longer-term	2025
8b	Myanmar (Yangon)	PRC	• 8a is the preferred option	2025
9	Lao PDR (North)	Viet Nam (North)	• 570 MW developed in 2025 • 2500 MW in place by 2029	2025

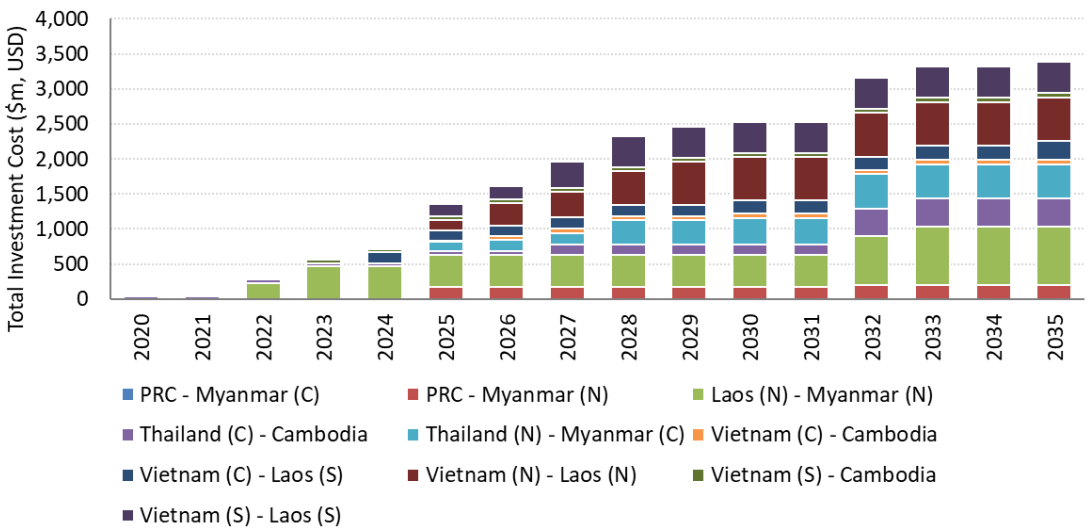
Laos ⇔ Viet Nam	Cambodia ⇔ Viet Nam or Thailand	Myanmar ⇔ Lao PDR, PRC or Thailand

Table 3 Proposed Strategy for Cross-Border Expansions

Period	Priority Business Case Augmentation	From Region	To Region	Expansion From (MW)	Expansion To (MW)	Estimated Cost* ($m)
2022-24	✓	Lao PDR (South)	Viet Nam (Central)	0	1200	154
		Cambodia	Viet Nam (South)	200	470	29
	✓	Lao PDR (North)	Myanmar (North)	0	1100	466
2025-27	✓	Lao PDR (North)	Viet Nam (North)	0	1400	365
	✓	Myanmar (Mandalay)	PRC	0	800	168
	✓	Myanmar	Thailand	0	670	163
	✓	Lao PDR (South)	Viet Nam (South)	0	1700	385
		Cambodia	Viet Nam (Central)	0	250	63
		Thailand (Central)	Cambodia	80	270	101
2028-30	✓	Myanmar	Thailand (North)	670	1550	215
		Lao PDR (South)	Viet Nam (Central)	1200	1400	31
		Lao PDR (South)	Viet Nam (South)	1700	2000	62
	✓	Lao PDR (North)	Viet Nam (North)	1400	2400	255
Beyond 2030	✓	Lao PDR (South)	Viet Nam (Central)	1400	2000	79
	✓	Myanmar	Thailand (North)	1550	2000	111
	✓	Lao PDR (North)	Myanmar (North)	1100	2000	373
	✓	Myanmar (Mandalay)	PRC	800	1000	30
		Thailand (Central)	Cambodia	270	730	252
		Cambodia	Viet Nam (South)	470	600	14

* Estimated cost is based on the incremental capacity, or investment required relating directly to the augmentation.

Figure 7 Total Transmission Investment Requirements over Time (Excludes National Grid Augmentations)



Interconnection Strategy for the GMS

The modelling of selected cross-border expansion projects and the Integrated case has enabled us to identify the benefits of each cross-border expansions in the GMS. Table 3 shows a proposed development strategy that is based on the principle of prioritising projects with the greatest economic benefits to the region. It is important to recognise that we did not consider low voltage / distribution network level connections and that, with the exception of cross-border links involving PRC, we have considered only AC (synchronous) interconnections of the transmission networks in the region.

In order to realise the identified benefits, an interconnection strategy is required that considers gradual steps towards implementing the projects in Table 3. In general, any such interconnection strategy would need to involve supporting investments in control schemes, building in N-1 redundancy, automatic control schemes and rules of power system dispatching. This highlights the importance of establishing a harmonised Grid Code for the region where suitable standards for connection and control would be defined. These issues have not been considered in the interconnection strategy – it has been based simply on matching a synchronisation programme to the prioritised investments. Further engineering studies would naturally need to be done.

The strategy is intended to provide guidance on a foreseeable synchronisation strategy to support the results of the integrated GMS case. In this discussion we do not discuss the lower voltage interconnections between Laos and Thailand, and between Laos and Vietnam. However, there may be some opportunities to revisit lower voltage connections as part of a wider strategy to synchronise grids in the region. A further comment on the foregoing is that we consider only the business cases that were analysed in this report; there may be other cross-border connections that warrant close attention such as between Northern Laos and Myanmar, PRC and Vietnam, and strengthening lower voltage connections between Laos and Thailand.

In Figure 8, we provide a conceptual roadmap for regional integration and in Table 4, we provide an interconnection strategy. The conceptual roadmap is intended to illustrate the high priority cross-border connections over time, along with other important actions that are required. The table provides further details across four stages of regional integration beginning with the present state of the GMS and progressively moving towards a fully integrated and synchronised GMS by year 2031.

Figure 8 Conceptual 10-year Roadmap for Regional Integration

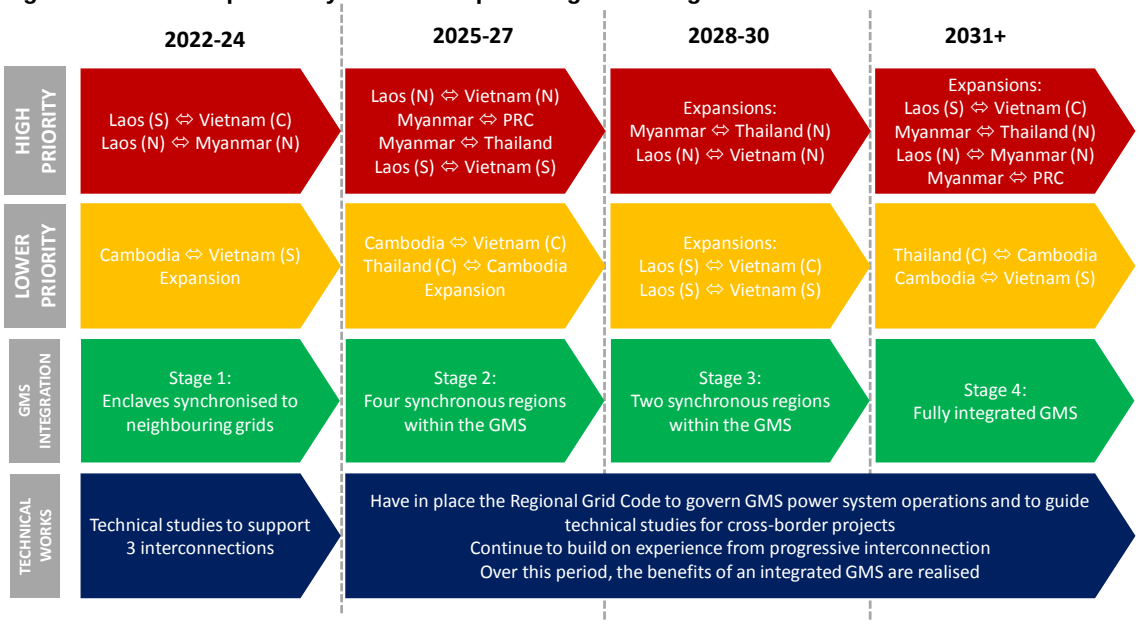


Table 4 Proposed Strategy for Integration of Synchronous Interconnections

Stage	Period	Preconditions	Key Actions	Purpose
1	2022-24	Technical feasibility studies for the proposed cross-border projects within this period.	Synchronisation of a portion of the southern Laos power system to Vietnam central and building upon the existing synchronous connection between Vietnam south and Cambodia and synchronising a portion of Las North grid to Myanmar.	Build on the limited number of existing synchronised interconnections and take initial steps towards interconnecting high priority cross-border interconnections with minimal implications for synchronised grid operations.
2	2025-27	Regional Grid Code in place to guide technical studies and identify supporting transmission network investments to enable synchronous interconnections to operate appropriately.	Form four synchronous interconnections within the region, with the synchronous interconnections being: (1) Vietnam and parts of Cambodia and Laos, (2) Laos and connections to Thailand, (3) Cambodia, Thailand and a portion of Myanmar's southern power system, and (4) Myanmar and PRC.	Build on the experience of stage 1 by expanding synchronous interconnections and subsequently managing power system operations under the Regional Grid Code. Continue to realise a significant fraction of the economic benefits of the high priority cross-border projects.
3	2028-30	Successful implementation of stage 2, and completion of technical studies to support further cross-border connections in the region.	Formation of eastern and western GMS synchronous interconnections through integration of Laos, Cambodia and Vietnam to form the eastern system, and integration / synchronisation of PRC, Myanmar, Thailand and Cambodia to form the western system.	Establish two significant synchronous regions within the GMS and have them operated under the Regional Grid Code. Most of the "low hanging fruit" benefits of the Integrated case are realised within this period.
4	2031 & beyond	Successful implementation of Stage 3, and completion of technical studies to support further cross-border connections in the region.	integration of western and eastern GMS synchronous interconnections to have a fully integrated and synchronised regional power system	Gain the full benefits of an integrated GMS.

Next Steps

This study has demonstrated the benefits of greater integration of the GMS region and in particular, has identified the cross-border interconnections that will lead to the greatest benefits in the region. Based on these results we have formulated a 10-year roadmap that has prioritised the investments in cross-border connections based on those that deliver the greatest benefits to the region. The roadmap has identified a high level strategy for interconnection as well as identifying some important preconditions that need to be implemented as part of progressing the GMS towards a fully interconnected region.

In order to support the conceptual roadmap and facilitate the progression of the GMS towards a more tightly integrated power system, there are a number of important next steps that need to be taken. These include the following:

- More detailed technical studies need to be carried out to support the individual business cases. These need to identify additional investments that may be required in order to ensure power system operations will be reasonable;
- The economic viability of HVDC interconnection in the region needs consideration as an alternative to the AC interconnections that we have studied;
- A Regional Grid Code needs to be agreed and established, and the standards within subsequently used to guide, among other areas: (1) the technical studies for interconnection to ensure that they comply to the Regional Grid Code standards, and (2) operation of synchronised regions such that this is carried out in accordance with the rules defined in the Regional Grid Code). The adoption of the regional Code by each of the GMS countries and the agreement of a minimum set of requirements for interconnection will be key facilitating steps;
- Planning frameworks within the member countries need to be adjusted to incorporate cross-border transmission projects;
- A rigorous approach needs to be taken to the development and implementation of regional transmission wheeling charges, to give a clear path for the remuneration of major transmission investments;
- A country-by-country implementation is needed of specific policies and regulatory reforms that will ensure open access to the national power networks and underpin the transparency with which the regional power systems are planned and operated;
- Further consideration should be given by the RPTCC and possible successor or subsidiary groups to the trading rules and balancing arrangements that should be implemented in parallel with the technical expansion of the power systems, to ensure that a sound basis for power trading is created.

Many of these steps build on work that is already being undertaken by the RPTCC members and other organisations within the GMS countries with support from international agencies. Work on other projects, as well as earlier work under this assignment, has demonstrated that the GMS member countries are at different stages both at policy level and in terms of practical implementation regarding issues such as:

- Power sector unbundling and ensuring the independence of the transmission function and the guarantee of third-party access to facilitate increased power trading;
- Defining the roles and responsibilities of the government ministries and other agencies responsible for power sector regulation;
- Creating the regulations and licences that will be needed to enable a combination of incumbent power utilities and new private sector developers of transmission infrastructure to work together in an integrated way;
- Identifying capacity building needs in the areas that are required to enhance the technical, project management and financial/economic capabilities of the power sector stakeholders.
- Addressing the challenges posed particularly in Lao PDR by the existence of IPPs that are exporting power across borders over dedicated interconnectors constructed on a BOT basis, the utilisation of which is defined under the terms of PPAs, but which will need to form part of the synchronised regional network.

In order to progress towards the vision of an interconnected regional transmission system and regional synchronisation that can lead to effective power trading and the levels of benefits demonstrated in the business case analysis, achieving the highest level of regional cooperation is essential. We recognise the importance of the continued role of the RPTCC and the potential evolution of this body into the RPCC in future as being critical to the future evolution of the GMS power sector.

1 Task 1 Overview

1.1 Scope of Task 1

The objective of Task 1 is to establish business cases that enhance power market integration in the Greater Mekong Subregion (GMS) and to provide a convening platform to bring together relevant stakeholders to engage in regional dialogue on the opportunities and challenges that specific businesses cases face in terms of greater power market integration.

The objective of Task 1 was originally to analyse ten (10) business cases with each to be discussed and critically analysed with the convening platform stakeholders (consisting of energy policy makers, regulators, utilities and potential investors). This in turn will enable the consultant to rank and prioritise the businesses cases that have the highest potential to not only accelerate power trade within the GMS, but also to be those projects most likely to be of commercial interest to prospective project investors.

Having completed nine (9) business cases, it was decided that Task 1's remaining work would be focused on analysis of an Integrated cross-border transmission plan to understand the sequencing and prioritisation of business cases, rather than to continue assessing individual cross-border interconnections.

1.2 Purpose of this Report

The purpose of this report is to document the modelling methodology, assumptions and results underpinning all eight (8) business cases and an integrated GMS case. These relate to business cases that were presented and discussed at RPTCC-23 and RPTCC-24. A component of the business case assessments is cost-benefit analysis based on technical-economic modelling of the Greater Mekong Sub-region (GMS) and with the use of information that the Consultant has compiled from previous work in the GMS.

The modelling that we have used to facilitate the business case assessments is of a preliminary nature and may be refined with further discussion between the relevant stakeholders. We have set out all of the key assumptions that we have made in order to make the assumptions and our approach transparent.

1.3 Report Structure

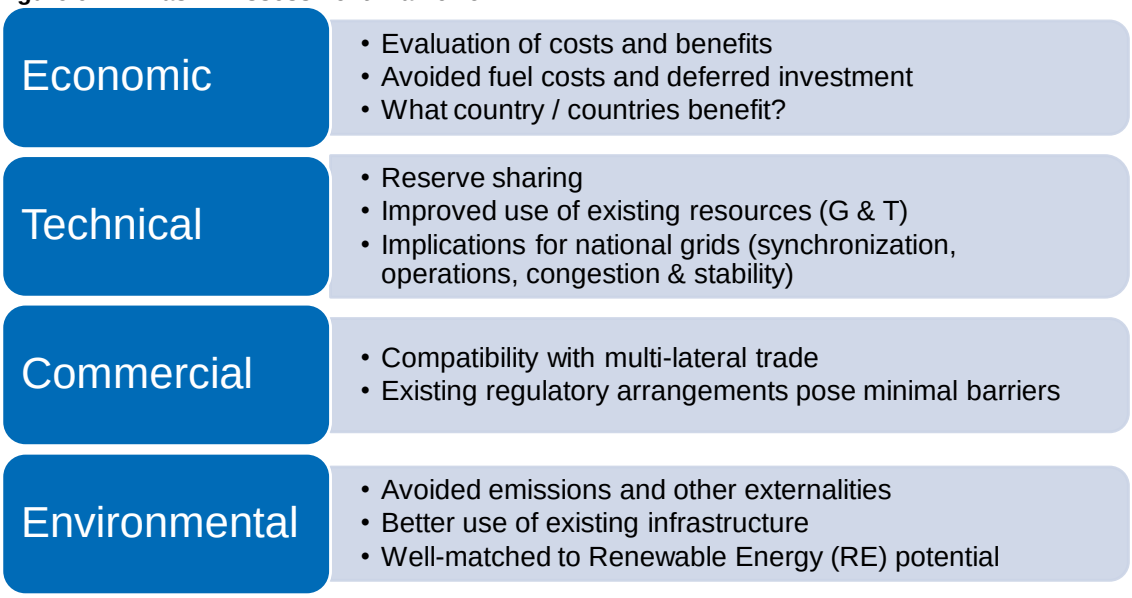
We have structured the report in the following way:

- Section 2 covers the Task 1 objectives;
- Section 3 provides an overview of the current status of the GMS country networks;
- Section 4 discusses the current state of cross-border connections in the GMS;
- Section 5 outlines the possible cross-border interconnections;
- Section 6 forms a list of the Business Cases studied;
- Section 7 summarises the Business Case key modelling results;
- Section 8 describes the integrated case where we seek to optimise generation and transmission projects jointly, providing insight into how best to prioritise the business cases that we study on this project;
- Section 9 provides a high-level conclusion of the various business case links on GMS trading;
- Section 10 sets out our suggested next steps; and
- Appendices A, B and C respectively provide additional detailed results breakdown, a summary of the assumed base case power sector outlooks and details of the modelling assumptions and methodology used.

2 Task 1 Objectives

Task 1 involves ranking and prioritising up to ten (10)[4] business cases (grid-to-grid connections only) that could be expected to enhance power market integration in the GMS, accelerate electricity trade in the GMS and is of commercial interest to project investors. We subsequently studied 9 of the 10 business cases in detail before analysing an integrated case. The assessment framework was based on a consideration of economics, technical, commercial and environmental factors as illustrated in Figure 9.

Figure 9 Task 1 Assessment Framework



This report discusses the all of the business cases and is highlighted in Table 5 and Figure 10 below. The Table shows the main focus areas of the sets of business cases we have studied on this project:

- Business cases that have been focused around Lao PDR and Viet Nam;
- Business cases that have been focused around Cambodia and Viet Nam; and
- Business cases that have been focused around Myanmar.

[4] Note that it has been agreed for the Consultant to study nine (9) business cases with remaining work focused on the development of an overall cross-border transmission plan for the GMS (Integrated Case), as a way to rank and prioritize the cross-border interconnection projects. The Integrated Case includes a tenth business case (Cambodia to Thailand) which was not studied in isolation.

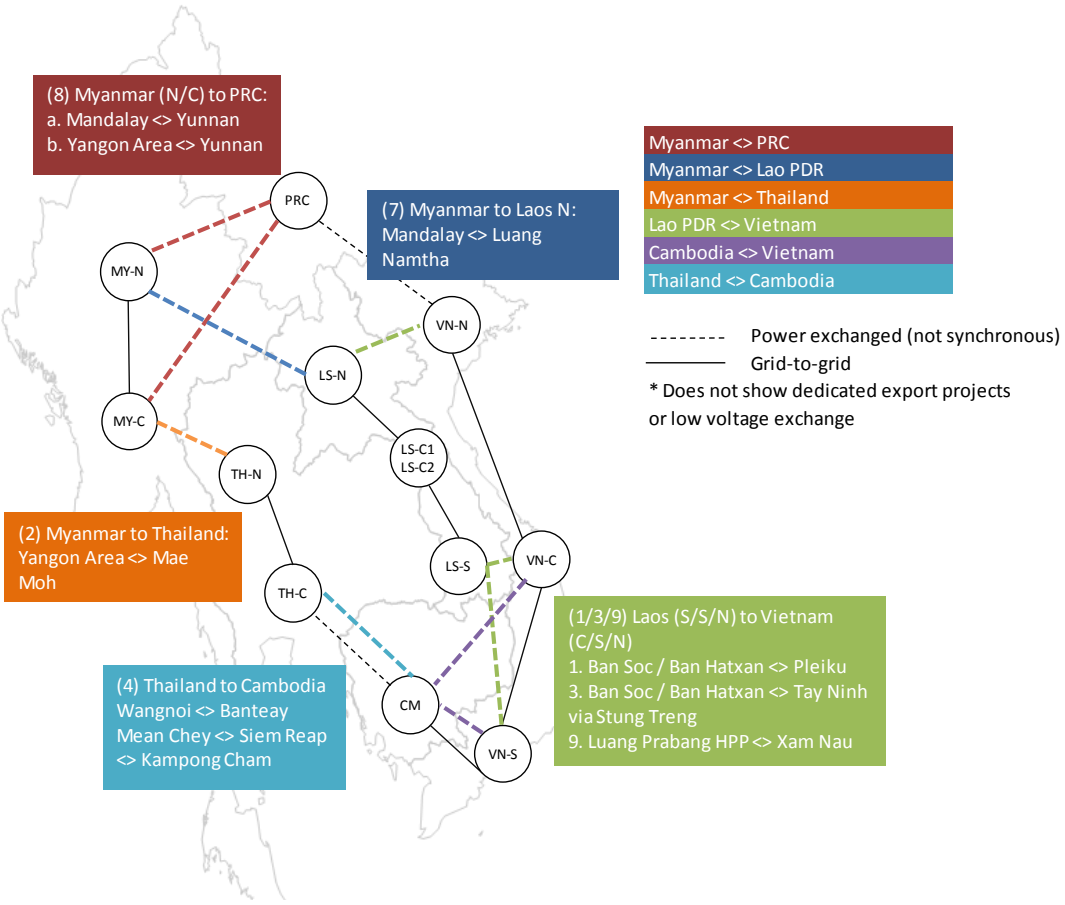
Table 5 List of Business Cases Studied

No.	Region (From)	Region (To)	Connection Points (From – To)	Length (km)
1	Lao PDR (South)	Viet Nam (Central)	Ban Soc / Ban Hatxan ⇔ Pleiku	190
2	Myanmar	Thailand (North)	Yangon area ⇔ Moe Moh	350
3	Lao PDR (South)	Viet Nam (South)	Ban Soc / Ban Hatxan ⇔ Tay Ninh via Stung Treng	320
4*	Thailand (Central)	Cambodia	Wangnoi ⇔ Banteay Mean Chey ⇔Siem Reap ⇔ Kampong Cham	500
5	Cambodia	Viet Nam (South)	Kampong Cham ⇔ Tay Ninh	100
6	Cambodia	Viet Nam (Central)	Lower Se San 2 (HPP) ⇔ Pleiku	230
7	Lao PDR (North)	Myanmar	Luang Namtha ⇔ Northern Myanmar	150
8a	Myanmar	PRC	Yangon ⇔ Yannon	350
8b	Myanmar	PRC	Mandalay ⇔ Yunnan	500
9	Lao PDR (North)	Viet Nam (North)	Luang Prabang (HPP) ⇔ Xam Nau (Lao-N) ⇔ Nho Quan	400

Laos ⇔ Viet Nam | **Cambodia ⇔ Viet Nam** | **Myanmar ⇔ Lao PDR, PRC or Thailand**

** Business case 4 was not separately studied but was included in the Integrated GMS case.*

Figure 10 Task 1 Business Cases



3 Current Status of Transmission Systems and Power Development Plans

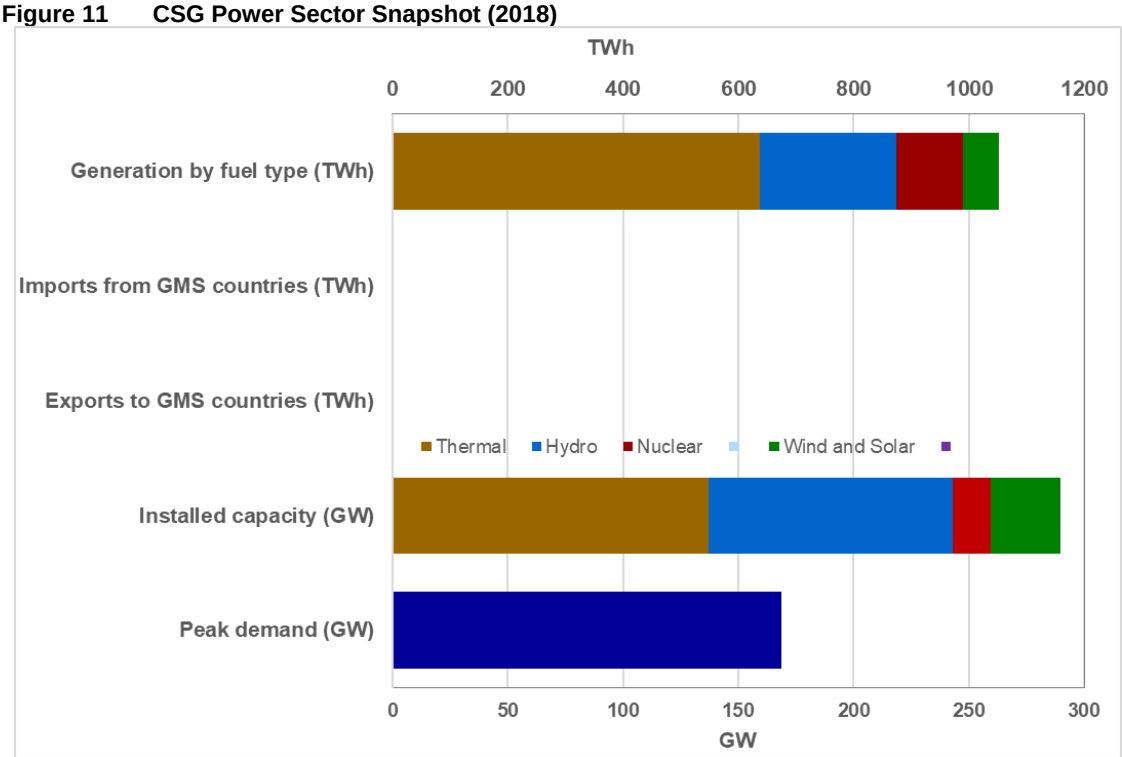
In this section, we provide a summary of the present state of national transmission systems and a brief description of our understanding of the main features of the power development plans in each country.

3.1 PRC – Guangxi and Yunnan

3.1.1 CSG: Power Sector Snapshot

Yunnan province and Guangxi autonomous region are the Chinese members of the GMS. They are two of the five sub-grids served by the government-owned China Southern Power Grid (CSG), which also covers Guandong, Guizhou and Hainan provinces. A snapshot of the CSG in 2018 is provided in Figure 11, which summarises the generation and installed capacity by fuel type, peak demand and power exchanges between the CSG and other GMS countries.

Figure 11 CSG Power Sector Snapshot (2018)



Source: Compiled by Consultant from various sources and CSG RPTCC25 Presentation.

The installed capacity of CSG in 2018 was around 290 GW relative to a peak demand of around 170 GW. Yunnan province and Guangxi account for more than 30% of the installed capacity in the CSG. The majority of capacity is in the western region of the CSG while more than half of electricity demand is in Guangdong, an industrial area in the east of the CSG. More than 1000 TWh of electricity was generated in 2018. Yunnan accounts for around 15% of total electricity demand and more than half of electricity demand is in the industrial area of Guangdong. The main fuels used for electricity generation in the CSG are coal and hydropower, accounting for around 60% and 23% of total generation respectively.

3.1.2 CSG: Transmission Network

The transmission networks of CSG are shown in Figure 12. There are a number of 500 kV AC and DC transmission lines connecting the east and west of the CSG, transferring electricity from

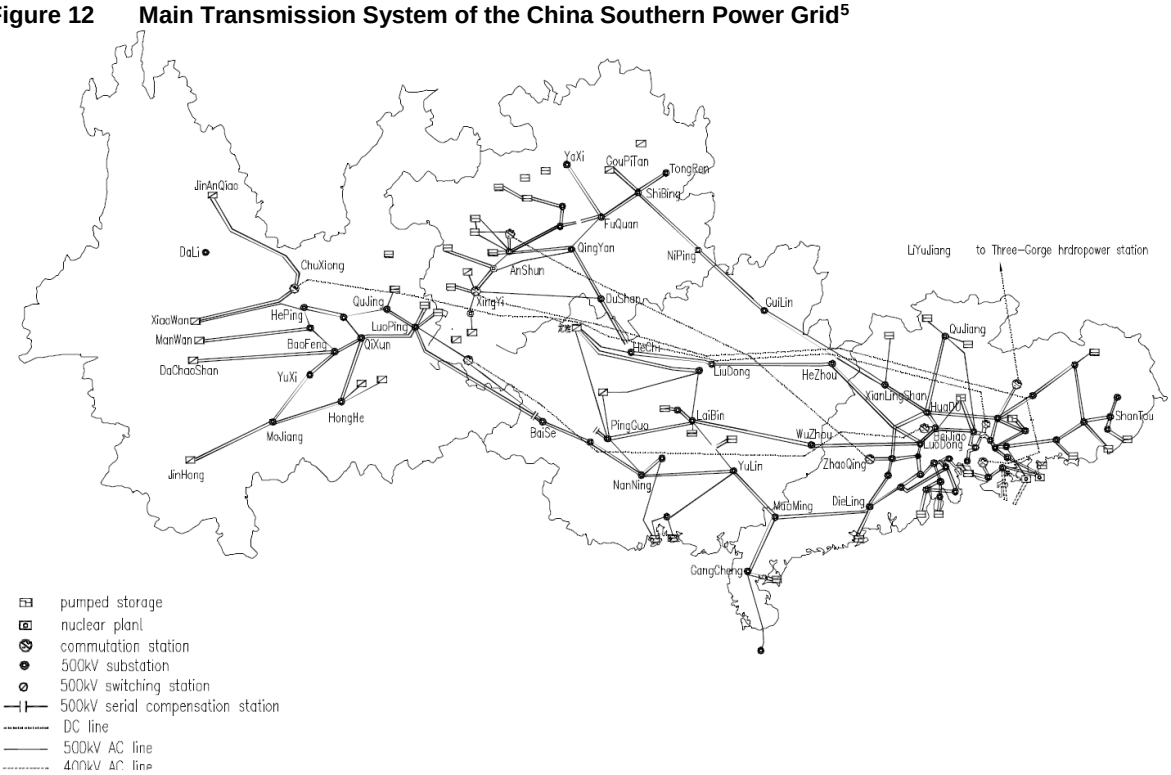
Yunnan, Guizhou and Guangxi to Guangdong in the west, which is the load centre of CSG. Recently the 800 kV HVDC transmission lines with the rated capacity of 5,000 MW has been built to connect Yunnan and Guangdong.

The Yunnan sub-grid is bordered with Myanmar and Viet Nam with the Guangxi sub-grid is bordered with Viet Nam. Guangxi sub-grid locates in the centre of CSG and it plays an important role in supporting the west-east transmission channel in CSG. Both Guangxi and Yunnan have a combined installed generation capacity in excess of 50 GW, most of which are large hydro and coal power plants.

Yunnan province exports power to the norther part of Viet Nam via 110 kV and 220 kV transmission lines while power export from Guangxi to Viet Nam is via a 110 kV transmission line. Yunnan province also exports power to northern part of Lao PDR. Recently, Yunnan province has started to import power from hydro power plants in Myanmar via 220 kV DC lines (Shewli-1 HPP to Dehong), and 500 kV transmission lines (Dapein-1 HPP to Yunnan Province near Dehong). The existing cross-border power trade is described in detail in Section 4.

Given the significant generation capacity of both Guangxi and Yunnan provinces there exist excellent opportunities for power exchanges between PRC with Myanmar, Viet Nam and Lao PDR.

Figure 12 Main Transmission System of the China Southern Power Grid[5]



3.1.3 CSG: Power Development Plan

Yunnan province has abundant energy resources, particularly coal and hydropower. The province is estimated to have coal reserves of around 70 billion tons. Hydro power is the main energy resource is hydropower in which the exploitable capacity is estimated to be higher than 100 GW with the annual generating capacity at nearly 400 TWh. There is also substantial geothermal resource.

Power sector policy is formulated by the central government agencies consisting of the National Energy Commission (NEC) and the National Energy Administration (NEA). The government has announced an action plan to curb the rise in both greenhouse emissions and local air pollutants

[5] ADB (2010). Facilitating Regional Power Trading and Environmentally Sustainable Development of Electricity Infrastructure in the Greater Mekong Subregion, Asian Development Bank. **ADB RETA No. 6440**.

with targets to control coal consumption. This plan would also involve promoting hydropower development, gradually increasing the share of nuclear power, accelerating the deployment of renewable technologies particularly wind, solar and biomass using policy mechanisms including renewable energy targets and the Emissions trading Scheme (ETS). In the 12th Five-Year Plan, PRC aims to increase the share of renewable generation to 20% and renewable generation capacity by 160 GW, while reducing coal-fired electricity generation by around 65% in the 12th five year period.[6]

In the past, PRC has focused primarily on developing its own resources and infrastructure (generation and transmission) to meet the domestic electricity demand, particularly in mobilising generation resources in the west to meet demand in the east of the country via long-distance transmission lines. Recently, however, PRC has placed higher priority to expanding its electricity trade with the ASEAN countries, particularly between Yunnan, Guangxi and other GMS countries.

3.1.4 CSG: Power Sector Current Challenges

One of the major challenges for the State Power Corporation is related to mobilizing generation resources in the west in Yunnan to the major load centres in the east, particularly the industrial area in Guangdong province. A number of long-distance HVDC transmission lines have therefore been built to address this challenge as has been described in the previous section.

PRC's interest in cross-border power trade with other GMS countries appears to be in both exporting and importing. PRC has been interested in investing in power projects in GMS countries since it provides the opportunity of the Chinese firms to invest in the region. The most notable projects are Shweli and Dapein hydro projects in Myanmar. There are also other projects in Cambodia, Lao PDR and Viet Nam although they are not directed at exporting power to the regional market. However, with the recent reductions in demand growth resulting in over generation supply, the CSG has been seeking opportunities to export power, particular from Yunnan where there is excessive generation capacity.

3.2 Cambodia

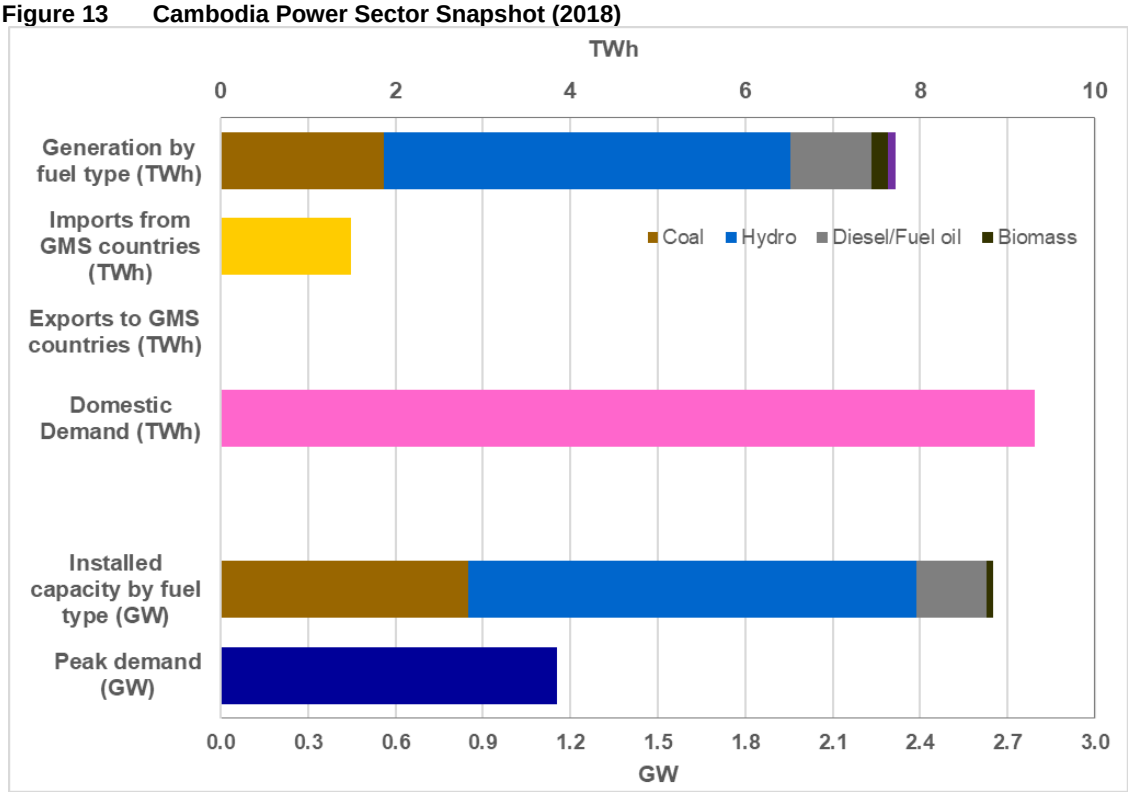
3.2.1 Cambodia: Power Sector Snapshot

Prior to 2010, Cambodia relied almost entirely on diesel/fuel oil for electricity generation and the total generation capacity was very limited. Since 2010, the total installed capacity has increased significantly and has become more diversified with hydro and coal projects playing roles in the capacity mix.

Figure 13 shows a snapshot of the power sector in Cambodia in 2018. Hydro is the dominant fuel type, accounting for around 58% of the total installed capacity, followed by coal and diesel/fuel oil at 32% and 9% respectively. The share of coal generation has significantly increased over the past years increasing from 860 GWh in 2014 to over 1,800 GWh in 2018. The recent developments in generation capacity bringing it to 2650 MW has reduced Cambodia's reliance on its diesel/fuel oil units and power imports from neighbouring countries in the GMS, particularly Viet Nam and Thailand. The share of electricity generation is dominated by hydro and coal which accounts for more than 84% of total generation. Cambodia is estimated to have imported less than 1.5 TWh of electricity in 2018 compared to almost 2 TWh in 2012/13.

[6] The State Council of China (2012). Energy Development 12th Five Year Plan. Beijing, The State Council of China.
IEA (2014). World Energy Outlook 2014. Paris, International Energy Agency.

Figure 13 Cambodia Power Sector Snapshot (2018)

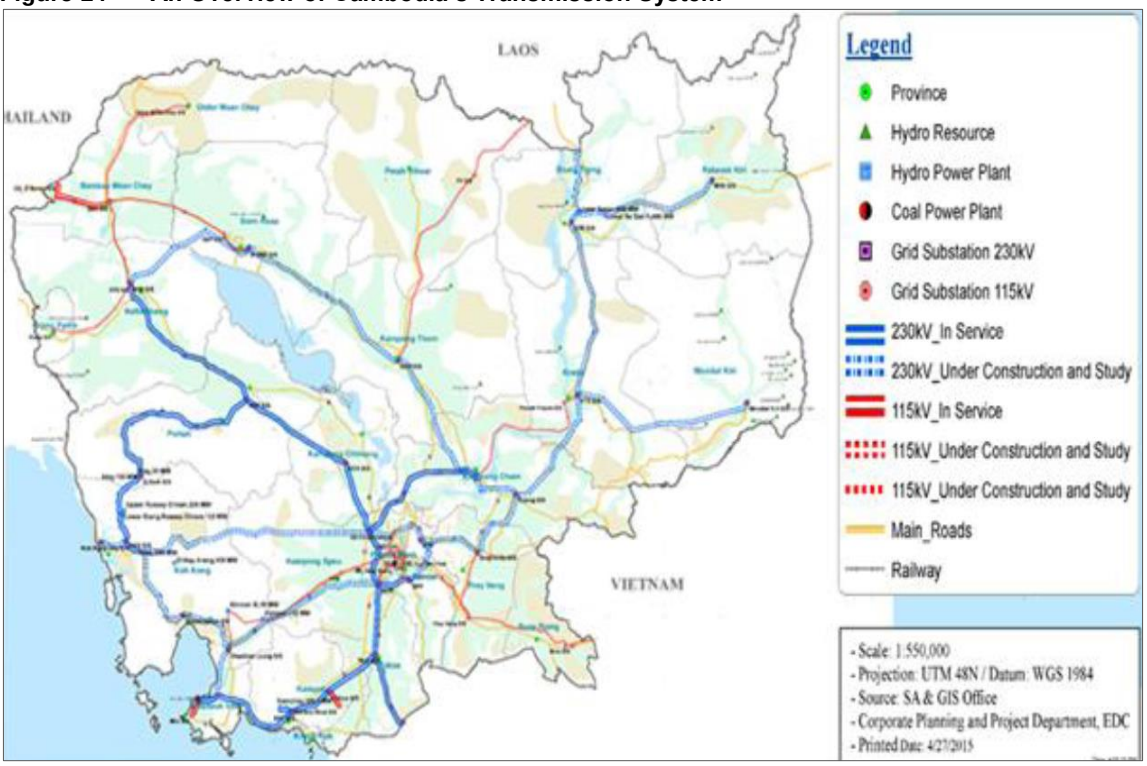


Source: Compiled by Consultant from various source including Cambodia RPTCC25 Presentation

3.2.2 Cambodia: Transmission Network

A representation of Cambodia's main transmission network is illustrated in Figure 14. The diagram highlights the locations of key generation resources and the 115/220 kV transmission lines that interconnect the national system. Cambodia's transmission system initially consisted of 24 isolated provincial supply grids, which have gradually been integrated into the single main grid over the past 10 years with all provinces expected to be connected by 2020. Cambodia has in the past relied heavily on power imports from Lao PDR, Thailand and Viet Nam via existing transmission/distribution lines at 230 kV, 115 kV and 22 kV voltage levels. In 2013, 56% of Cambodia's total electricity demand was met by power transfers from Thailand, Lao PDR and Viet Nam. There are several connection points between Viet Nam and Cambodia as agreed by the Governments of the two countries. Supply from Thailand is via a distribution line at the Cambodia and Thailand border. Imports from Lao PDR are through Electricite Du Cambodge (EDC) and supplied to the Steung Treng area in the northeast. Since the recent completion of new hydro and coal power plants in Cambodia, power imports significantly reduced.

Figure 14 An Overview of Cambodia's Transmission System[7]



3.2.3 Cambodia: Power Development Plan

The Royal Government of Cambodia sets targets for the energy sector in the National Strategic Development Plan (NSDP) which sets priorities on increasing electricity supply capacity and reducing electricity tariffs to an appropriate level, while strengthening the institutions to manage the energy industry. One of the key focus areas has been to enhance access to electricity, and so an electrification master plan was established around the following three principles: (1) develop electricity generation capacity including hydropower and coal or gas, (2) leverage power imports from neighbouring countries to enhance access to provinces near the Cambodian borders, and (3) continue investments and enhancements to the national transmission system.

Most of Cambodia's committed generation capacity is currently coal and hydro projects. Cambodia has in place a Renewable Energy Action Plan (REAP) to promote renewable energy. However, there are no specific targets in place although 10 MW of large-scale solar was recently commissioned in Bavet. There is also a National Energy Efficiency Policy which has a target to reduce future national energy demand by 20% to 2035 against a business as usual projection and to reduce CO_2 emissions in 2035 by 3 million tons. In the longer-term, it is expected that offshore gas reserves that have been identified could be developed.

3.2.4 Cambodia: Power Sector Current Challenges

The historical challenges for the power sector in Cambodia has been low electricity access, high electricity prices due to the large share of imported diesel/fuel oil for electricity generation, as well as high dependence on energy import in the short-term. Cambodia's electricity prices are one of the highest in the ASEAN region as the power sector has traditionally relied on imported diesel to satisfy demand for electricity.

Over the past few years there have been substantial coal and hydro capacity built with further additions planned over the short and medium term. Electrification continues to increase with the expansion of the national transmission system and cost of generation is expected to improve along with a reduction in imports from Vietnam, Thailand and Lao PDR.

[7] Source: EDC (2015). Updated Cambodia Country Report, 19th RPTCC Meeting. Bangkok, Thailand

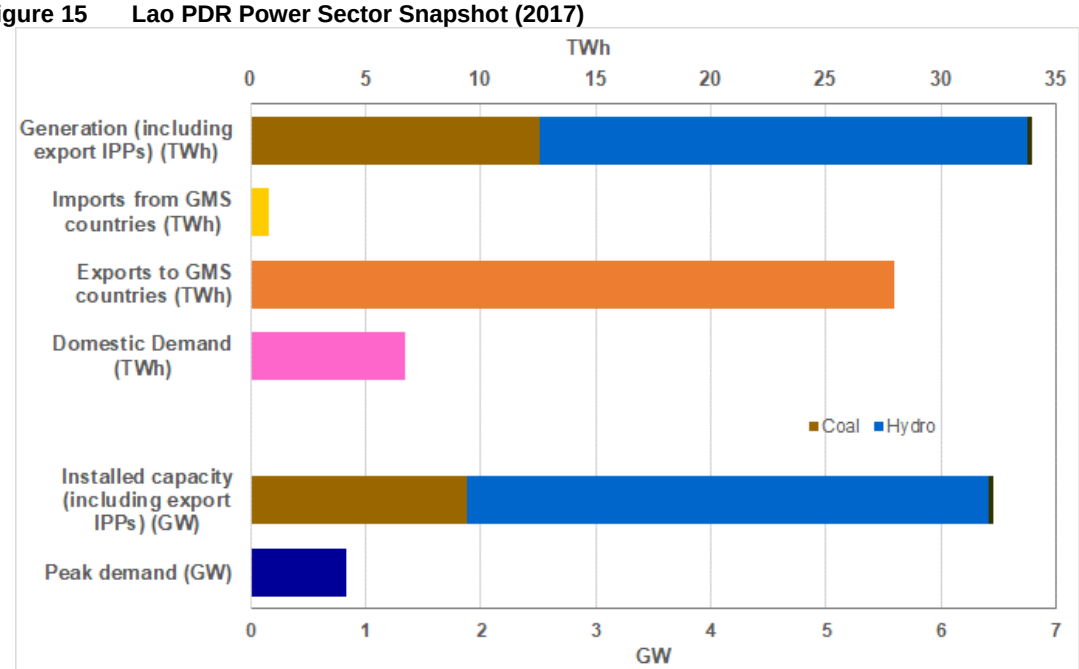
Cross-border imports are still required to address short-term challenges, however, the main motivation for long-term cross border electricity trading is for Cambodia to become a net electricity exporter in the GMS by focusing on expanding its generation capacity, particularly hydro and natural gas for exporting power to Thailand and Viet Nam.

3.3 Lao PDR

3.3.1 Lao PDR: Power Sector Snapshot

Figure 15 shows a snapshot of the power sector in Lao PDR in 2017. All of the generation projects in Lao PDR were traditionally based on hydro power although this has recently changed with the recently constructed Hong Sa Lignite power plant with the total capacity of 1,878 MW (175 MW of which supplies to EDL), which was fully commissioned in March 2016. Around 70% of the generation capacity in Lao PDR has been dedicated for exporting to Thailand, and to a lesser extent Viet Nam. Domestic demand has been growing rapidly; in particular, annual electricity consumption increased at an average rate of 14.5% per annum over the past 10 years. Although Lao PDR exports a large amount of power to Thailand (through dedicated IPP projects), it also imports electricity to supply provinces that are not connected to the national power grid. The amount of imports to meet the domestic demand has been increasing over the past decade.

Figure 15 Lao PDR Power Sector Snapshot (2017)



Source: Compiled by Consultant from various sources.

3.3.2 Lao PDR: Transmission Network

A representation of Lao PDR's transmission systems is shown in Figure 17. The diagram highlights the present state of the country's national system in terms of the main hydro and coal generation resources and transmission network within the country. The transmission and distribution networks are separated into three regions: central (central 1 and 2), northern and southern region which only until recently was isolated from one another. In addition to the main grid operated by EDL, provincial authorities operate several isolated mini grids that are supplied by diesel generators or small-scale hydro power stations in remote areas.

There is a significant amount of power exchange between Lao PDR and neighbouring countries including Thailand, Viet Nam, PRC and Cambodia. Power is imported at a number of border points to meet local demand and exported from dedicated hydro and thermal generating plants. Lao PDR exports a large amount of hydropower to Thailand, but in exchange imports electricity

to supply provinces that are not connected to the national power grid. These demand points include copper and gold mining operations, which consume significant amounts of power.

With a number of committed and planned hydro and thermal power plant projects, the amount of power exports to neighbouring countries, particularly Thailand and Viet Nam, is expected to increase substantially over the next 5 years. The export via wider electricity trading arrangements, including PPAs, is viewed by the government as an opportunity to improve EDL's financial position, foster economic growth and over the longer-term reduce poverty. Presently Lao PDR has a number of cross-border interconnections with other GMS neighbouring countries. The agreed MOU capacities between Lao PDR and each country as at 2018 are:

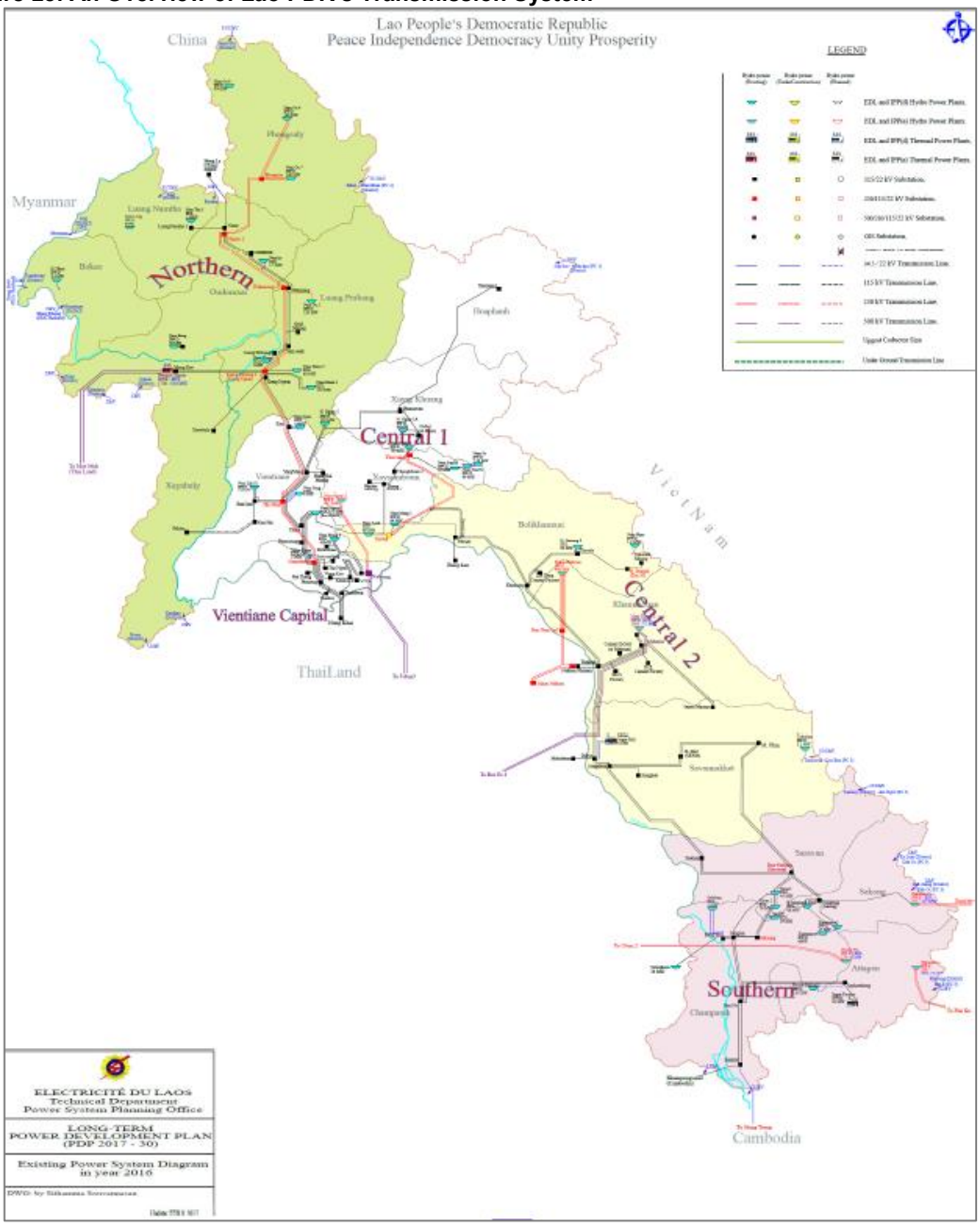
- Thailand: 7,000 MW with the potential for additional capacity in the longer-term;
- Viet Nam: 1000 MW by 2020, 3000 by 2025, and 5000 by 2030;
- Myanmar: 500 MW by 2025, and 1000 by 2030; and
- Cambodia: up to 500 MW by 2025.

Dedicated transmission lines (existing and committed) to accommodate power export of power plants to Thailand and Viet Nam countries include:

- Theun Hinboun to Sakhonnakhon (Thailand) 230 kV, 176 km, 440 MW;
- Houay Ho to Ubon 2 (Thailand) 230 kV, 230 km, 150 MW;
- Nam Theun 2 to Roi Et (Thailand) 500 kV, 300 km, 950 MW;
- Na Bong to Udon 3 (Thailand), 500 kV, 100 km, 1,050 MW;
- Hong Sa to Mae Moh via Nan (Thailand), 500 kV, and 325 km, 1,878 MW
- Xekaman 3 to Thanh My (Viet Nam) 230 kV, 115 km, 250 MW.

Lao PDR also has four interconnections with China, with capacity of 2,000 MW, to ensure adequate power supplies in Luang Prabang and the Northern provinces. The interconnection allows for power imports from China due to lower river levels up north and would indirectly relieve pressure on the central Lao PDR hydro plants.

Figure 16: An Overview of Lao PDR's Transmission System[8]



3.3.3 Lao PDR: Power Development Plan

Energy policy in Lao PDR is focused on making energy supplies affordable and reliable while also ensuring the exploitation of energy resources is done in an environmentally-friendly, efficient and sustainable manner. Key policies for Lao PDR are: (1) maintain and expand generation capabilities that will deliver affordable, reliable and sustainable electricity supply to promote socioeconomic development, (2) promote cross-border trade (exports) to generate additional revenue used to further reduce poverty, (3) develop policy, legal and regulatory frameworks to promote private investments and/or partnerships and (4) ensure accountability and transparency in power market developments in relation to sustainable outcomes and enhancing technical knowledge.

Lao PDR's socioeconomic policy also pushes for further industrialisation and higher electrification rates. The former has resulted in focused effort on developing special economic zones which will

[8] Source: EDL Electricity Statistics 2014

have implications for electricity demand and transmission development. The latter has resulted in a government electrification target of 90% by 2020, which is nearly achieved. The vast majority of Lao PDR's generation development is based on hydro projects geared towards export[9].

3.3.4 Lao PDR: Power Sector Current Challenges

The power sector in Lao PDR is undergoing a rapid expansion, with a number of hydro and thermal power projects have been constructed and committed over the past decade. Although most of the power projects are for exporting, some of the capacity have been dedicated for supply the domestic demand. With abundant hydro generation resources, the export of energy via wider electricity trading arrangements in the GMS region is viewed by the government as an opportunity to improve EDL's financial position, foster economic growth and reduce poverty. The government also views such opportunity as a way to increase the electricity access domestically, hence it has been very active in promoting export projects, opening up the power sector to private and foreign investment. The projects earmarked for exports to drive such growth is still in the early planning stages with firm contractual agreements yet to be signed along with the required investment in transmission capability.

Almost all of the generation capacity is hydro therefore there are some challenges during the summer dry season, which also coincides with the peak demand period. Effective hydro generation capacity typically reduces during the dry season due to low water inflows. However, there are some geographical diversification in water inflows between northern and southern regions but the benefit is limited given the lack of sufficient transmission link capacity without significant augmentation.

3.4 Myanmar

3.4.1 Myanmar: Power Sector Snapshot

A snapshot of Myanmar's power sector is shown in Figure 17. The system's combined installed capacity in 2017 is around 5.2 GW, the majority of which comes from hydro and gas-fired generation, accounting for around 60% and 35% of total generation capacity respectively[10].

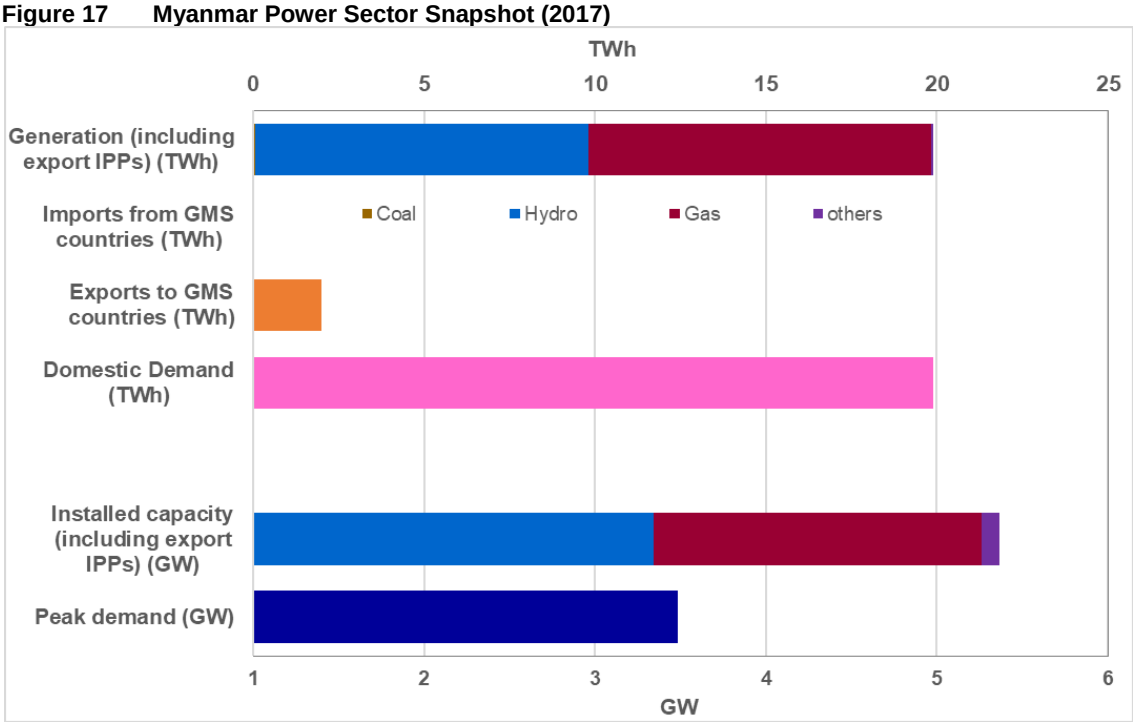
Although power generation and installed capacity have increased considerably over the past ten years as a result of several newly commissioned hydro facilities, the plant capacity factor is relatively low. Major drawbacks in power generation are largely attributable to low maintenance capacity and lack of additional infrastructure investments. The ageing infrastructure coupled with system base load instability leads to frequent power supply shortages, occurring particularly during the summer months.

Electricity consumption has increased significantly in the last five years at an annual average growth rate of 15.7%. Myanmar has in previous years been heavily dependent on hydropower with it being the source of around 70% of total electricity supplied, but has since commissioned new gas generation facilities to meet growing demands and relieve short-term supply pressures.

Myanmar is endowed with very significant amounts of hydro, solar, wind and biomass. There are also prospects for geothermal. In terms of fossil fuel resources, the country's coal deposits mainly consist of lignite and subbituminous types and are limited in terms of having low calorific value with proven reserves not being sufficient to support large coal power station developments. While Myanmar has significant offshore gas reserves, most produced natural gas is exported to PRC and Thailand.

[9] Hong Sa coal project is the only exception.
[10] IES estimates

Figure 17 Myanmar Power Sector Snapshot (2017)



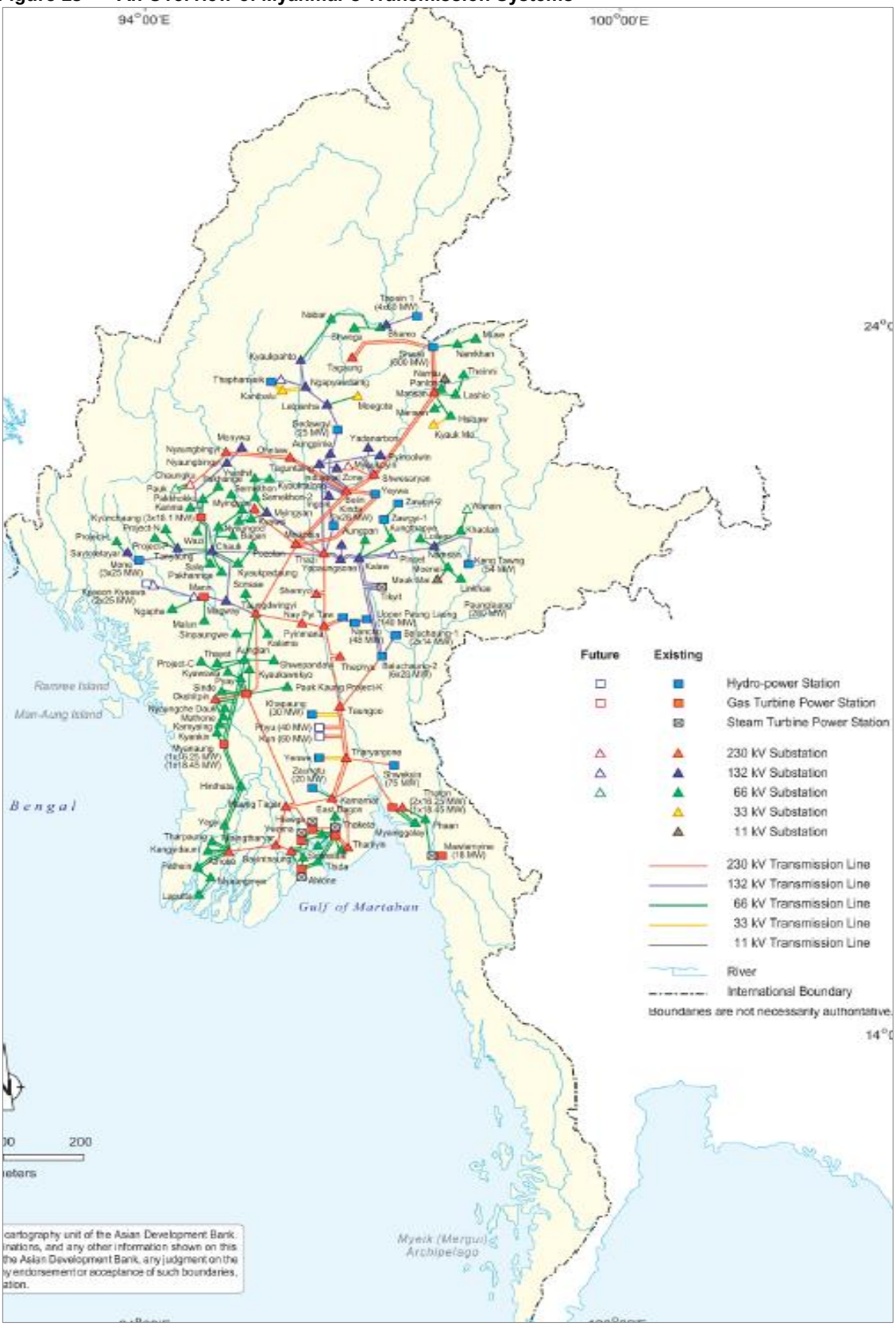
Source: Compiled by Consultant from various sources including own estimates.

3.4.2 Myanmar: Transmission Network

A representation of Myanmar's transmission system is illustrated in Figure 18. The high voltage transmission systems consist of 230 kV and 132 kV transmission lines connecting between two major load centres in the central north and southern regions of the country. Before 1960, the generation system consisted mainly of isolated grids supplied by diesel generators and mini-hydropower. However, with the recent development and expansion of the power sector in Myanmar, a number of large power plants, particularly hydro, have been constructed to supply domestic electricity demand as well as for import to PRC. The transmission network had to also be expanded to accommodate increased generation capacity and demand. From 2005 to 2011, eight power plants, totalling 1,934 MW, were built. Two large-scale hydropower plants, one partly for export to the PRC (Shewli-1, 600 MW) and the other for domestic supply (Yeywa, 790 MW), were commissioned in 2008 and 2010, respectively. Over the past years more plants have been added bringing total capacity to above 5,000 MW by 2017. Gas generation is situated between Manadalay and Mori in the south and hydro is located from northern Myanmar towards Bago.

Since 2008, Myanmar has been exporting power from hydro power plants to Yunnan province in the PRC via 220 kV DC lines (Shewli-1 HPP to Dehong), and 500 kV transmission lines (Dapein-1 HPP to Yunnan Province near Dehong).

Figure 18 An Overview of Myanmar's Transmission Systems[11]



[11] ADB (2015). Power Sector Development in Myanmar, Asian Development Bank. ADB Working Paper Series No. 460.

3.4.3 Myanmar: Power Development Plan

Myanmar's power system is currently dominated by hydro and gas-fired generation. Within the GMS, Myanmar has the highest proportion of its population without access to electricity and increased economic activity over the last 5 years is straining existing infrastructure, highlighting the need for greater investment. In 2014, a World Bank study proposed a target to achieve 100% central grid electrification by 2030. The main energy policy goals for Myanmar are to increase electricity access, promote wider adoption of renewable energy and energy efficiency.

Ministry of Electricity and Energy (MOEE)[12], who is responsible for planning, developed a 15-year power development plan[13] where demand was forecast to increase at double-digit rates to 2030 and generation expanded to achieve a technology mix of around 81% hydro, 9% coal, and the rest natural gas and renewables (wind, solar and geothermal). However, since this plan was developed in 2014, there have been ongoing debates around what constitutes the most appropriate generation expansion plan to satisfy high demand growth, particularly given constraints on the amount of natural gas that is available for domestic markets[14], ensuring sustainable hydro development and opposition to coal. However, it is understood that this stance on coal generation has changed and coal is expected to play a greater role in meeting Myanmar's long-term demand requirements. Nonetheless, power sector planning in Myanmar continues to evolve, particularly in light of enhanced understanding of the country's renewable energy potential.

3.4.4 Myanmar: Power Sector Current Challenges

With the rapid increase in electricity demand over the last 5 years and a lack of sufficient investment in generation capacity and transmission infrastructure, Myanmar is currently facing supply shortages in the immediate term. This is in addition to the extremely low electricity access, particularly in rural areas. Myanmar has abundant natural gas and hydro resources which are still largely undeveloped. However, there is significant lead-time in developments of new generation capacity, particularly hydro and natural gas reserves. The supply shortage situation has expedited gas developments in the near-term and highlights the need for Myanmar to explore power import options to help to meet demand growth in the immediate term. Significant demand growth is expected to continue to 2030 therefore long term development plans are essential in order to satisfy the demand in an affordable and reliable manner.

In the longer term, the large hydro potential represents opportunities to export power to the neighbouring countries, particularly Thailand and PRC. The prospect of turning resources into revenue appears to be the main driving motivation for power export in the long term.

3.5 Thailand

3.5.1 Thailand: Power Sector Snapshot

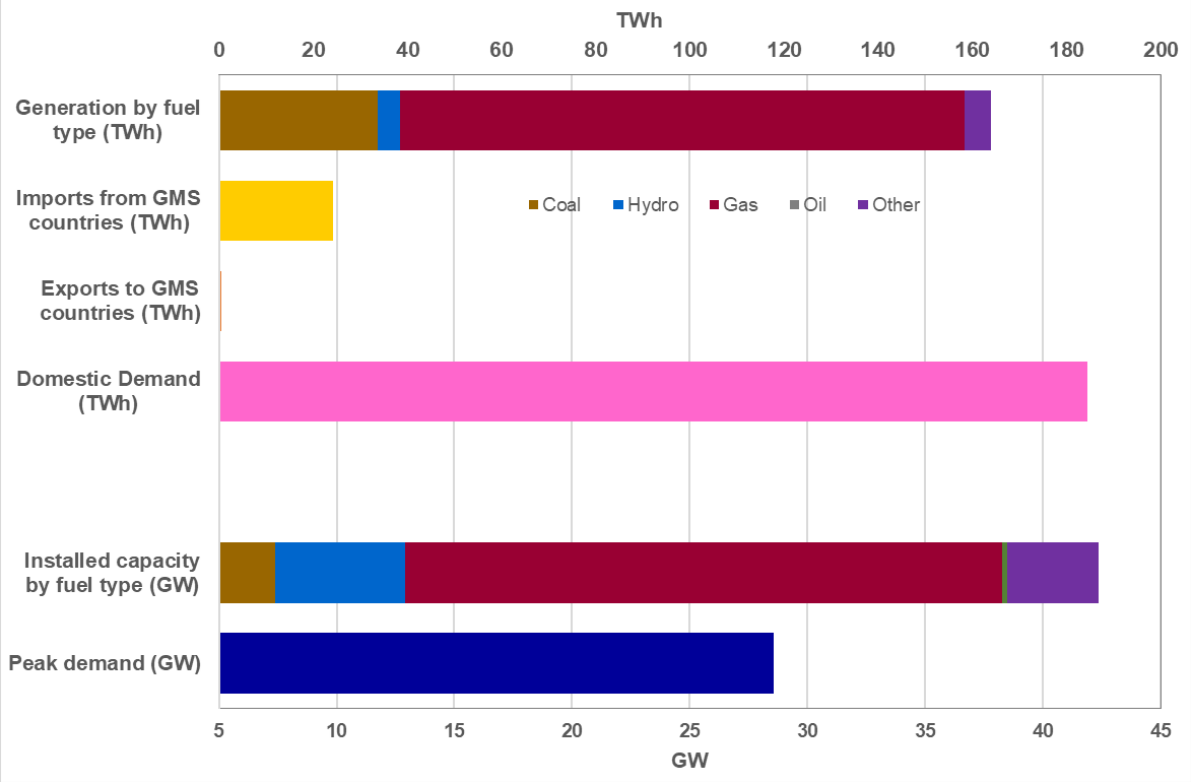
Figure 19 shows a snapshot of the current state of the power system in Thailand. At the end of 2017, the total installed capacity was over 42 GW including generation from EGAT power plants, IPPs, SPPs and power imports from neighbouring Lao PDR and Malaysia. Thailand has a moderate demand growth rate, with electricity consumption with the average annual growth rate of around 4% over the last ten years. Peak demand in 2017 was 28.5 GW, with the average annual growth rate of around 5%.

The major fuel types used for electricity generation in Thailand are natural gas, which accounts for approximately 70% of the fuel mix, followed by coal at 20%. The share of hydro generation is relatively small accounting for only 3% of total generation. The amount of power import from Lao PDR has significant increased over the past five years and it is estimated to keep increasing with

[12] Formerly, Ministry of Electric Power (MOEP).
[13] http://www.ifc.org/wps/wcm/connect/46f9da00471bab5caff4ef57143498e5/1.4.Min+Khang.pdf?MOD=AJPERES.
[14] While Myanmar has significant proven reserves of natural gas the majority is for export to neighbouring countries under long term gas supply agreements, which entitle Myanmar to a fraction of the gas for domestic use.

a number of committed power projects in Lao PDR are expected to commission over the next decade. Dedicated power import capacity from Lao PDR accounted for 8% of total installed capacity, which significantly increased with the commissioning of the coal-fired Hong Sa power station. Thailand also exports a relatively small amount to Lao PDR and Cambodia (as well as Malaysia).

Figure 19 Thailand Power Sector Snapshot (2017)



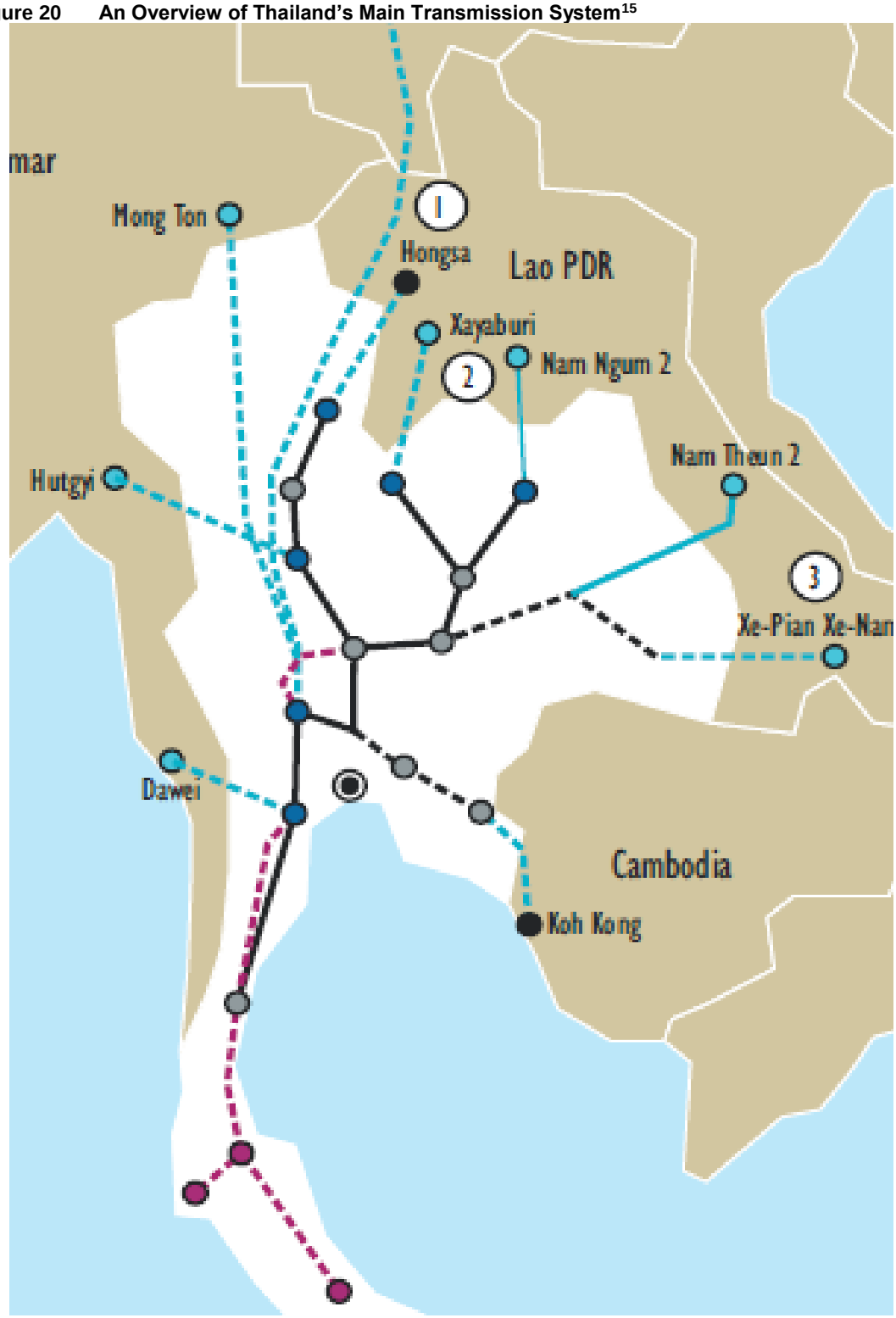
Source: EGAT Annual Report 2017 and consultant estimates.

3.5.2 Thailand: Transmission Network

An overview of Thailand's existing transmission backbone including cross-border interconnectors is shown in the Figure 20 (the dotted lines represent planned and committed projects). The main transmission networks comprise 500 kV and 230 kV transmission lines. The main 500 kV transmission lines carry bulk electricity from generation sources located in the North, East and West to the major demand centres in the Bangkok metropolitan and central areas. The 230 kV lines are distributed throughout the country.

Thailand imports electricity from Lao PDR via 230 kV and 500 kV transmission lines of capacity up to 1,800 MW through the Northeast region of the country. Thailand also exchange power with Lao PDR via grid to grid connections at 115 kV and 22 kV voltage levels. Thailand exchanges power in the south with Malaysia via a HVDC transmission system with capacity of 300 MW. Since 2010, Thailand has been exporting power to Cambodia via a 115 kV distribution line in the east.

Figure 20 An Overview of Thailand's Main Transmission System[15]



According to the latest Power Development Plan (PDP) released in 2015, there are a number of transmission expansion projects which have been committed and planned during 2016-2036. These projects include cross-border interconnections in the north, northeast and south of Thailand in order to facilitate power integration in GMS and ASEAN and power purchase from neighbouring countries including Lao PDR, Myanmar and Cambodia. A number of hydro and thermal plant projects in Lao PDR have been committed which will be dedicated for exporting power to Thailand. In order to accommodate cross-border power exchanges, major transmission

[15] IEA (2016). Thailand Electtricity Security Assessment 2016. Partner Country Series, International Energy Agency.

upgrades in the north and northeast of Thailand have been planned or currently underway to increase the capability of the transmission system from those regions to central area. The most notable transmission upgrade projects include the construction of new 500 kV transmission lines (Nam Phong 2 – Chaiyaphum 2 - Tha Tako) and the upgrade of the existing 230 kV to become 500 kV lines (Ban Na Bong – Udon Thani 3 – Chaiyaphum 2 – Tha Tako).

Although the MOUs regarding cross-border power exchanges with China and Myanmar have not been implemented, the PDP suggests that there are plans to import electricity from Myanmar and China's Yunnan province.

3.5.3 Thailand: Power Development Plan

Thailand's power development plan of 2015 (PDP2015) was proposed to the National Energy Policy Council (NEPC) on 14 May and subsequently approved on 15 May 2015. It is based on the following three principles: (1) energy security to support economic and social developments and to diversify the fuel mix to not be too reliant on natural gas, (2) ensure that electricity prices are cost-reflective in order to ensure efficient investment and consumption patterns, and (3) reduce negative impacts on the environment and aim to reduce carbon emissions by promoting renewable energy and energy efficiency.

The latest PDP suggests some 57.4 GW of new capacity by 2036 and is characterised by a capacity mix based on 30% to 40% natural gas, renewable energy in the range 15% to 20%, coal around 20% to 25% with an unspecified portion based on carbon capture and sequestration technology, hydro 15% to 20%, and up to 5% in nuclear technologies. Complementing the PDP2015 are two other plans: (1) the Alternative Energy Development Plan 2015 (AEDP2015) which targets a total of 19,635 MW of renewables (based on waste, biomass, biogas, hydro, wind, solar and energy crops) by 2036; and (2) the Energy Efficiency Development Plan (EEP) which targets to reduce energy intensity by 25% in 2030 compared to 2005 levels, or equivalently, a 20% reduction against a business as usual (BAU) demand outlook.

3.5.4 Thailand: Power Sector Current Challenges

One of the main challenges in Thailand's power sector is the heavy reliance on natural gas for electricity generation. This has raised concerns over the security of electricity supply in both short-term and long-term. This has been evidenced during a number of events involving natural gas supply interruptions. With these concerns and given the limited large-scale hydro development within the country, alternative generation technologies including renewable technologies and power imports from neighbouring countries have been considered as the cost-effective and low-carbon options for diversifying fuel sources.

Despite the slowdown in the economic growth and increased reserve margins resulting in over-supply, Thailand appears to remain committed to large-scale hydropower imports. In fact, the growing amount of reserve margin has provided another motivation for cross-border power exports to Myanmar and Cambodia over the short to medium term.

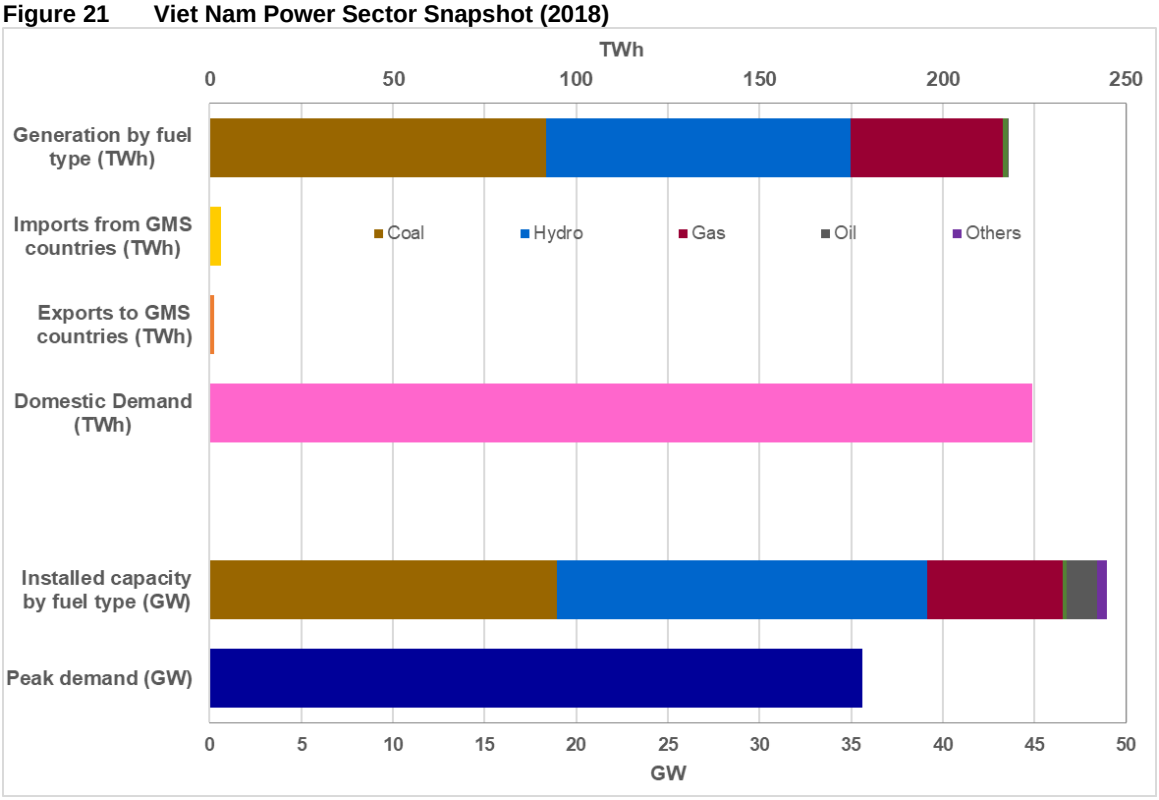
3.6 Viet Nam

3.6.1 Viet Nam: Power Sector Snapshot

Figure 21 shows a snapshot of the power sector in Viet Nam. The total installed generation capacity in Viet Nam at the end of 2018 was approximately 49 GW. Viet Nam is also dependent on a small amount of power import from China and dedicated hydro projects in Lao PDR. The majority of generation capacity are hydro and coal, which accounted for around 41% and 39% of the total installed capacity respectively, followed by gas around 15% and very small amount of oil and renewables. The share of fuel in electricity generation is also dominated by hydro, coal and gas. Viet Nam has experienced high electricity demand growth over the past decade, with an average annual growth rates of around 10% across total energy and peak demand measures.

In the north, electricity generation is dominated by hydro power plants and coal plants which are being supplied by domestic sources. The central region of Viet Nam is almost entirely dominated by hydro generation. The southern region is dominated by hydro and gas-fired generation which is supplied for a number of offshore natural gas fields.

Figure 21 Viet Nam Power Sector Snapshot (2018)



Source: Vietnam RPTCC25 Presentation and consultant estimates

3.6.2 Viet Nam: Transmission Network

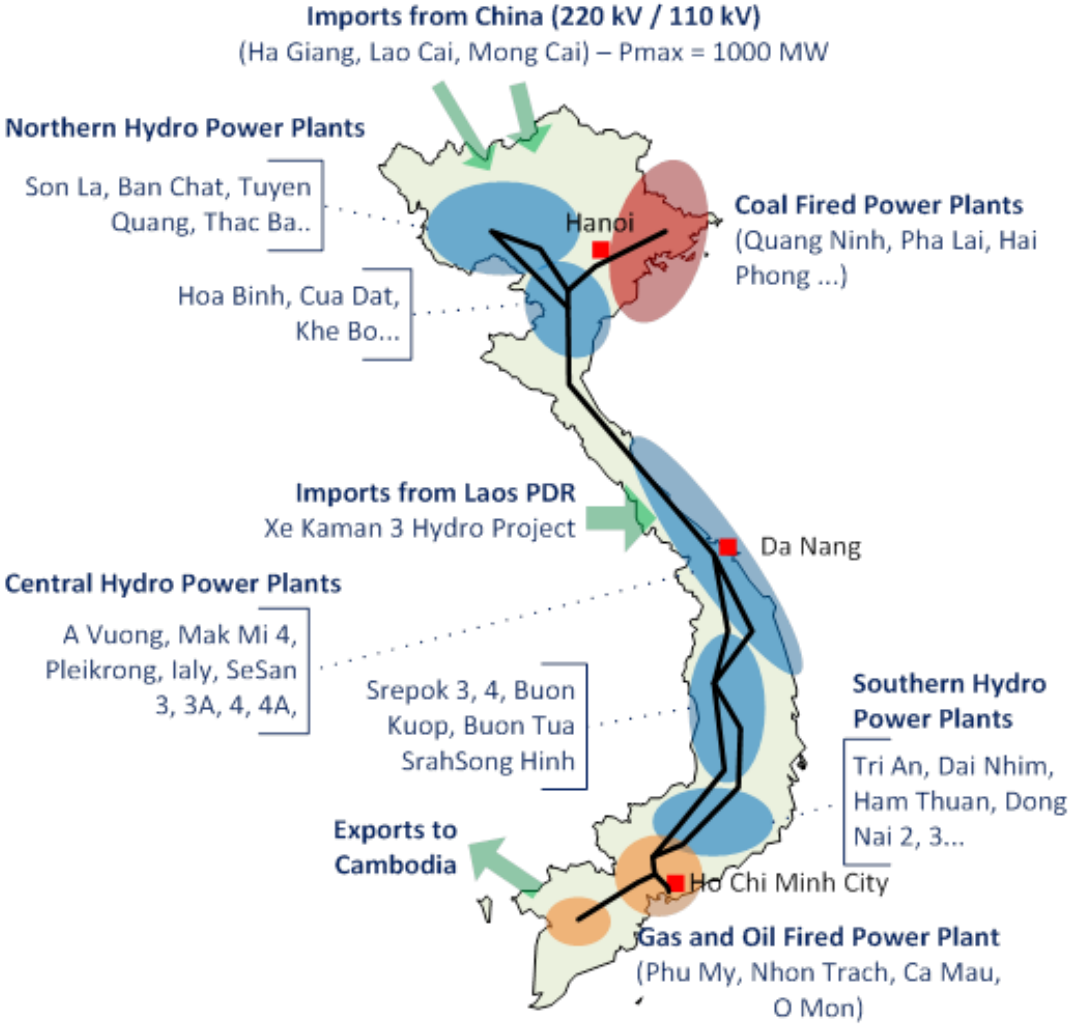
Figure 22 provides an overview of the main transmission system topology in Viet Nam. It also highlights the main generation resources and their locations. The transmission networks in Viet Nam are interconnected, stretching from north to south. Viet Nam imports power from PRC to supply a number of small load centres in the north and from several dedicated hydro projects from Lao PDR into the central region. Viet Nam also exports power to Cambodia in the south.

Power imports from PRC commenced in 2004 via two 110 KV lines and later two 220 kV lines. The combined maximum capacity of these interconnections is 1,000 MW. The annual imported amount is around 3.1 TWh on average but has been generally declining from 5.6 TWh in 2010 to around 1.8 TWh in 2015. Note that the Chinese grid and Vietnamese grids are not electrically connected; loads in the north are switched from being connected to the Vietnamese national system to the Chinese grid. At present the following transmission lines import power from PRC to Viet Nam:

- 220 kV transmission line from Maguan (PRC) to Ha Giang;
- 220 kV transmission line from Xinqiao (PRC) to Lao Cai; and
- Three 110 kV lines

Power import from Lao PDR is via the Xe Kaman 3 Hydropower project in Lao PDR, which is dedicated to exporting power to Viet Nam's transmission system. The 250 MW project was mostly financed by the Government of Viet Nam. The project started commercial operation in 2013. Power export from Viet Nam to Cambodia is via a 220 kV Chau Do – Takeo transmission line. Details of cross-border electricity trade are provided in Section 4.*

Figure 22 An Overview of Viet Nam's Main Transmission System[16]



3.6.3 Viet Nam: Power Development Plan

Viet Nam's electricity consumption has had annual growth rates in the range of 10% to 15% over the last decade. This has placed pressure on the government to ensure adequate levels of generation and network investment. EVN and other state-owned corporations involved in electricity generation have not been financially capable to build all the required additional capacity, and this has created a heavy focus to date on least (direct) cost planning coupled with a desire of the government to encourage investment participation from the private sector in ensuring energy security. Planning has revolved mainly around domestic coal, imported coal and development of offshore gas reserves in the short term while in the longer-term renewables may also play a part in delivering energy diversity. Nuclear technology has been ruled out as a credible option. Plans for RE have generally been at a modest level within the 2011 Power Development Plant 7 (PDP7), having targeted only a 6% share for RE generation by 2030. More recently the government has made announced intentions to raise the RE share in the system generation mix to 15% by 2030, however, no additional details have been announced and the renewable energy policy is still considered to be evolving.

3.6.4 Viet Nam: Power Sector Current Challenges

In order to accommodate the rapid increase in electricity demand, Viet Nam's power sector is undergoing rapid developments to increase its generation capacity and expand the transmission network. A number of large coal-fired generating plants have recently been commissioned or

[16] Source: Consultant

have been planned and is expected to become one of the major generation resource along with hydropower and natural gas in meeting demand growth. The increased dependence on coal, which is mostly imported, can have long-term implications for security of the electricity supply. Gas-fired generation will also play an important role in Viet Nam's generation mix given the country's abundant natural gas reserves, which is the largest among the GMS countries. However, further developments of the offshore natural gas reserve will take time to accomplish. Investment in coal-fired capacity over the past few years has helped curb potential supply issues in the south and combined with additional committed coal capacity is expected outpace the slowing demand growth compared to what was forecast in the RPDP7.

Electricity imports, particularly from hydro projects in Lao PDR, have been viewed as one of the options in meeting the demand growth and also addressing concerns over power supply shortage in the short term, as well as providing low-cost electricity in the long term. Vietnam has indicated a preference to wind-down its reliance on power imports from PRC and increase focus on renewable generation technologies.

3.7 Summary

The status of the power sector including current demand, installed capacity and fuel mix in electricity generation in the GMS countries is summarised in Table 6, Table 7 and Table 8. Note that the installed capacity and generation in Lao PDR and Myanmar shown in Table 7 and Table 8 also reflect the amount from export power projects.

In general, most of the GMS countries (except Thailand) have been experiencing very high electricity demand growth in both annual consumption and peak demand, which have been greater than 10% per year over the last five years. The increase in peak demand requires each of the GMS country to rapidly expand its generation capacity as well as transmission infrastructure in order to cope with the demand growth.

Coal, gas and hydropower dominate the share of electricity generation in the GMS. The CSG and Viet Nam appear to have reasonable balance in their fuel mixes while Thailand relies heavily on natural gas. Cambodia, Lao PDR and Myanmar also rely significantly on hydropower.

Table 6 GMS Country Electricity Demand and Growth Rates (2015)

Country	Electricity Consumption		Peak Demand	
	TWh	CAGR[17], %	GW	CAGR[18], %
PRC (CSG)*	887	5.5%	143	5.5%
Cambodia	4.2	19.4%	0.93	16.0%
Lao PDR	3.4	14.5%	1.01	12.5%
Myanmar	9.6	15.7%	2.3	16.2%
Thailand	174.8	4.4%	27.3	2.9%
Viet Nam	162	12.7%	25.8	10.2%

*Source: Compiled by Consultant from various sources. *For PRC, 2015 figures were estimated from 2014 data based on a 5.5% CAGR from 2014 to 2018 (RPTCC25 Presentation).*

[17] The Compound Annual Growth Rate (CAGR) is for the last ten years for Cambodia, Lao PDR, and Viet Nam, last five years for Myanmar and twelve years for Thailand.
[18] Last five years for Cambodia, Myanmar, and Thailand, ten years for Lao PDR and Viet Nam.

Table 7 Installed Capacity (MW) by Fuel Type (2017)

Generation Type	PRC (CSG)*	Cambodia	Lao PDR	Myanmar	Thailand	Viet Nam
Coal	123,000	538	1878	30	7,378	16,191
Gas		0	0	1,918	25,385	7,087
Hydro	97,000	929.73	4540	3,315	5,521	18,828
Fuel Oil/Diesel	0	240.528	0	100	33	1,661
Nuclear	6,100	0	0	0	0	0
Others (renewables & import	5,900	10	35	0	4,064	363
Total (MW)	232,000	1,718	6,453	5,364	42,381	44,129

*Source: Estimated by Consultant from various sources. *For PRC, these are the estimates based on the available data in 2014.*

Table 8 Generation (TWh) by Fuel Type (2017)

Generation Type	PRC (CSG)*	Cambodia	Lao PDR	Myanmar	Thailand	Viet Nam
Coal	572	3.4	12.6	0.1	33.7	94.5
Gas		0.0	0.0	10.0	120.0	46.1
Hydro	219	2.9	21.2	9.7	4.7	53.9
Fuel Oil/Diesel	-	0.2	0.0	0.0	0.0	0.0
Nuclear	42	0.0	0.0	0.0	0.0	0.0
Others (renewables & import	8	0.8	1.0	0.1	29.8	2.8
Total (TWh)	**841**	7.3	34.7	19.9	188.2	197.4

*Source: Estimated by Consultant from various sources. *For PRC, these are the estimates based on the available data in 2014.*

Table 9 show the amount of power trade within the GMS for 2017 (2014 data for the CSG). Note that PRC exports to Lao PDR and Viet Nam while imports from power projects in Myanmar, Viet Nam exports to Lao PDR and Cambodia while imports from PRC and power projects in Lao PDR and Thailand imports from power projects in Lao PDR while also exports to Lao PDR and Cambodia.

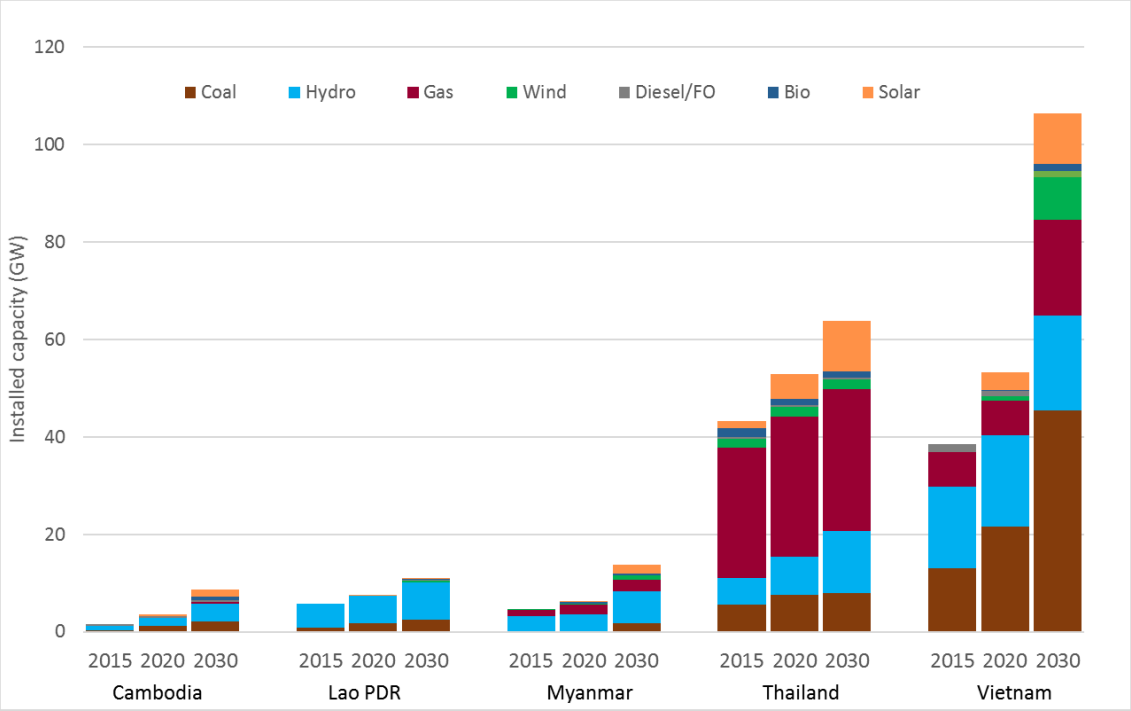
Table 9 Power Imports and Exports among the GMS Countries (2017)

Country	Imports (TWh)	Exports (TWh)
PRC (CSG)*	1.72	5.96
Cambodia	0.8	0
Lao PDR	0.8	28
Myanmar	0	1.7
Thailand	24.3	0.6
Viet Nam	2.0	1.2

*Source: Estimated by Consultant from various sources. *For PRC, these are the estimates based on the available data in 2014, hence the sum of exports and imports are not equal.*

Figure 23 shows a comparison of the projected installed capacity between the GMS countries for 2020 and 2030 based on the current PDPs. Coal and hydro will be the main generation sources while natural gas will also contribute in meeting the demand growth. Between 2020 and 2030, major developments will be in Viet Nam where the installed generation capacity is expected to double within the ten-year periods. The share of renewables, particularly solar, is expected to increase considerably in all of the GMS countries. Table 10 provides a summary of the power sector, transmission networks, current power development plan and key challenges facing the power sector in the GMS countries.

Figure 23 Projected Installed Capacity by Country in the GMS[19]



[19] Estimated by Consultant based on current PDPs. CSG has not been included due to limited available data.

Table 10 Summary of Transmission Network, Power Sector Status and Power Development Plans

Country / Region	Power Sector Snapshot	Key Features of Transmission Network and Interconnectivity with neighbouring GMS countries	Main Features of Current Power Development Plans	Key Challenges
PRC(CSG)	**Demand:** 841 TWh **Peak Demand:** 136 GW **Installed cap.:** 232 GW **Capacity Mix:** • 53% coal & gas • 40% hydro	• 500 kV AC and DC transmission backbone • Grid to grid connections for exporting to Viet Nam (switching loads) • Import power from dedicated hydro power plants in Myanmar	• Reduce carbon intensity • Reduce the share of coal • Promote developments in low-carbon technologies including hydropower, nuclear and renewables • Expanding electricity trade with ASEAN countries	• Mobilising generation sources in the west to load centres in the east • Slowdown of economic and therefore electricity demand growth • A growing surplus of generation
Cambodia	**Demand:** 6.1 TWh **Peak Demand:** 1.1 GW **Installed cap.:** 1.7 GW **Capacity Mix:** • 31% coal • 53% hydro • 13% diesel/fuel oil	• 115/220 kV transmission lines interconnect different grids of the national system • Grid to grid connections with Viet Nam, Thailand and Lao PDR via 220/230 kV, 115 kV and 22 kV connections	• Develop new generation capacity from coal and hydro in the near term and gas (offshore or LNG) in the longer term • Increase grid electricity access to 70% by 2030 • Reduce electricity prices • Investments and enhancements of the transmission system to develop a stronger gird	• Low electrification rate • High electricity prices • Reducing reliance on power imports in the short term
Lao PDR	**Demand:** 6.7 TWh **Peak Demand:** 0.8 GW **Installed cap.:** 6.5 GW **Capacity Mix:** • 30% coal • 70% hydro	• Four connected regions: north, central 1 & 2 and south. • 115 kV transmission lines connecting between hydropower plants and loads • Most cross-border electricity trade is in the form of dedicated hydro and lignite power projects which export to Thailand and Viet Nam • A number of grid to grid connections at low and medium voltage levels for importing from Thailand and PRC as well as exporting to Cambodia	• Expand generation capacity in order to deliver reliable and sustainable electricity supplies at affordable prices • Increase electrification to 90% by 2020 • Promote power exports to earn more revenues which will be used to reduce poverty • Promote deployment of small hydro, solar, wind and biofuels • Improve transmission lines in the northern, central and southern areas and links with Thailand and Vietnam	• High dependence on hydropower • Unable to exploit the benefits from geographical diversification of hydro generation in the north and south given the absence of north-south transmission interconnections
Myanmar	**Demand:** 19.9 TWh **Peak Demand:** 3.5 GW **Installed cap.:** 5.4 GW **Capacity Mix:** • 61% hydro	• 132 kV and 230 kV transmission backbone connecting between two major load centres in the central north and south	• A target to achieve 100% central grid electrification by 2030	• Low electrification rate • High demand growth is expected to continue to 2030 • Unreliable supply resulting in power supply shortages

Country / Region	Power Sector Snapshot	Key Features of Transmission Network and Interconnectivity with neighbouring GMS countries	Main Features of Current Power Development Plans	Key Challenges
	• 35% gas	• HVAC and HVDC cross-border transmission lines for exporting electricity from dedicated hydro power projects to Yunnan in PRC	• MOEP's plan suggests long-term capacity mix dominated by hydro, followed by coal, gas and renewables although this is understood to be under revision • Power development plans continue to evolve with the optimal generation mix being strongly debated. • Immediate term risk of supply shortages with gas availability being limited and minimal new generation investment in the near term.	• Long lead time to exploit hydro and gas resources • Immediate term tightness in supply and demand
Thailand	**Demand:** 184 TWh **Peak Demand:** 28.6 GW **Installed cap.:** 42 GW **Capacity Mix:** • 18% coal • 60% gas • 13% hydro	• 230 kV and 500 kV transmission backbone for transferring power from generation sources in the north, west and northeast to load centre in the central area • HVAC cross-border transmission lines for importing power from dedicated power projects in Lao PDR • 115 kV and 22 kV grid to grid connections for exchanging power with Lao PDR and exporting to Cambodia	• Enhance security of supply by diversifying the fuel mix and reducing the share of gas-fired electricity generation • Promote renewable energy and energy efficiency in order to reduce carbon intensity • Latest PDP (2015) suggests long-term capacity mix consisting of 30-40% gas, 20% renewables, 20-25% coal, 15-20% hydro	• High dependence on natural gas for electricity generation, and also high associated fuel costs compared to rest of GMS • High reserve margin over the next 15 years due to lower than expected demand growth and excessive investment in generation capacity
Viet Nam	**Demand:** 197 TWh **Peak Demand:** 30.9 GW **Installed cap.:** 44.1 GW **Fuel Mix:** • 37% coal • 43% hydro • 16% gas	• High voltage transmission backbone connecting between north, central and south of Viet Nam • Cross-border power trade exists with PRC, Lao PDR and Cambodia • 220 kV grid to grid connections for importing power from PRC and exporting power to Cambodia • HVAC cross-border transmission lines for Importing power from dedicated hydro projects in Lao PDR	• Reforming the power sector to create competition and support private participation • Latest PDP (2016) suggests long-term capacity mix consisting of 43% coal, 17% hydropower, 15% gas, 21% renewables and with rest from nuclear and imports • Revised stance on nuclear now not an option in long-term planning • Developments in the energy sector revolve around domestic and imported coal and off-share gas reserves	• High electricity demand growth • Increasing reliance on imported coal • Long lead times in developing off-shore gas reserves • Formulating a mechanism to implement high RE generation share into the system

4 Current State of Cross-Border Power Trading in the GMS

This section discusses the current state of cross-border power trade in the GMS for the two forms that are common: power transfers associated with power projects located in one country but dedicated to supplying most of the output to a neighbouring country, and transmission projects that are of a "grid-to-grid" nature allowing power exchange from one national transmission network to that of a neighbouring country.

4.1 Types of GMS Power Trade at Present

Existing cross-border interconnections in the GMS can be broadly categorised into two groups:

- Interconnectors that are largely dedicated to transporting power from specific power projects located in one country to another country. Such interconnectors are at high voltage levels (220/230 kV and 500 kV) and represent the majority of the cross-border interconnections in the GMS at this time and generally are between Lao PDR and Thailand, Lao PDR and Viet Nam and Myanmar and PRC.
- Cross-border interconnections for power exchanges which typically at medium and low voltage levels (110/115 kV and 22 kV). These exchanges occur between PRC and Viet Nam, Viet Nam and Cambodia, Thailand and Cambodia, Thailand and Lao PDR, Lao PDR and Viet Nam and PRC and Lao PDR.

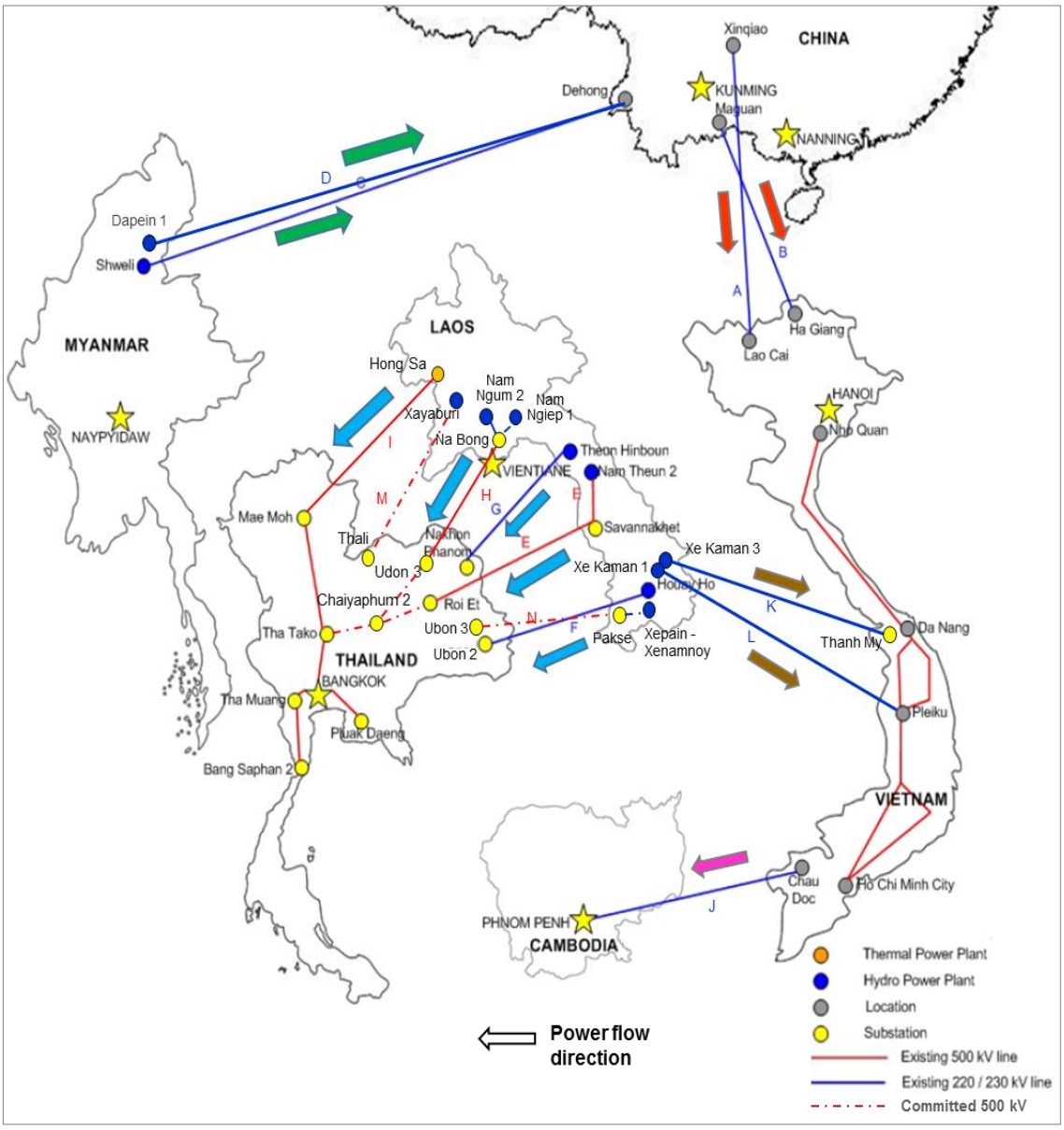
The high voltage interconnections take place in such a way that they connect power stations in exporting countries to the importing grid by extending the grid of importing countries on a foreign territory. Therefore, the importing system retains isolation from the exporting power system. At present, 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. This obstacle could be removed if legislative reforms were introduced, primarily in Lao PDR, to grant third party access.

On the other hand, the cross-border interconnections for power exchanges in the GMS exist at medium and low voltage levels where the importing grid is either synchronised with the exporting grid or switching operations are preformed to effectively connect load to a foreign grid. Interconnections exist between PRC and Viet Nam, Cambodia and Viet Nam, Cambodia and Thailand, and Thailand and Lao PDR, PRC and Viet Nam is an example of where the grids are not synchronised, while Cambodia and Viet Nam is an example of synchronised operations.

4.2 High Voltage Interconnections: Existing and Committed

The existing high voltage cross-border interconnections with voltage levels greater than 115 kV are shown in Table 11 while the committed and planned projects are shown in Table 12. These interconnections are depicted in Figure 24. A summary of the existing high voltage interconnections between countries including commercial arrangement and known operational issues is also provided in Sections 4.2.1 to 4.2.5.

Figure 24 Existing and Committed High Voltage Cross-Border Interconnectors and Flow Direction[20]



[20] Source: Diagram was based on ADB RETA 6440, with a number of modifications made by the Consultant to illustrate the present state of cross-border power transfers.

Table 11 Existing High Voltage Cross-Border Interconnectors

Project No.	Country (From)	Country (to)	Connection Points	Type	Length (km)	Capacity (MW)	Commercial Arrangement
1	PRC (Yunnan)	Viet Nam	Xinqiao - Lao Cai	220 kV	56	300	Grid to grid connections with PPA between EVN and CSG
2	PRC (Yunnan)	Viet Nam	Maguan - Ha Giang	220 kV	51	200	
3	Myanmar	PRC (Yunnan)	Shweli 1 HPP – Dehong	220 kV DC	120	600	Dedicated hydro project with PPA between MOEP and the private producer
4	Myanmar	PRC (Yunnan)	Dapein 1 HPP - Dehong	500 KV	120	240	Dedicated hydro project (90% to PRC) with PPA between MOEP and the private producer
5	Lao PDR	Thailand	Nam Theun 2 HPP - Roi Et 2	500 kV	304	950	Dedicated hydro project with PPAs between EGAT (and EDL) and the private producer
6	Lao PDR	Thailand	Houay Ho HPP – Ubon 2	230 kV	230	126	Dedicated hydro project with PPA between EGAT and the private producer
7	Lao PDR	Thailand	Theun Hinboun HPP - Thakhek – Nakhon 2	230 kV	176	434	Dedicated hydro project with PPA between EGAT and the private producer
8	Lao PDR	Thailand	Nam Ngum 2 - Na Bong – Udon 3	230 kV (500 kV)	187	600 (1,050)	Dedicated hydro projects with PPA. The line will be upgraded to 500 kV in 2017
9	Lao PDR	Thailand	Hongsa TPP - Nan - Mae Moh 3	500 kV	325	1,878	Dedicated coal plant with PPA between EGAT and the private producer
10	Viet Nam	Cambodia	Chau Doc - Takeo - Phnom Penh	220/ 230 kV	111	200	Grid to grid connection
11	Lao PDR	Vietnam	Xekaman 3 HPP – Thanh My	220 kV	115	250	Dedicated hydro project with PPA between EVN and the private producer
12	Lao PDR	Viet Nam	Xekaman 1 HPP (Hatxan) – Pleiku	220 kV	120	300	Dedicated hydro project with PPA between EVN and the private producer

Table 12 Committed and Planned High Voltage Cross-border Interconnectors[21]

Project No.	*Country (From)*	*Country (to)*	*Connection Points*	*Status*	*Type*	*Length (km)*	*Capacity (MW)*	*Remarks*
13	Lao PDR	Thailand	Xayaburi HPP – Thali – Kon Kaen 4	Committed Project	500 kV Double	*390*	1,220	Dedicated hydro project with PPAs between EGAT (EDL) and the private producer. Committed project that is expected to be completed in 2019.
14	Lao PDR	Thailand	Pakse – Ubon3	Committed Project	500 kV Double	90	400	For Xepian-Xenamnoy HPP (360 MW) and to be completed in 2019. This line can potentially increase to 1200 MW once the grid in the northeast of Thailand has been reinforced.
15	*Lao PDR*	*Viet Nam*	*Xekaman 4 HPP – Ban Soc - Pleiku*	*Planned Project*	*500 kV*	*120*	*80*	For Xekaman 4 HPP in Southern Lao PDR with 75 MW capacity. Connecting with a proposed 500 kV Ban Soc – Pleiku (to be examined in the next Section).
16	*Lao PDR*	*Viet Nam*	*Nam Mo HPP – Ban Ve*	*Planned Project*	*220 kV Double*	*200*	*120*	*For a Nam Mo HPP in Northern Lao PDR which is planned to come in after 2020.*

[21] Committed projects refer to projects which are already under construction (irreversible) and to be completed before 2020. Planned projects are those that have been included in PDPs and are expected to come in after 2020.

4.2.1 PRC and Northern Viet Nam

There are currently two high voltage transmission lines connecting between Yunnan Province in PRC and Viet Nam:

- 220 kV AC Xinqiao (PRC) – Lao Cai (Viet Nam); and
- 220 kV AC Maguan (PRC) – Ha Giang (Viet Nam).

These are grid-to-grid connections for importing power from CSG grid to Viet Nam however the two grids are not synchronised to each other. The transfer occurs by switching loads (of certain transformers) from the Vietnamese grid to connect with the CSG grid.

In terms of commercial arrangement, CSG and EVN entered into a PPA based on agreed prices for the power exchanges. The cost of electricity imported from China is generally lower than that of generation by replacing imported coal thermal power plants in Viet Nam.

Since the two grids are not connected, there are no issues from the operational aspect. However, the switching operations for transferring the load have to be carried out manually, at least in part.

4.2.2 Myanmar and PRC

The existing interconnections between Myanmar and PRC are for exporting power from dedicated hydro power projects in Myanmar to Yunnan province in PRC. These transmission lines are:

- 220 kV HVDC Shweli 1 HPP (Myanmar) – Dehong (PRC); and
- 500 kV AC Dapein HPP (Myanmar) – Dehong (PRC).

Shweli 1 hydro power plant has the capacity of 600 MW, consisting of 6 units. The project was completed in 2009. Half of the power generated from Shweli 1 HPP is exported to PRC while the rest is supplied to Myanmar's grid at no cost. The line connection Shweli HPP and CSG is 220 kV HVDC. The purchase of electricity by PRC is carry out under a PPA between Yunnan United Power Development Company Limited and Electric Power Generation Enterprise (EPGE), which is under the Ministry of Electric Power (MOEP) of Myanmar. The transaction price for electricity purchased by Myanmar Power Grid from Shweli 1 is maintained at the same transaction price for electricity purchased by Yunnan Power Grid.

Dapein hydro power plant has the total capacity of 240 MW, consisting of 4 units with 60 MW of capacity each. The power plant began the operation in 2011 where 90% of output is exported to PRC while the rest is supplied to Myanmar's grid. There is a PPA between China Datang Group and EPGE. The 500 kV transmission line connecting Depein to PRC is generally lightly loaded compared to its actual load carrying capability therefore there are issues with high voltage in the area.

During dry seasons, the capacity of both Shweli and Dapein generally falls by around 4% on average.[22]

4.2.3 Lao PDR and Thailand

There are several high voltage connections between Lao PDR and Thailand, all of which are for dedicated power projects.

4.2.3.1 500 kV Nam Theun 2 HPP (Lao PDR) - Roi Et 2 (Thailand)

In terms of capacity, this is the largest cross-border interconnection in the GMS. The link consists of double circuit 500 kV transmission lines dedicated for Nam Theun 2 hydro power plant in Central Lao PDR. The power plant consists of six generating units with a total generating capacity of 1,075 MW (4 units at 250 MW and 2 units at 37.5 MW). Nam Theun 2 HPP is contracted to supply 995 MW to EGAT's grid in Thailand via the cross-border transmission lines and 75 MW to EDL's grid under 25-year take-or-pay PPAs between Nam Theun 2 Power

[22] ADB (2015). Power Sector Development in Myanmar, Asian Development Bank. **ADB Working Paper Series No. 460**.

Company Limited and EGAT (and EDL). The average annual capacity factor of the plant is around 60%.

Given the large amount of power flow into Thailand via the northeast corridor, it required significant reinforcement and expansion of the transmission networks in Thailand to accommodate increased power flow for the northeast to the load centre in central region.

4.2.3.2 230 kV Theun Hinboun HPP – Thakhek (Lao PDR) – Nakhon 2 (Thailand)

This four circuit 230 kV transmission link is for a dedicated hydro power plant, Thuen Hinboun, in Lao PDR. The plant has the total capacity of 430 MW and it consists of three generating units (2 units x 108 MW, 1 unit x 214 MW). The first phase of the hydro project started to export power in 1998 while the expansion phase was completed in 2013.

All of the generation output is supplied to EGAT under a 25-year PPA with a take-or-pay obligation for 95% of available output. Delivered energy is paid based on the agreed tariff (50% in USD and 50% in THB), with 1% annual escalation. There are also penalties applied for each kWh shortfall. The average annual capacity factor of this hydro plant is approximately 70%.

4.2.3.3 230 kV Huoay Ho HPP (Lao PDR) – Ubon 2 (Thailand)

This transmission link consists of double circuit 230 kV transmission lines, which are dedicated for Huoay Ho hydro power plant in Southern Lao PDR. The hydro power plant consists of two generating units with a combined capacity 150 MW, all of which is exported to EGAT's grid under a 30-year PPA between Houay Ho Power Company and EGAT which commenced in 1999.

Delivered energy is paid based on the agreed tariff, escalated annually. There are penalties applied for each kWh shortfall. The average annual capacity of Huoay Ho power plant is around 40%, which is relatively low compared to other hydro power plants in Lao PDR. Throughout the commercial period, there have been issues with low inflows which resulted in the plant failing to meet the generation target under the PPA.

4.2.3.4 230kV/500 kV Na Bong (Lao PDR) – Udon 3 (Thailand)

This cross-border connection links northern Lao PDR with the northeast of Thailand to facilitate a number of dedicated existing and committed hydro projects in Lao PDR for exporting to Thailand as well as supplying domestic demand. At present, the connection is via double circuit 230 kV transmission lines but the construction is underway to upgrade the lines to 500 kV, which is expected to be completed in 2017. The dedicated hydro projects that are (or will be) connected to these lines are Nam Ngum 2 (existing), Nam Ngiep 1 (2019) and other potential projects including Nam Ngum 3 and Nam Thuen 1. These hydro plants are connected to Na Bong substation in Lao PDR via 230 kV transmission lines. Na Bong is then connected to Udon 3 substation in Thailand via double circuit 500 kV cross-border transmission lines.

The combined hydro generation capacity to be connected to this line is around 900 MW, consisting of the following plants:

- Nam Ngum 2 with the total capacity of 615 MW (3 units x 205 MW); and
- Nam Ngiep 1with the total capacity of 261 MW (2 units x 130.5 MW).

Both of these hydro power projects have a long-term PPA with EGAT (25 years for Nam Ngum 2 and 27 years for Nam Ngiep 1) where delivered energy are paid based upon the rates for three different periods.

This cross-border interconnection can be viewed as a significant step in establishing regional interconnections since the lines are shared between multiple users rather than entirely dedicated to an individual power project.

Due to the large amount of power flow and the lack of reactive power sources, this part of Lao PDR and Thailand have issue with low voltage

4.2.3.5 500 kV Hongsa TPP (Lao PDR) - Nan (Thailand) - Mae Moh 3 (Thailand)

This cross-border interconnection consists of double circuit 500 kV transmission lines connecting between a lignite power plant, Hong Sa, in the north of Lao PDR and Northern Thailand. The

power plant consists of three generating units with a combined capacity of 1,878 MW. The three units were fully commissioned in 2016. Hong Sa Power Company Limited entered into a 25-year PPA with EGAT and EDL to supply 1,473 MW and 175 MW to EGAT and EDL respectively.

With the large amount of cross-border power flow into northern Thailand, it required reinforcement and expansion of the existing transmission networks in Thailand to accommodate increased power flows from northern to central Thailand and to maintain the N-1 security constraint.

4.2.3.6 Committed: 500 kV Xayaburi HPP (Lao PDR) – Thali – Kon Kaen 4 (Thailand)

This double-circuit 500 kV transmission line is currently under construction and it aims to accommodate the power transfer from the Xayaburi hydro power plant in northern Lao PDR to north eastern Thailand. The transmission line along with the power plant, which has the capacity of 1,220MW, will commence to supply power in the latter half on 2019. The transmission lines will connect the power plant to Tha Li substation and to Khon Kaen 4 substation in Thailand with a total distance of 390 km.

4.2.3.7 Committed: 500 kV Pakse (Lao PDR) – Ubon 3 (Thailand)

This double-circuit 500 kV transmission line is currently under construction and it will facilitate power purchase from Xepian-Xenamnoy hydro power plant in Southern Lao PDR. The 500 kV lines will be built between the Pakse substation in Lao PDR to Ubon 3 in Thailand with the total distance of 90 km. Xepian-Xenamnoy hydro plant consist of three generating units with a combined capacity of 390 MW. This transmission line will also accommodate future power purchase from other potential hydropower projects in Lao PDR.

4.2.4 Viet Nam and Cambodia

The existing high voltage interconnection between Viet Nam and Cambodia is the double circuit 220 kV Chau Doc – Takeo – Phnom Penh. This is a grid-to-grid connection to export power from Southern Viet Nam to Cambodia. This line was commissioned in 2009 with a transfer capacity of 200 MW. Commercial arrangement is through a bilateral contract between the two governments. The average amount of annual electricity trade is between 1.1 and 1.4 TWh. This cross-border trade has a number of benefits for Cambodia given the generation shortage and high electricity price in the country. Power import from Viet Nam was able to substitute, at least in part, substitute electricity generation from diesel and fuel oil

4.2.5 Lao PDR and Viet Nam

There are currently two high voltage cross-border connections between Lao PDR and Viet Nam, both of which are for a dedicated hydropower project in Lao PDR. The lines connecting hydro power plants in Southern Lao PDR to Central Viet Nam are:

- 230/220 kV Xekaman 3 HPP (Lao PDR) – Thanh My (Viet Nam); and
- 230/220 kV Xekaman 1 HPP (Lao PDR) – Pleiku 2 (Viet Nam).
- Xekaman 3 began its operation in 2010. The plant consists of two generating units with the total capacity of 250 MW. Power purchase is contracted under a 29-year PPA between Xekaman 3 Power Company Limited and EVN.
- Xekaman 1 hydro power plant commenced its operation in 2015. It consists of two generating units with the installed capacity of 322 MW.

4.2.5.1 Planned: 500 kV Xekaman 4 HPP (Lao PDR) – Ban Soc/Ban Hatxan (Lao PDR) – Pleiku (Viet Nam)

This planned transmission project is to support power flow from a proposed hydro power plant, Xekaman 4 (as well as other future hydro projects), in Southern Lao PDR to Central Vietnam. The line would connect the power plant to Ban Soc/Ban Hatxan in Lao PDR which is then connect to Pleiku in Vietnam via 500 kV double circuit transmission lines. Although the capacity of Xekaman 4 power plant is expected to be only around 80 MW, a number of other future hydro projects in the region are planned to connect via this transmission line. This project has been included in Vietnamese's PDP for under planned project post 2020.

The proposed 500 kV Ban Soc/Ban Hatxan – Pleiku would open up an opportunity to develop of a number of hydro power plants in Southern Lao PDR for exporting to Vie Nam. This connection has been viewed as an important step towards the integration of power markets in the GMS. This transmission option is to be assessed in the next Section.

4.2.5.2 Planned: 220 kV Nam Mo HPP (Lao PDR) – Ban Ve (Viet Nam)

This transmission line would facilitate power export from Nam Mo HPP in Lao PDR to northern Viet Nam. The line would be double circuit to accommodate around 120 MW of power flow initially. This project has been included in Vietnam's PDP to be built during 2021-2025 (not committed but highly likely)

4.3 Medium and Low Voltage Interconnections

In addition to the high voltage cross-border interconnections, there exist several connections at low and medium voltage (from 115 kV and below) as shown in Table 13.

Table 13 Existing Medium Voltage Cross-Border Interconnectors

Country (From)	Country (to)	Connection Points	Type	Length (km)	Capacity (MW)	Commercial arrangement
Lao PDR	Thailand	Takhek – Nakhon Phanom	115 kV Double	61	160	Governmental agreement
Lao PDR	Thailand	Nam Leuk HPP – Pakxan – Bueng Kan	115 kV Single	11	80	Governmental agreement
Lao PDR	Thailand	Phontong – Nong Khai 1	115 kV Double	51	160	Governmental agreement
Lao PDR	Thailand	Pakbo - Savannakhet – Mukdahan 2	115 kV Single	5	80	Governmental agreement
Lao PDR	Thailand	Xeset HPP – Sirindhorn HPP – Ubon 1	115 kV Single	61	80	Governmental agreement
PRC (Yunnan)	Lao PDR	Mengla – Na Mo	115 kV Single	60	35	Governmental agreement
PRC (Yunnan)	Viet Nam	Maomatiao – Ha Giang	110 kV Single		115	Governmental agreement
PRC (Yunnan)	Viet Nam	Hekou – Lao Cai	110 kV Single	20	91	Governmental agreement
PRC (Guangxi)	Viet Nam	Fangcheng – Mong Cai	110 kV Single	60	25	Governmental agreement
Thailand	Cambodia	Aranyaprathet- Banteay Manchey	115 kV single	40	80	PPA with TOU tariff

There are also a number of low voltage interconnections between countries in the GMS which can be summarised as follows:

- Two 22 kV connections between Lao PDR and Cambodia in the Steung Treng area;
- Eight 22 kV connections between Thailand and Cambodia;
- Six 22 kV connections between Lao PDR and Viet Nam; and
- Eighteen connections at 22 kV at 35 kV between Viet Nam and Cambodia.

The main issues or concerns with the power exchanges in the GMS are related to hydro generation supply and demand balances during wet and dry seasons between the countries, particularly between Lao PDR and Thailand. Generally Lao PDR does not have sufficient hydro

generation to meet demand in the dry season therefore it imports power from Thailand via 115 kV interconnections to meet domestic demand. In order to make up the imbalances, Lao PDR expects to export power to Thailand during the wet season when there are plenty of water inflows however Thailand does not necessarily need that power during the wet season. This may prevent effective bilateral electricity trade within the GMS. This issue, however, could be addressed through changes in bilateral agreements in order to allow for effective resource sharing.

5 Possible Cross-Border Interconnection in the GMS

In this section we compile the cross-border interconnection projects based on various country and regional reports and studies that have been conducted and published by a number of different organisations (including ADB, APERC, and IEA among others). For each potential cross-border interconnection project we then provide some preliminary comments on the benefits / opportunities and drawbacks / barriers, in line with the TOR requirement.

5.1 Summary of Candidate Cross-Border Interconnections

A list of Candidate cross-border interconnection projects has been compiled based upon various country and regional reports and studies conducted by a number of organisations including ADB, APERC, ECA and IEA. The candidate interconnection projects are shown in Table 14 and Figure 18.[23] For each of the interconnections, a preliminary qualitative assessment to identify potential benefits and drawbacks are provided in the sections that follow. This analysis provides a platform for identifying ten business cases to perform a more detailed assessment and modelling of in Task 1. The majority of these interconnections are to support large-scale hydro generation export, which is being viewed as the main mechanism for power exchanges in the GMS over the short to medium term.

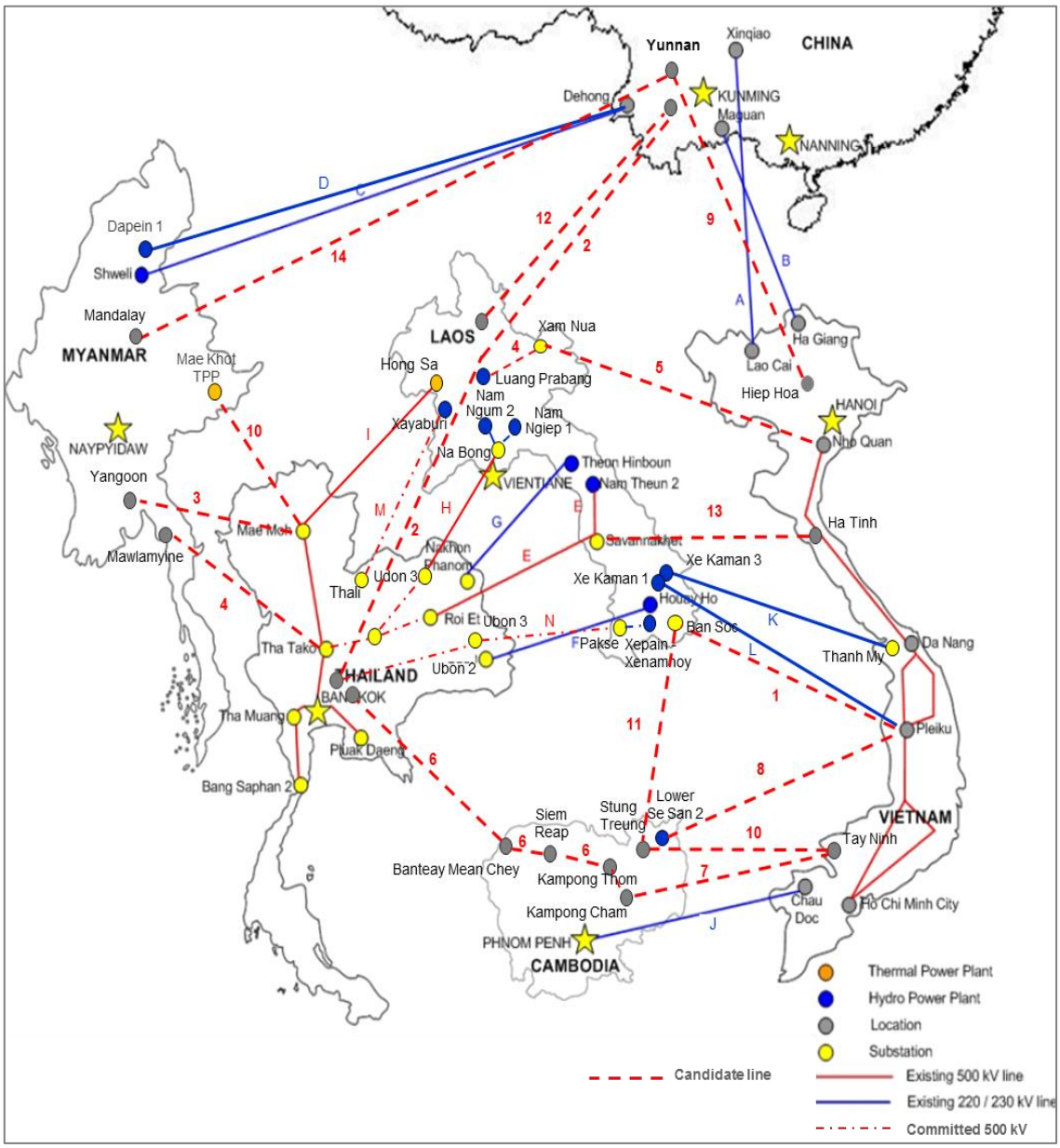
[23] Note that this list does not include projects which have already been committed (and to be completed before 2020).

Table 14 Candidate Cross-border Interconnection Projects[24]

No.	Country (From)	Country (to)	Connection Points (From – To)	Type	Length (km)	Capacity (MW)	Source(s)
1	Lao PDR - South	Viet Nam - Central	Ban Soc/Ban Hatxan – Pleiku	500 kV double circuit	190	1,000	ADB RIF, APERC
2	PRC (Yunnan)	Thailand - Central	Gan Lan Ba – Tha Wung via Lao-N	600 kV HVDC	1,300	3,000	ADB RIF, APERC
3	Myanmar - Central	Thailand - North	Yangon area – Mae Moh	500 kV	350	1,500	ADB, APERC, IEA
4	Myanmar - Central	Thailand - Central	Mawlamyine – Tha Tako	500 kV	300	1,500	ADB RIF, IEA
5	Lao - North	Viet Nam - North	Luang Prabang HPP - Xam Nau (Lao-N) – Nho Quan	500 kV double circuit	400	2,500	ADB, APERC
6	Thailand - Central	Cambodia	Wangnoi – Banteay Mean Chey – Siem Reap – Kampong Cham	500 kV double circuit	500	300	ADB, APERC
7	Cambodia	Viet Nam - South	Kampong Cham – Tay Ninh	500 kV double circuit	100 km	300	ADB
8	Cambodia	Viet Nam - Central	Lower Se San 2 HPP – Pleiku	230 kV double circuit	230 km	200	ADB
9	PRC	Viet Nam - North	Yunnan – Hiep Hoa	500 kV DC	1,200 km	3,000	ADB
10	Myanmar - North	Thailand - North	Mae Khot TPP – Mae Chan	230 kV	115 km	370	ADB
11	Lao PDR - South	Viet Nam - South	Ban Soc/ Ban Hatxan – Tay Ninh via Stung Treng	500 kV	320 km	1,000	ADB, World Bank
12	Lao - North	PRC	Luang Prabang - Yunnan	500 kV	350 km	650	ADB
13	Lao PDR - South	Viet Nam - Central	Savannaket – Ha Tihn	500 kV	200 km	600	ADB
14	Myanmar - North	PRC	Mandalay - Yunnan	500 kV	350 km	600	ADB

[24] Sources:
APERC (2004). Electric Power Grid Interconnections in the APEC Region, Asia Pacific Energy Research Centre.
ADB (2010). Facilitating Regional Power Trading and Environmentally Sustainable Development of Electricity Infrastructure in the Greater Mekong Subregion, Asian Development Bank. **ADB RETA No. 6440**.
ADB (2015). Vietnam Energy Sector Assessment, Strategy and Roadmap, Asian Development Bank.
IEA (2016). Thailand Electtricity Security Assessment 2016. Partner Country Series, International Energy Agency.
ADB (2013). Assessment of the Greater Mekong Subregion Energy Sector Development: Progress, Prospects and Regional Investment Priorities, Asian Development Bank
ADB (2015). Vietnam Energy Sector Assessment, Strategy and Roadmap, Asian Development Bank.
ADB (2015). Power Sector Development in Myanmar, Asian Development Bank. **ADB Working Paper Series No. 460**.
ECA (2010). Greater Mekong Subregion (GMS) Transmission and Trading Case Study, Economic Consulting Associates.

Figure 25 Candidate Cross-border Transmission Projects[25]



5.2 Southern Lao PDR (Ban Hatxan/Ban Soc) – Central Viet Nam (Pleiku)

This proposed 500 kV interconnections would connect Southern Lao PDR with Central Viet Nam to facilitate power export from hydro power plants in Lao PDR to Viet Nam. These hydro plants include Xekaman Sanxay, Sekong 3, Sekong 3 Ha, Nam Kong 2 with total capacity of around 700 MW (not including Xekaman 1 and 3 which have already been committed). This transmission project has been identified by ADB and APERC as one of the priority energy projects in the GMS as it has been viewed to accelerate power market integration in the GMS. It has also been included in the PDP of Viet Nam. It will allow for the connection between Southern Lao PDR, which has extensive network of hydro power plants, and the Central Highlands of Viet Nam.

[25] Source: Consultant has adapted the diagram from ADB RETA 6440 based on numerous sources to illustrate the candidate cross-border interconnection projects in the GMS.

5.2.1 Benefits/Opportunities

- It opens up opportunities for new hydro projects in Southern Lao PDR to export to Thailand, Viet Nam and Cambodia. Such opportunities will generate revenue and provide economic benefits for Lao PDR, which is in accordance with the objectives of the government in promoting export hydro projects.
- This line provides a platform for interconnecting the grids in Thailand, Lao PDR, Viet Nam and Cambodia since there are existing (and committed) transmission lines nearby which connect Southern Lao PDR (at Pakse) and Thailand. It provides a possibility of linking to Thailand through the north-eastern region and north-east Cambodia and hydropower plants in the Lower Se San region in Cambodia.
- Pleiku in Viet Nam is considered one of the transmission hubs in Central Viet Nam where a 500 kV substation is already existing that could provide cost saving advantages on substation facilities. Currently Xekaman 1, 4 are connected at 220/230 kV level at the border between Viet Nam and Lao PDR and reaching 500 kV Pleiku 2 substation.
- Potential for effective resource sharing between four of the GMS countries during wet and dry seasons.
- With expansions of transmission and distribution networks in Lao PDR, this project can support improved electricity access in Lao PDR.

5.2.2 Drawbacks/Barriers

- Investment to reinforce the grids within the south of Lao PDR would be required to accommodate multilateral power trade between Thailand, Lao PDR, Viet Nam and Cambodia. This may not be approved by the Government of Lao PDR since the primary focus is on power export.
- If connected via HVAC lines, it would require power systems in these countries to be synchronised, which would have implications for power system operation. Coordination with regard to technical and operating arrangements is key. There is a need to build up general standards between countries participating in interconnection grid for safety and effective operation purposes.
- Institutional and contractual arrangements for multilateral trades will be complex and difficult to achieve.

5.3 PRC (Yunnan/Galangba) – Central Thailand (Thawung) via Lao PDR

Transmission lines connecting Yunnan in PRC and Thailand at Thawung in Lopburi province have been identified by both ADB and APERC to enhance power trade and resource sharing within the GMS. This project was intended to primarily export hydro power from Yunnan, which has significant hydro and coal generation capacity, to Thailand through 600 kV HVDC transmission lines. There has been an MOU in place since 1998 for Thailand to purchase 3,000 MW of electricity from PRC.

5.3.1 Benefits/Opportunities

- Resource sharing benefits by exporting from a resource rich region in Yunnan to Thailand, the country with one of the largest demand growth in the GMS. The HVDC transmission link can potentially provide a platform for effective power exchanges and accelerate multilateral power trade within the GMS.
- Due to geographical diversity and different hydrological conditions, there is also a potential for Thailand to export to PRC since Thailand imports a significant amount of hydro power from Lao PDR during wet seasons in Lao PDR.
- Improving the security of electricity for Thailand through fuel diversification and reducing the share of gas-fired generation which currently accounts for around 70%.
- This project would likely reduce or delay investment in new generation capacity in Thailand.

- With the HVDC interconnection, there are several benefits including controllability and the speed of operation. There will be no issues with regard to synchronisation between the two separate power grids.
- There are reserve sharing benefits as well as a potential to enhance the security of power systems in both countries through HVDC given the relatively fast and highly controllable power transfer. Hence HVDC is suitable for providing all forms of frequency control ancillary and for supporting a range of protection schemes in the power systems.
- PRC already has had experience in constructing and operating several long-distance HVDC transmission lines (between west and east). Thailand also have been operating HVDC cross-border interconnectors since 2001.

5.3.2 Drawbacks/Barriers

- Due to its extremely long distance from Yunnan to Central Thailand (around 1,300 km), this project will require substantial amount investment and there remain questions over financial arrangements and funding sources.
- Both countries will also have to invest in converter stations, which again will be very expensive.
- In addition, upgrades to the existing transmission network within Thailand are likely to be required to accommodate increased power flow through the central region.
- Since the lines will have to pass through Lao PDR, there are questions over the involvement of Lao PDR and relevant regulatory and commercial arrangements.
- Although both countries have been operating HVDC transmission lines for several years, the operation of long-haul bulk HVDC systems can be complex since it requires continuous communication to control power follow.

5.4 Central Myanmar (Yangon Region) – North Thailand (Mae Moh)

This transmission project would connect Yangon area in Myanmar and Northern Thailand with the purpose of exporting power from Thailand to Myanmar. This transmission project, with the capacity of around 1,500 MW, is intended to ease the power supply shortage in Yangon region, which accounts for more than 50% of the country's electricity demand. The issues of power supply shortage and low electricity access have been highlighted by not only Myanmar officials but also other international organisations including ADB, IEA and APERC.

5.4.1 Benefits/Opportunities

- In the short-term, this project can alleviate the looming power supply shortage situation in Myanmar, particularly in Rangoon area. In the long-term this transmission link can also support development of a number of power projects for exporting to Thailand.
- With appropriate expansions of Myanmar's grid, this project would support improved electricity access in Myanmar.
- This project would allow for a better utilisation of power plants in Northern Thailand (Mae Moh) and Hong Sa power plant in Lao PDR, which is a dedicated coal-fired generating plants supplying power to Thailand in the north. Presently these power plants, which have a combined capacity in excess of 4,000 MW, cannot be operated at their full capacity at the same time due to transmission bottleneck between north and central of Thailand.
- It would enable effective resource sharing since the reserve margin in Thailand is estimated to be greater than 30% over the next fifteen years.
- This project may not require significant upgrades of transmission networks in Thailand since Mae Moh is already a main generation hub. However, expansions of transmission and distribution networks in Myanmar appear necessary.

5.4.2 Drawbacks/Barriers

- Power supply to Yangon area will come primarily from coal-fired (lignite) power plants in Northern Thailand (Mae Moh) and Lao PDR (Hong Sa), resulting in increased carbon emissions and local air pollutants in Thailand.
- Although the length of the transmission lines appears reasonable, they have to go through highly mountainous areas. This represents a considerable challenge from construction and operational and maintenance perspectives.
- Expansions of the transmission and distribution networks in Myanmar would be necessary but this may not be approved by the government.
- The existing MOU between Myanmar and Thailand is for exporting power from Myanmar therefore contractual and institutional arrangements are likely to be challenging.
- There are questions over whether this project will facilitate multilateral electricity trade and the integration of power markets in the GMS since it appears that the transmission lines may only benefit Thailand and Myanmar.

5.5 Central Myanmar (Mawlamyine) – Central Thailand (Tha Tako)

This project is on the Regional Investment Framework Implementation Plant (RIF-IP) 2014 -2018 list of energy projects to connect the eastern part of Myanmar to the western/central region of Thailand under the concerted planned development of energy, transport and urban infrastructure in the East-West transmission alignment. This transmission link would allow power flow from central Thailand to Mawlamyine region in Myanmar.

5.5.1 Benefits/Opportunities

- This project can alleviate the power supply shortage situation and help to improve electricity access in the surrounding areas of Mawlamyine.
- Tha Tako is already one of the main 500 kV transmission hubs located in central Thailand with transmission lines connecting with northern and north-eastern regions. This provides an opportunity for multilateral electricity trade in the GMS.
- It will enable effective resource sharing and higher utilisation of generating plants given the high reserve margin in Thailand.

5.5.2 Drawbacks/Barriers

- Mawlamyine is isolated from the main grid in Myanmar therefore substantial investment to expand Myanmar's grid is required to enable the power transfer to the load centre in Yangon region. Such a large sum of investment may not be approved by the government.
- Reinforcement in Thailand's grid, particularly the backbone transmission lines between north and central, would be required to accommodate increased power flow to Myanmar via central Thailand.

5.6 North Lao PDR (Luang Prabang HPP – Xam Nua) – Northern Viet Nam (Nho Quan)

This project has been listed by ADB (in RETA 6440) as one of the post-2015 base case projects. The transmission project is intended to facilitate power transfer from hydro power plants in northern Lao PDR to northern Viet Nam. These hydro power plants are to be constructed in Luang Prabang Province in the northwest and Huaphanh province in the northeast of Lao PDR. The line will connect Luang Prabang Province to Nho Quan in Viet Nam via Xam Nua in Lao PDR.

5.6.1 Benefits/Opportunities

- Opportunities for new hydro projects in the north of Lao PDR with a combined generation capacity in excess of 1,200 MW. Power generated from these projects will be exported to Viet Nam as well as supplying domestically within Lao PDR.
- This transmission link and the new hydro power plants can help to improve electricity access in Lao PDR.
- The project will promote power exports and generate revenue for Lao PDR which is in accordance with the Government development objectives.
- There is another large hydro power plant nearby (Xayaburi HPP), which is currently under construction for exporting power to Thailand via 500 kV double-circuit transmission lines. Therefore, there is a potential to interconnect Thailand, northern Lao PDR and northern Viet Nam by extending this proposed with the existing lines.

5.6.2 Drawbacks/Barriers

- The proposed Luang Prabang hydro power project is in close geographical proximity with the 1,200 MW Xayaburi hydro power plant, which has been committed and to be completed by 2019. Although this represents an opportunity for interconnecting the grids between the three countries, there are concerns over the lack of geographical diversity since the two hydro plants would have similar hydrological conditions.
- The similar hydrological conditions would result in similar generation patterns, which may not provide benefits in terms of resource diversification during wet/dry seasons. The proposed Luang Prabang hydro project may also reduce downstream water inflows and the output of other downstream hydro plants such as Nam Ngum and Nam Ngiep.

5.7 Central Thailand (Wangnoi) – Cambodia (Banteay Mean Chey – Siem Reap – Kampong Cham)

This transmission project would connect the central area of Thailand with Cambodia in the northwest. It will allow for increased power export from Thailand to Cambodia (which is currently connected via a 115 kV transmission line – see Table 13).

5.7.1 Benefits/Opportunities

- The increased power export from Thailand to Cambodia can, to some extent, improve electricity access in Cambodia, which is currently below 40%. In addition, it will help to reduce power supply shortages and blackouts, which have occurred very frequently in Cambodia.
- Power import from this transmission lines can potentially ease the high electricity costs in Cambodia due to the considerable share of diesel/fuel oil in electricity generation.
- This project, together with the transmission projects connecting Cambodia to Southern Viet Nam at Tay Ninh (see Section 5.8) will allow for the grids in Thailand, Cambodia and Viet Nam to be interconnected. There is also another proposed project nearby to connect Cambodia (at Stung Treung) to Southern Lao PDR (see Section 5.12). The relatively short distance between Stung Treung and Kampong Cham represents an opportunity to interconnect Central Thailand with Cambodia, Southern Lao PDR and Southern Viet Nam in the future.
- The possibility of connecting Thailand and Viet Nam, the two largest systems (beside Yunnan), has a broad appeal as it would represent a major step towards the integration of power markets in the GMS.
- It will enable effective resource sharing since the reserve margin in Thailand is estimated to be greater than 30% over the next fifteen years.

5.7.2 Drawbacks/Barriers

- Cambodia is already relying quite heavily on power imports from Thailand and Viet Nam (around 40%), therefore increased reliance of power import may have long-term implications on energy security (although this transmission project provides a quick

solution for addressing the low electricity access and high electricity price issues in Cambodia).

- This project may hinder the development of electricity supply infrastructure (generation and transmission) within Cambodia to address electricity accessibility.
- The operation of interconnected power systems via AC transmission lines can be challenging, particularly in terms of frequency control since the power systems have to be synchronised. In the specific case of interconnecting Cambodia and Thailand, frequency control would not be a major issue as the Cambodia system is relatively small and the Thailand frequency will dominate. However there could be issues with the power flow control, given the limited transfer capacity of an 115kV interconnection.
- The length of transmission lines from Central Thailand to the Thai-Cambodian border is rather long (500 km), hence substantial amount of investment will be required.
- Although there has been a MOU on cross-border electricity trade in place since 2000, the political tension between the Thai and Cambodian governments due to the border dispute represents the major barrier in the development of the project.

5.8 Cambodia (Kampong Cham) – Southern Viet Nam (Tay Ninh)

This project will connect the eastern part of Cambodia with Southern Viet Nam. Over short to medium term, this line is intended for importing power from Viet Nam to Cambodia at Kampong Cham.

5.8.1 Benefits/Opportunities

- This transmission link will allow Cambodia to import lower-cost electricity from Viet Nam to meet the domestic demand. It will also help to improve the electricity access and power supply shortages in Cambodia (see Section 5.7).
- Together with the Central Thailand – Cambodia interconnection project (described in Section 5.7), this transmission project has a potential to facilitate long-term multilateral electricity trade between Thailand, Cambodia and Viet Nam.
- The relatively short distance between Kampong Chan and Tay Ninh (100 km), and hence moderate investment costs, makes this project very attractive from the economic aspect in relation with the other candidate projects.
- The reserve margin in Viet Nam is projected to be in excess of 30% over the next 20 years therefore this project will allow for effective resource sharing through higher utilisations of generating plants in Viet Nam.
- In terms of regulatory and commercial arrangements, this project can build upon the framework which is already in place for the existing 220/230 kV Viet Nam – Cambodia interconnector.

5.8.2 Drawbacks/Barriers

- Increased reliance of power import may have long-term implications for energy security in Cambodia (as discussed in Section 5.7).
- Developments in Cambodia's transmission and distribution grids are required to transfer power to other areas within Cambodia.
- The increased power flow from Viet Nam to Cambodia may require upgrades of transmission network in Viet Nam, particularly transmission lines connecting between the Central and Southern regions.

5.9 Cambodia (Lower Se San 2 HPP) – Central Viet Nam (Pleiku)

This project has been listed by ADB (in RETA 6440) as one of the post-2015 base case projects. It is intended for connecting Lower Se San 2 hydro power plant in Stung Treng province, Cambodia to Central Viet Nam at Pleiku. With the proposed capacity of 400 MW, Lower Se San

2 will be the largest hydro project in Cambodia. Electricity generated from this hydro project will be supplied to meet domestic demand and exported to Viet Nam under a long-term PPA.

5.9.1 Benefits/Opportunities

- This project facilitates the development of a large hydro power project in Cambodia to provide low-cost electricity domestically and for exporting to Viet Nam.
- The transmission line and the hydro power project will improve electricity access and reduce power supply shortages in Cambodia.
- The transmission link corresponds with the long-term objective of Cambodia in reducing the share of power import and becoming net electricity exporter. This will enhance long-term security of electricity supply.
- Pleiku in Central Viet Nam is already one of the transmission hubs therefore some of the transmission infrastructure are already in place.

5.9.2 Drawbacks/Barriers

- In order to supply electricity generated by Lower Se San 2 HPP within Cambodia, new high voltage transmission infrastructure connecting the hydro power plant to other parts of Cambodian (from Stung Treng in the northwest to Kampong Cham and to the load centre in Phnom Penh) will be required. This represents substantial investment for the Cambodian government and it remains unclear whether there will be adequate funding to cover all sections of this network.

5.10 PRC (Yunnan Region) – Northern Viet Nam (Hiep Hoa)

This project is intended to export power from Yunnan in PRC, which has abundant of generation resources, to Northern Viet Nam via a long-distance HVDC transmission line. The study of this project has been initiated since mid-2000 and is also in the list of energy projects in the RIF-IP.

5.10.1 Benefits/Opportunities

- The transmission link would allow for effective resource sharing between the two countries, particularly during peak/off-peak periods and wet/dry seasons given the geographical diversification of hydro resources in these two countries. Given the large share of hydro generation in Viet Nam, power import from PRC can make up for reductions of hydro generation during dry seasons in Viet Nam.
- The transmission line will also result in a better utilisation of power plants in the CSG grid given the non-coincidental peak demand between Viet Nam and Yunnan (and also other grids in PRC since power typically flows from the west east to supply load in the west
- The proposed HVDC interconnection would increase reliability and security of power supply in both countries since HVDC systems can be set up to provide several forms of frequency control ancillary services.

5.10.2 Drawbacks/Barriers

- The project will require a significant amount of investment given the long distance therefore it may not be economically feasible.
- There are no other grid-to-grid interconnections nearby in the north of Viet Nam (other than the potential lines for importing from dedicated hydro plants in Lao PDR), hence there are concerns that this project may not promote or accelerate multilateral power trade within the GMS compared to the other projects.

5.11 North Myanmar (Mae Khot TPP) – North Thailand (Mae Chan)

This transmission link is intended for exporting power from a lignite thermal power plant in Myanmar to northern Thailand. The capacity of the proposed power plant is around 350 MW.

5.11.1 Benefits/Opportunities

- This project converts resources into economic benefits that will generate significant revenue for Myanmar.
- The power import for this power plant and transmission line can help to reduce the share of gas-fired generation in Thailand and provide fuel diversity in electricity supply.

5.11.2 Drawbacks/Barriers

- The reserve margin in Thailand is projected to be greater than 30% over the next fifteen years therefore the proposed transmission lines (and power plant) appear to be low priority in short to medium term. In addition, the project does not appear to accelerate multilateral trade in the GMS.
- Given the recent supply shortage situations in Myanmar, the focus at least in the immediate term should be placed on meeting domestic demand rather than power export.
- Reinforcement of the main 500 kV grid in Thailand from the north to central area will be required to accommodate increased power flow. There is already a large amount of power flow from the north to central Thailand (from the existing lignite power plants) therefore additional power flow from the north can have implications for power system security in Thailand, particularly if there is a force outage on the north-central transmission lines.

5.12 Southern Lao PDR (Ban Hatxan) – Cambodia (Stung Treng) – Southern Viet Nam (Tay Ninh)

This transmission project will connect Southern Lao PDR with Southern Viet Nam via Cambodia. The transmission link is intended to accommodate power export from hydro power projects in Southern Lao PDR and Cambodia to Southern Viet Nam.

5.12.1 Benefits/Opportunities

- This line will facilitate the development of several hydro power projects in Southern Lao PDR for exporting to Viet Nam and Cambodia as well as supplying domestic demand.
- With additional investment in transmission infrastructure in Cambodia, this project has a potential to greatly benefit Cambodia by increasing electricity access, reducing power supply shortages and easing high electricity prices.
- The geographical diversification of hydro generation resources between Southern Lao PDR and Southern Viet Nam, and hence diversified hydrological conditions, provide a cost-effective mean to increase the reliable of electricity supply for Viet Nam, particularly during dry seasons.
- Being in a close proximity with the Ban Soc/Ban Hatxan – Pleiku interconnection, this transmission line can facilitate multilateral connection between Lao PDR, Cambodia and Viet Nam. There is also a potential to link central and southern Viet Nam via Cambodia and Lao PDR.

5.12.2 Drawbacks/Barriers

- Commercial and regulatory arrangements as well as establishing operation standards will be the key challenge.
- Issues with funding for new transmission infrastructure in Cambodia as described in Section 5.9.

5.13 North Lao PDR (Luang Prabang) – PRC (Yunnan Region)

This interconnection will accommodate two-way power exchanges between Lao PDR and PRC, the systems with abundant generation resources (hydro and coal in Yunnan and hydro in Lao PDR).

5.13.1 Benefits/Opportunities

- This project has the potential to facilitate effective resource sharing between Lao PDR and PRC given their different energy sources and geographical locations.
- Since the majority of generation sources in Lao PDR are hydro, this transmission link will be an additional source of electricity supply, resulting in a more diversified generation mix and hence greater reliability. The line will be used to import power from PRC during dry seasons and exporting to PRC during wet seasons.
- PRC will also benefit from importing low-cost electricity generated by hydro plants in Lao PDR.
- This line can potentially contribute towards increased electricity access in Lao PDR.

5.13.2 Drawbacks/Barriers

- In order for Lao PDR to take the full advantage of this transmission link, reinforcement and new investment in transmission and distribution networks within Lao PDR will be required. There may be issues over funding to carry out necessary transmission and distribution network upgrades.
- Connecting the two systems via HVAC presents a range of operational challenges as has been described previously.

5.14 Southern Lao PDR (Savannaket) – Central Viet Nam (Ha Tinh)

This transmission link provides grid to grid connection between southern Lao PDR with Central Viet Nam, which will enable power exchanges between the two countries.

5.14.1 Benefits/Opportunities

- Together with the existing 500 kV transmission lines between Savannaket and north-eastern Thailand, this proposed transmission project provides a platform for connecting the three systems and enabling multilateral electricity trade between Thailand, Lao PDR and Viet Nam.
- This line will enable the development of new power projects in Lao PDR, particularly areas along the Nam Theun River. This is in line with the government objectives in generating revenue from exporting power.
- In the long-term, subject to the transmission network development in Viet Nam, it is possible that this line will support power flow from Central Viet Nam into Savannaket since electricity demand in Central Viet Nam is relatively low compared to the north and south.

5.14.2 Drawbacks/Barriers

- To maximise the benefits of this project, the transmission and distribution networks within Lao PDR need to be expanded, particularly transmission lines linking the northern and southern grids in Lao PDR.
- The operations of trilateral interconnections via HVAC transmission lines are extremely complex given the different technical and operating standards in power system operation.
- Development of hydro projects in that area can have adverse impact environmentally and it may affect water inflows of other existing hydro plants in the area.

5.15 North Myanmar (Mandalay) – PRC (Yunnan Region)

This transmission link has been mentioned under generic cross-border transmission projects in the ADB RETA 6440 on the GMS Regional Master Plan. This project appears to provide a number of benefits for Myanmar and PRC. This project would enable power import from PRC to Myanmar in the short-term while in the long term it also supports power transfer from Myanmar to PRC from a number of planned generation projects.

5.15.1 Potential Benefits/Opportunities

- In the immediate term, the project would help to address the supply shortage situations in Myanmar, particularly in Mandalay region by importing electricity from PRC.
- In the long-term, this transmission link can also support a number of planned power projects for exporting electricity to Yunnan in PRC as well as for meeting demand domestically.

5.15.2 Drawbacks/Barriers

- It is necessary to expand Myanmar's grid, particularly from the border to the load centre in Mandalay. Obtaining an approval from the government may prove to be a key challenge.

5.16 Other Possible Interconnections

In addition to the fourteen candidate interconnections described in Sections 5.2 - 5.15, there are other possible cross-border interconnections which are shown in Table 15. These transmission interconnection projects do not appear to have been considered in detail in other publicly available studies as they are deemed to offer limited benefits or are potentially infeasible, as has been indicated by member countries during previous RPTCC meetings and workshops. In addition, there is very limited information on finer details of the transmission projects – such as the locations of potential connection points or power plants (for those projects that involve having a dedicated power project). Some of the projects are subject to uncertainties in relation to whether they are grid-to-grid connections or whether they would involve a dedicated power project. For completeness, we have documented the information that we have been able to gather. We note that there is some redundancy between the projects appearing in this list compared as compared to the candidate projects described in previous sections (for example project no. 2).

Table 15 Other Possible Interconnection Projects

No.	Country (From)	Country (to)	Connection Points (From – To)	Type	Length (km)	Capacity (MW)
1	PRC	Viet Nam - North	Hong He HPP - Lao Cai	HVDC	450	1,500
2	Cambodia	Viet Nam - South	HPPs (Se San, Sambor, Sre Pok) – Than Dinh	230 kV AC	150	200
3	Myanmar – North	Thailand - North	Tasang HPP - Mae Moh	500 kV AC	270	1,500
4	Myanmar – Central	Thailand - North	HPP in Thanlwin - Phtisanulok	500 kV AC	300	1,500
5	PRC (Yunnan)	Viet Nam - North	HPP in Yunnan – Soc Son	500 kV AC	270	460
6	PRC (Yunnan)	Lao PDR - North	Yunnan region – Northern Lao PDR region	HVDC	620	1,000
7	PRC (Guangxi)	Viet Nam - North	Fang Cheng – Quang Ninh	HVDC	610	500
8	Myanmar - North	Lao PDR - North	Mandalay region – Northern Lao PDR	HVDC	620	500

6 Business Case Selection

In the previous section, we identified 14 candidate business cases. Based upon the initial analysis of the candidate cross-border transmission projects in Section 5, this section reduces the list down to the ten business cases for which detailed modelling was performed .

6.1 Analysis of Potential Business Cases

The selection of the eight (8) business cases takes into consideration analysis carried out in a number of previous studies. It has been suggested that new interconnections between the following regions should be developed:

- PRC – Myanmar, and Thailand - Myanmar;
- Thailand – Northern Lao PDR;
- Northern Lao PDR – Northern Viet Nam;
- Southern Lao PDR – Central Viet Nam;
- Southern Lao PDR – Southern Viet Nam; and
- Cambodia - Southern Viet Nam.

In addition to connections linking between Northern and Southern Lao PDR (which is not considered as a business case in this project), connections between Viet Nam and Thailand (via Lao PDR and/or Cambodia) have been viewed as an essential step in establishing the regional power market given they are two of the largest grids in the GMS (besides the CSG in PRC given its different context). This viewpoint has been taken into consideration when identifying business cases.

More importantly, the business cases are selected in a manner that is consistent with the criteria suggested in the assessment framework. The screening criteria which have been taken into account in the preliminary analysis include:

- Reasonable project cost;
- Dispatch benefits;
- Avoided/Deferred generation investment;
- Reserve sharing benefits;
- Effective resource sharing;
- Technical feasibility;
- Supports multilateral trade;
- Achievable commercial arrangements;
- Environmental benefits; and
- Social benefits.

Table 16 shows the initial assessment and screening criteria for each of the candidate transmission projects. The ten original business cases are highlighted in green. Although some of these projects are not grid-to-grid connections in the short-term, they provide a platform for interconnecting power systems in the GMS and accelerating multilateral electricity trade not only within the GMS, but also in ASEAN. Note that some additional business cases were considered owing to changing priorities within the region over the duration of the study.

Note also that the analysis presented here is a preliminary high-level screening assessment. Detailed modelling and the application of the business case assessment framework provide a holistic assessment of the benefits of these transmission projects and the extent to which they could accelerate cross border trade.

Table 16 Initial Assessment and Screening of Candidate Transmission Projects

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

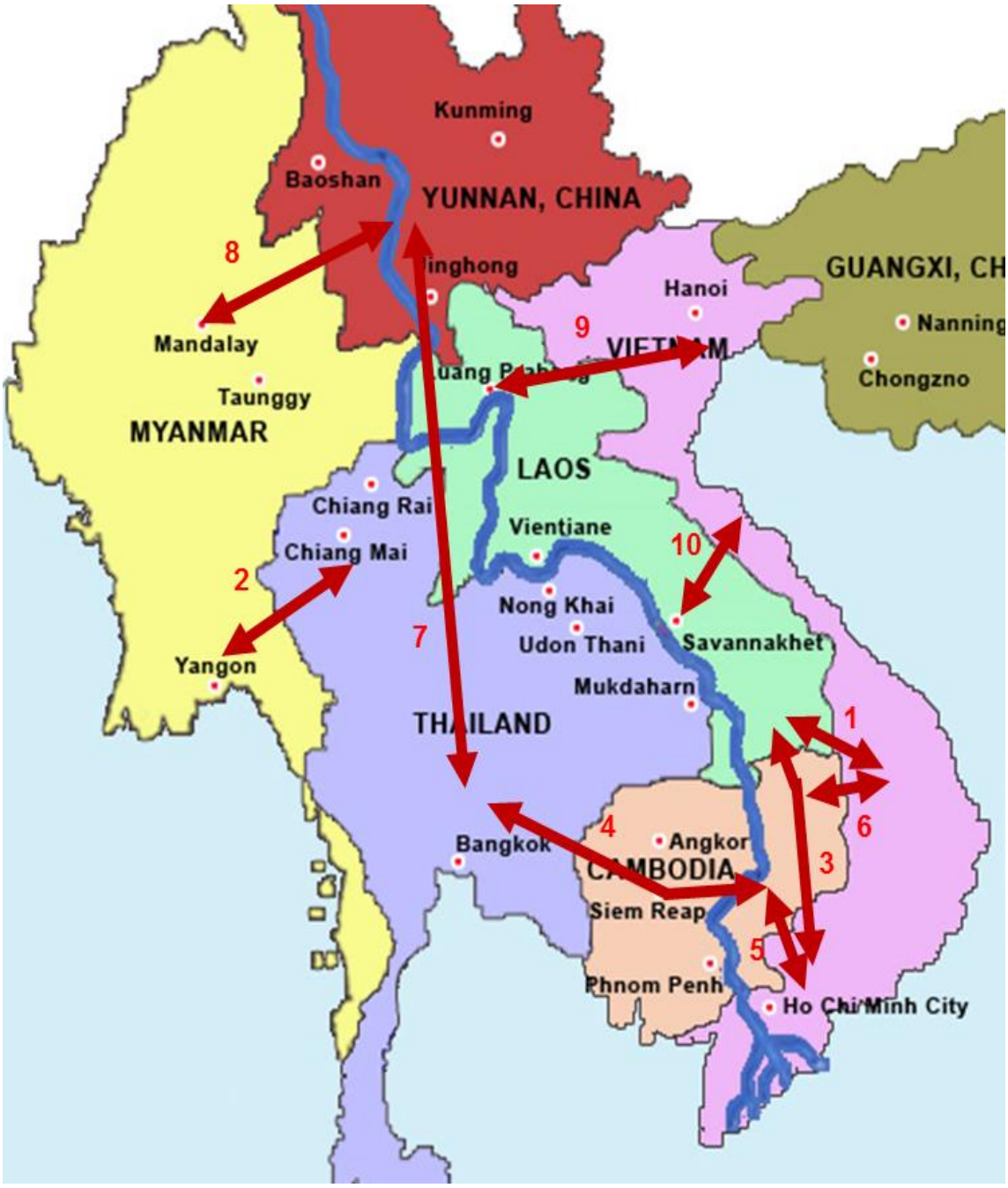
6.2 Analysis of Potential Business Cases

The ten selected business cases are shown in Table 16 and they are grouped into three sets of business cases to be assessed in detail. The projects that are considered as a high priority from the first set of business cases. The ten candidate projects are depicted in Figure 26, with the number corresponding to Table 16.

Table 17 Ten Selected Business Cases

Set of Business Cases	Business Case No.	Region (From)	Region (to)	Connection Points (From – To)	Length (km)
First set of business cases	1	Lao PDR – South	Viet Nam – Central	Ban Soc/Ban Hatxan – Pleiku	190
	2	Myanmar	Thailand – North	Yangon area – Mae Moh	350
	3	Lao PDR – South	Viet Nam - South	Ban Soc/ Ban Hatxan – Tay Ninh via Stung Treng	320
Second set of business cases	4	Thailand – Central	Cambodia	Wangnoi – Banteay Mean Chey – Siem Reap – Kampong Cham	500
	5	Cambodia	Viet Nam - South	Kampong Cham – Tay Ninh	100
	6	Cambodia	Viet Nam - Central	Lower Se San 2 HPP – Pleiku	230
Third set of business cases	7	PRC	Thailand - Central	Gan Lan Ba – Tha Wung via Lao-N	1,300
	8	Myanmar	PRC	Mandalay - Yunnan	350
	9	Lao PDR – North	Viet Nam - North	Luang Prabang HPP - Xam Nau (Lao-N) – Nho Quan	400
	10	Lao PDR – South	Viet Nam - Central	Savannaket – Ha Tihn	200

Figure 26 Ten Selected Business Cases of Cross-border Interconnections



7 Summary of Business Case Analysis Findings

This section summarises the modelling results for all of the individually modelled business cases (BC1 - BC9) and an integrated case allowing for all business case links modelling dynamically. The results focus on the capacity and generation impacts, significant changes in power flows across the GMS, power system costs and benefits and insights into the potential changes resulting from having the business cases become operational from the year 2020.

Modelling of the business cases separately all resulted in positive net present values arising from a deferral or avoidance of generation investment, and highly significant reductions in power generation costs. Figure 27 below summarises each of the eight (8) business case and Integrated Case results including the NPV[26] range across all size options modelled, and implications for generation and national transmission requirements. The Integrated case models all of the business case links as being available, and are augmented as required, with the aim of analysing which business case links have the highest benefit and therefore prioritised.

Sections 7.1 to Section 8 explores the results in more detail. Net present values are quoted in real 2016 US dollars and assume a 10% discount rate.

Figure 27 Summary Results: All Business Cases

No.	Name and Sizes	NPV Range ($m 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
1	**Lao (S) ⇔ VN (C)** Ban Soc/Ban Hatxan ⇔ Pleiku (190 km) Sizes: 500, 1000, 2000 MW	437 – 694	Hydro generation and capacity in Laos substitutes for coal developments in Viet Nam	Laos grid strengthening becomes critical to full utilization of hydro storages	Existing network infrastructure in Viet Nam and Laos can be leveraged therefore feasible
3	**Lao (S) ⇔ VN (S)** Ban Soc/ Ban Hatxan ⇔ Tay Ninh via Stung Treng (320 km) Sizes: 500, 1000, 2000 MW	402 – 573	Hydro generation and capacity in Laos substitutes for coal developments in Viet Nam	Laos grid strengthening becomes critical to full utilization of hydro storages	BC 1 is more feasible than BC 3 and they result in similar benefits
9	**Lao (N) ⇔ VN (N)** Luang Prabang HPP ⇔ Xam Nau (Lao-N) ⇔ Nho Quan (400 km)	953 - 971	Hydro generation and capacity in Laos substitute for coal and also augments hydro supply in Viet Nam North	Requires less grid strengthening that BC1 and BC3 because hydro generation in north of Laos is evacuated directly to north of Viet Nam	Generally considered a longer-term option for Viet Nam (prioritized lower than Laos imports in the central region) More hydro developed in Laos with higher link size

[26] Net present values based on a 10% discount rate, and in real 2016 USD.

No.	Name and Sizes	NPV Range ($m 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
	Sizes: 1500, 2500, 3500 MW				
5	**Cambodia ⇔ VN (C)** Lower Se San 2 HPP ⇔ Pleiku (230 km) Sizes: 200, 400, 800 MW	50 – 58	Cambodia imports surplus from VN initially and less hydro is developed to defer coal in Cambodia. Later, Cambodia develops coal and offsets gas capacity in VN	Requires Cambodia to develop its transmission network covering the north region hydro resource and southern corridor for thermal expansion	Depends on a lot of network developments within Cambodian national grid before it is realized (haven't studied this aspect)
6	**Cambodia ⇔ VN (S)** Kampong Cham ⇔ Tay Ninh (100 km) Sizes: 200, 400, 600 MW	36 – 58	Cambodia imports surplus from VN initially and hydro is developed to defer coal in Cambodia. Later, Cambodia develops coal and offsets gas capacity in VN	Requires Cambodia to develop its transmission network covering the north region hydro resource and southern corridor for thermal expansion	Network developments within Cambodia required
2	**Myanmar (C) ⇔ Thailand (N)** Yangon area ⇔ Mae Moh (350 km) Sizes: 500 MW	228	Myanmar does not need to build generators as quickly, instead they benefit from power imports from Thailand.	Critical that the link be supported by grid reinforcement within Myanmar to transfer power from Thailand to the north of Myanmar via the Yangon load centre.	Diversity in conditions and different technology mixes in the two power systems.
7	**Myanmar (N) ⇔ Laos (N)** Mandalay ⇔ Luang Namtha (600 km) Sizes: 500, 1000, 2000 MW	683-1,208	Some investments in coal in Myanmar are deferred and/or avoided altogether by 2035. Gas capacity is also avoided from 2033.	Requires slightly less national grid strengthening because power is evacuated from the north of Laos directly to Myanmar North	Results in joint optimisation of new Lao PDR hydro plants with storage and existing hydro in Myanmar allowing for better reserve sharing and optimisation
8	**Myanmar (N/C) ⇔ PRC** Mandalay ⇔ Yunnan (350 km)	1,187-1,624	PRC generation and capacity in substitute for coal and gas in Myanmar Central and	Requires transmission upgrades between Mandalay and Yangon to be	Opportunity to export surplus power into Myanmar with opportunity to

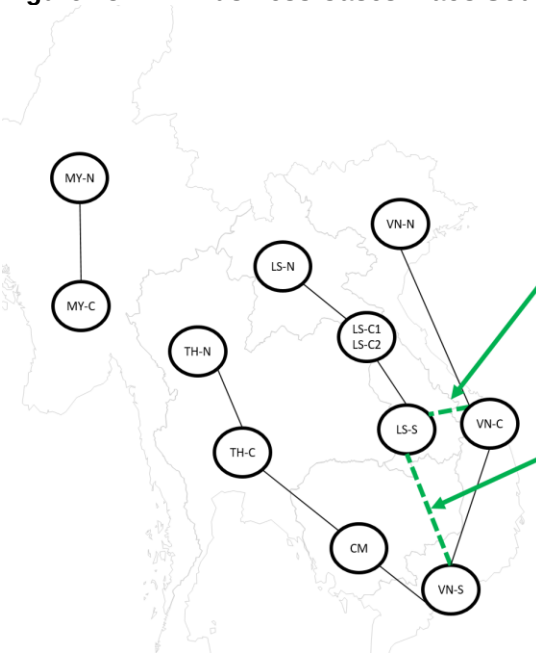
No.	Name and Sizes	NPV Range ($m 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
	Yangon ⇔ Yunnan (800 km) Sizes: 1000 MW		North, respectively	coordinated with the development and to be commissioned successively by 2020-22	sell power to Bangladesh
10	**Integrated Case, all links included except Myanmar N to Laos N** Sizes: Continuous investment modelled	$3.5billion or $2.4billion (China imports valued at $50/MWh)	Significant avoided thermal (mainly coal) capacity, with hydro developments. Avoided generation costs follow that of avoided capacity costs	Critical that national grid reinforcements in Myanmar and Laos are developed to support regional transmission expansion	Diversity in conditions and different technology mixes, significant reserve sharing. All links are developed and all GMS countries connected from the earliest date assumed

Note: Business Case 4 (Thailand to Cambodia) was not studied separately but was included in the Integrated Case (#10).

7.1 Business Case 1 and 3: Laos South to Viet Nam (Central and South)

This sub-section discusses Business Case 1 (BC1) and Business Case 3 (BC3) results against the Base Case. Business Cases 1 and 3 are of the transmission projects from Ban Soc (Lao PDR) to Pleiku (Viet Nam), and Ban Soc (Lao PDR) to Tay Ninh (Viet Nam) respectively. The size options studied include 500, 1000 and 2000 MW. This is shown in Figure 28 with the corresponding assumed cost tabled in Figure 29.

Figure 28 Business Cases: Laos South to Viet Nam



No.	Region (From)	Region (to)	Connection Points (From – To)	Length (km) & Sizes (MW)
1	Lao PDR (South)	Viet Nam (Central)	Ban Soc/Ban Hatxan ⇔ Pleiku	190 km **(500, 1000, 2000 MW)**
3	Lao PDR (South)	Viet Nam (South)	Ban Soc/ Ban Hatxan ⇔ Tay Ninh via Stung Treng	320 km **(500, 1000, 2000 MW)**

Examine different size interconnections

Figure 29 Business Case 1 and 3 Investment Cost

From	To	Size (MW)	Cost ($m's)
Lao PDR (South)	Vietnam (Central)	500	162
		1,000	207
		2,000	266
Lao PDR (South)	Vietnam (South)	500	272
		1,000	349
		2,000	448

7.1.1 Capacity and Generation Outcomes

Figure 30 and Figure 31 plot the capacity development differences between the two (2) business cases and the base case (positive represents additional capacity in the business case). In summary:

- Additional hydro installed capacity offsets coal capacity in both BC1 and BC3. Approximately 1,600 MW of coal capacity (in Viet Nam South) is replaced by 3,300 MW of hydro capacity in Laos South and 600 MW in Central 2 (roughly 2 MW of hydro for every 1 MW of coal by 2035). Some of the LNG that is brought into Viet Nam North in the longer-term is offset by the additional hydro in Lao PDR.
- There are changes in installed capacity from about 2025, five years after the business cases are modelled. This is due to the system balancing out from, or more efficient use of resources of, generation built in the earlier years.
- Prior to 2025, Viet Nam has sufficient capacity with the replacement gas projects from 2020 to 2025.

Figure 30 Business Case 1 Capacity Difference (Laos South to Viet Nam Central)

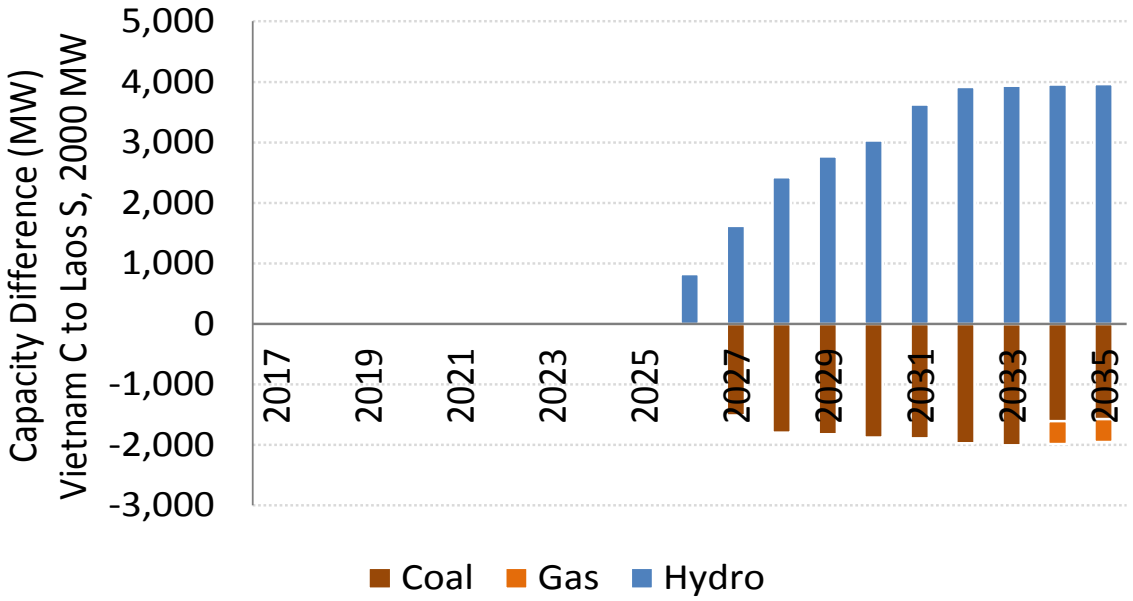


Figure 31 Business Case 3 Capacity Difference (Laos South to Viet Nam South)

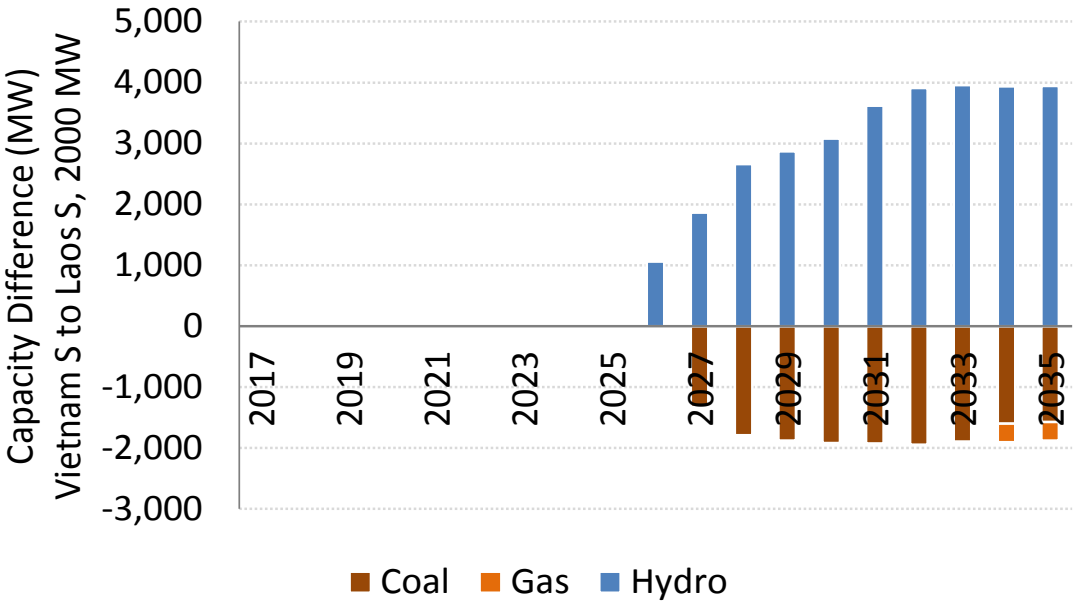


Figure 32 and Figure 33 plot the generation differences between the business cases (2000 MW option) and the base case (positive represents additional generation in the business case). Although capacity differences occur from 2025, generation differences are present from 2020. Lao PDR generation displaces coal and some gas generation in Viet Nam from 2020 which decreases towards 2025 as the systems rebalance with the additional transmission connection then increases in line with the capacity differences discussed above. This trend is consistent between both business cases.

Figure 32 Business Case 1 Generation Difference (Laos South to Viet Nam Central)

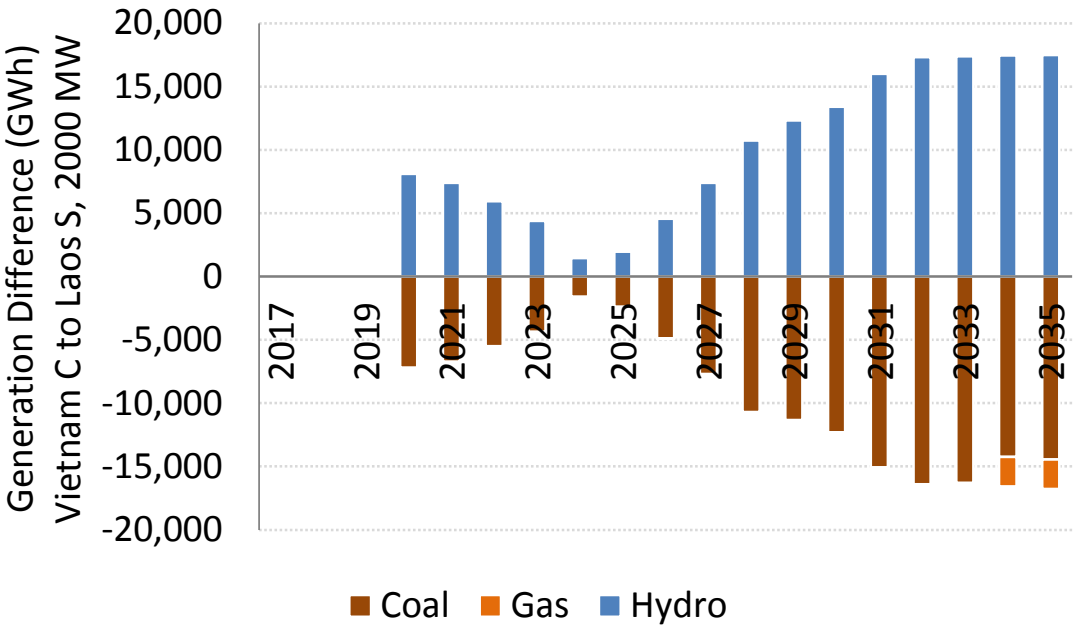
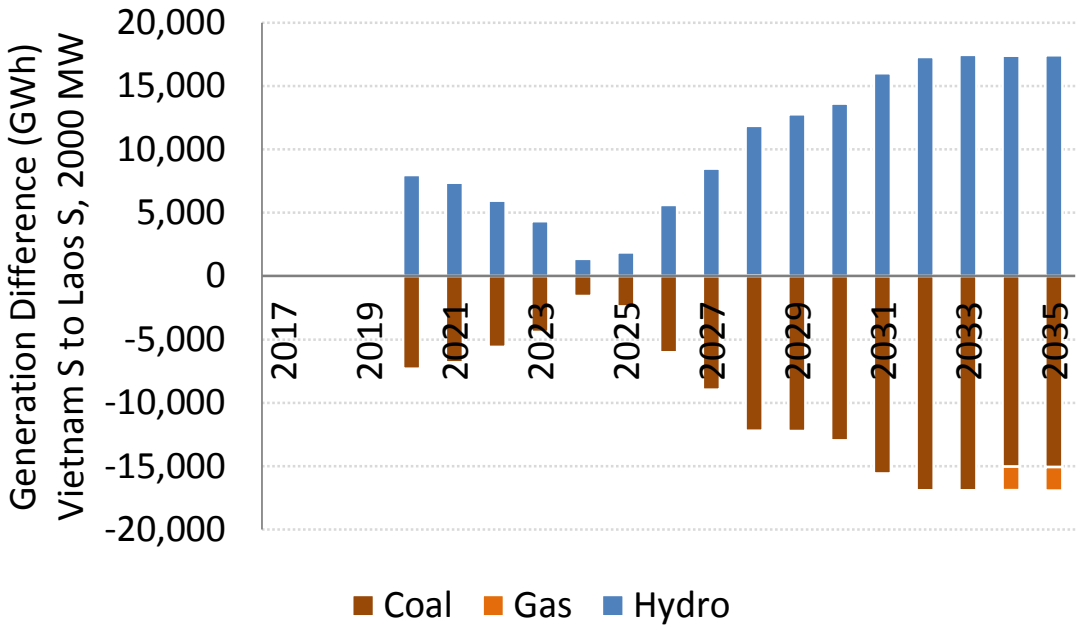


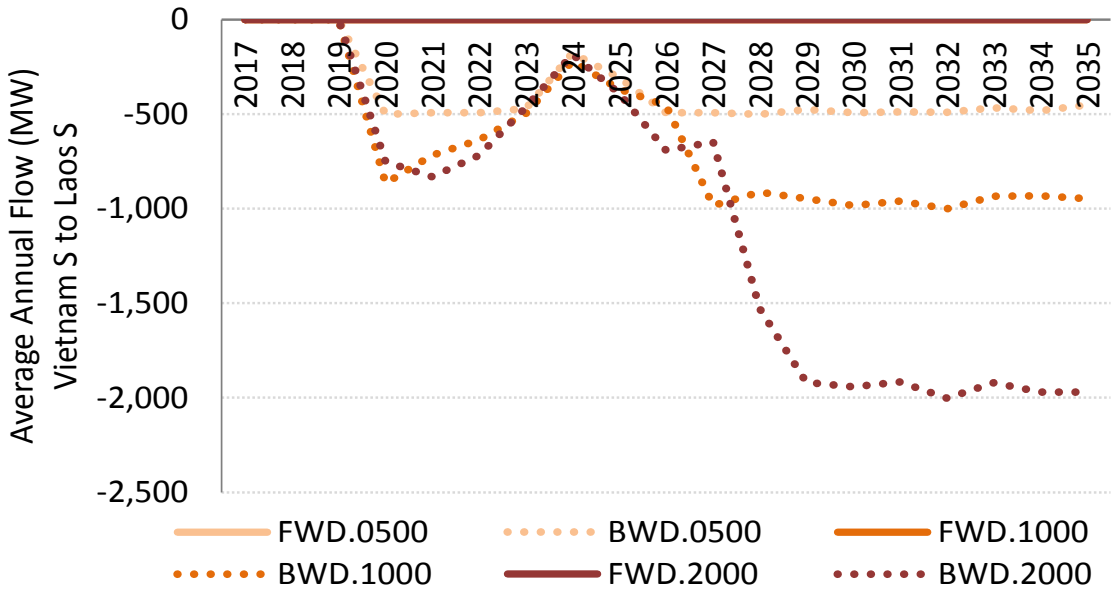
Figure 33 Business Case 3 Generation Difference (Laos South to Viet Nam South)



Power Flows

Figure 34 plots the annual average flow difference across the BC3 link for both forward (into Lao PDR) and backward flows (into Viet Nam) across all of the size options. The flows on the link result in additional flows from Lao PDR into Viet Nam South from 2020 to 2025 as a result of generation cost differences between hydro (Lao PDR) and coal (Viet Nam). From 2025, the flows increase as additional hydro is developed in Laos displacing coal developments in southern Viet Nam. The flexibility in Lao PDR hydro (large storages at the country level) drives the link utilisation towards 100% by 2028. Differences in power flows are presented for Business Case 3 only as the results for Business Case 1 are very similar.

Figure 34 Business Case 3 Annual Flows (Laos South to Viet Nam South)



Monthly flows across the link for the 2000 MW option is plotted in Figure 35 below. Flows on a monthly basis for the years 2020, 2025, 2030 and 2035 (for 2000 MW option) show a flat profile which increases in line with additional Lao PDR hydro developments. By 2025, Lao PDR leverages its storage capability across its power system to use stored water from the wet season for the dry season to deliver baseload power similar to coal projects in Viet Nam.

Figure 35 Business Case 3 Monthly Flows (Laos South to Viet Nam South)

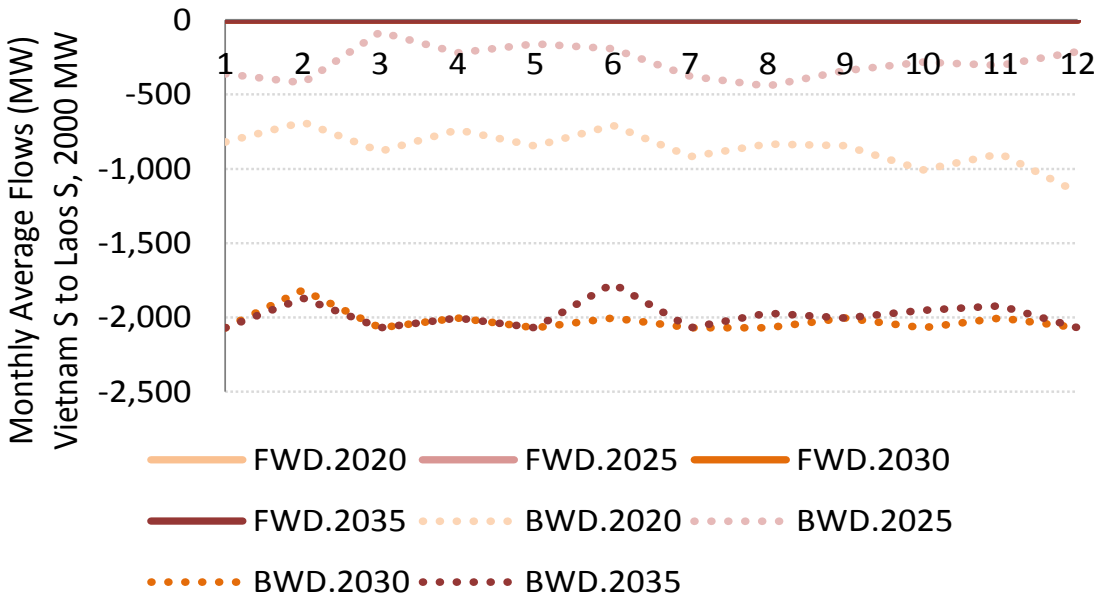


Figure 36 to Figure 38 plot the developed transmission capacities within the Lao PDR national transmission system for both business cases and the Base Case. The Base Case only requires gradual augmentations to the intra-country links to meet domestic demand, however, BC1 and BC3 require significant grid strengthening in Laos timed with the business case link. From Laos N through to the south region is required to support additional flows through to Viet Nam Central and South from 2020. Laos is able to leverage hydro storages and evacuate surplus generation in the North to the South region to Viet Nam with the additional augmentations over the Base Case.

In relation to the Viet Nam network, BC1 requires no major upgrades on Viet Nam network and BC3 defers the need for Viet Nam transmission expansion between the South and Central region (500 MW).

Figure 36 National Transmission Upgrades (Laos N to C1)

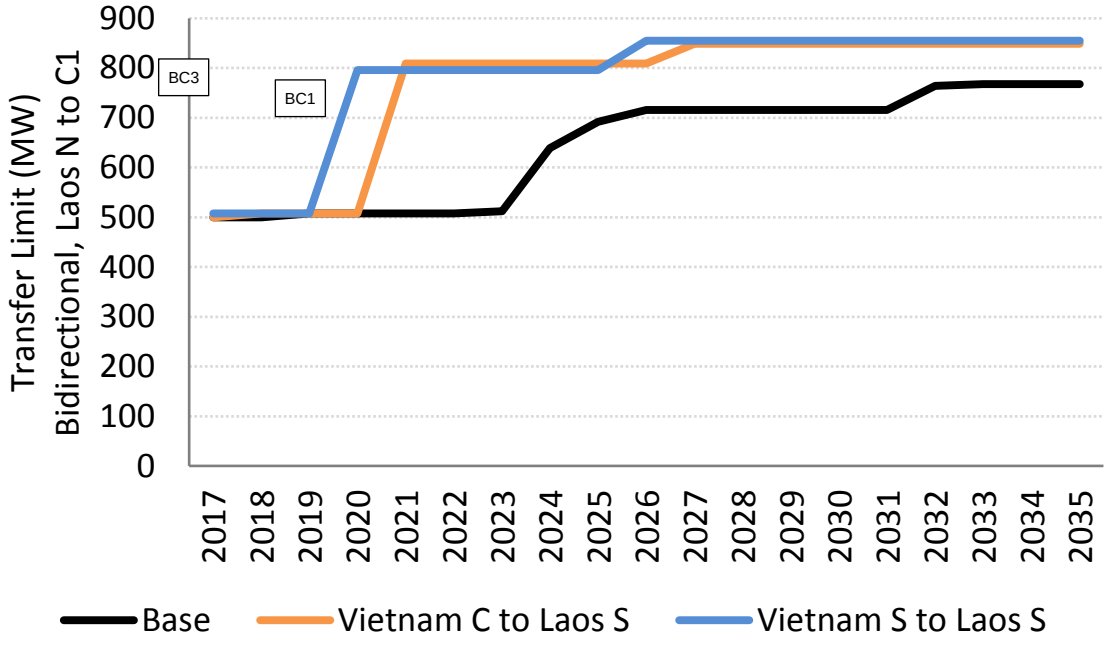


Figure 37 National Transmission Upgrades (Laos C1 to C2)

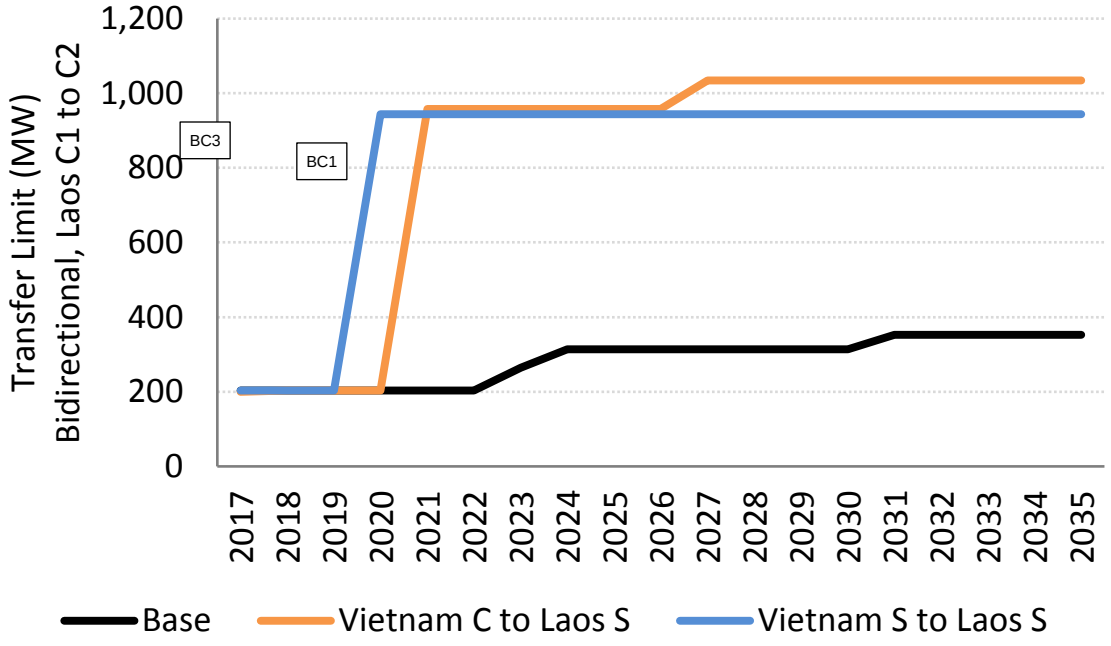
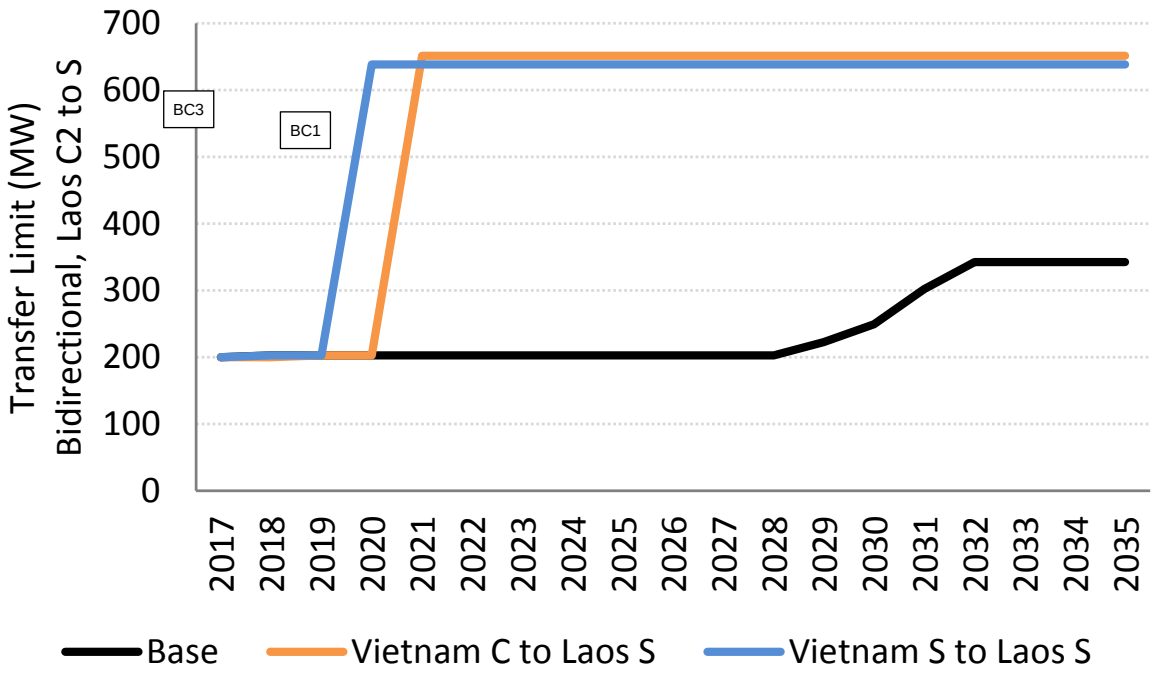


Figure 38 National Transmission Upgrades (Laos C2 to S)



7.1.2 Costs and Benefits

The annual benefits for the Viet Nam South to Laos South (BC3) are plotted in Figure 39. The result for BC1 is very similar and is not shown. Annual benefits become significant with the additional capex in hydro in Lao PDR offsetting fuel cost savings associated with displaced coal generation and gas to lesser extent. The cost of the national grid augmentations are insignificant compared to the other cost components.

Figure 39 Costs and Benefits of BC3 against Base Case

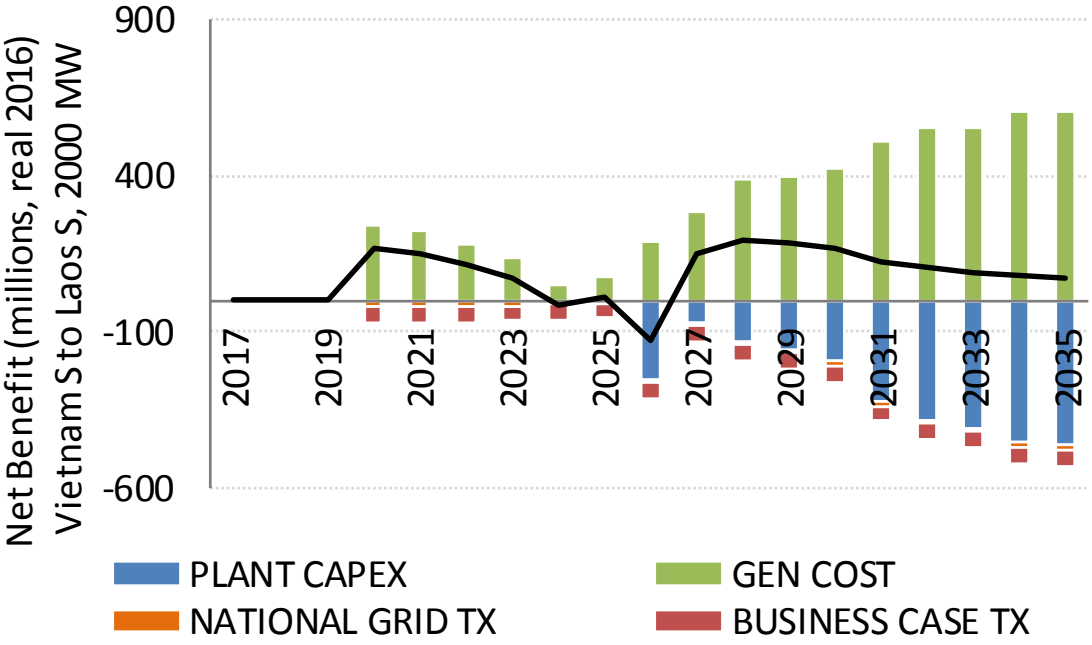
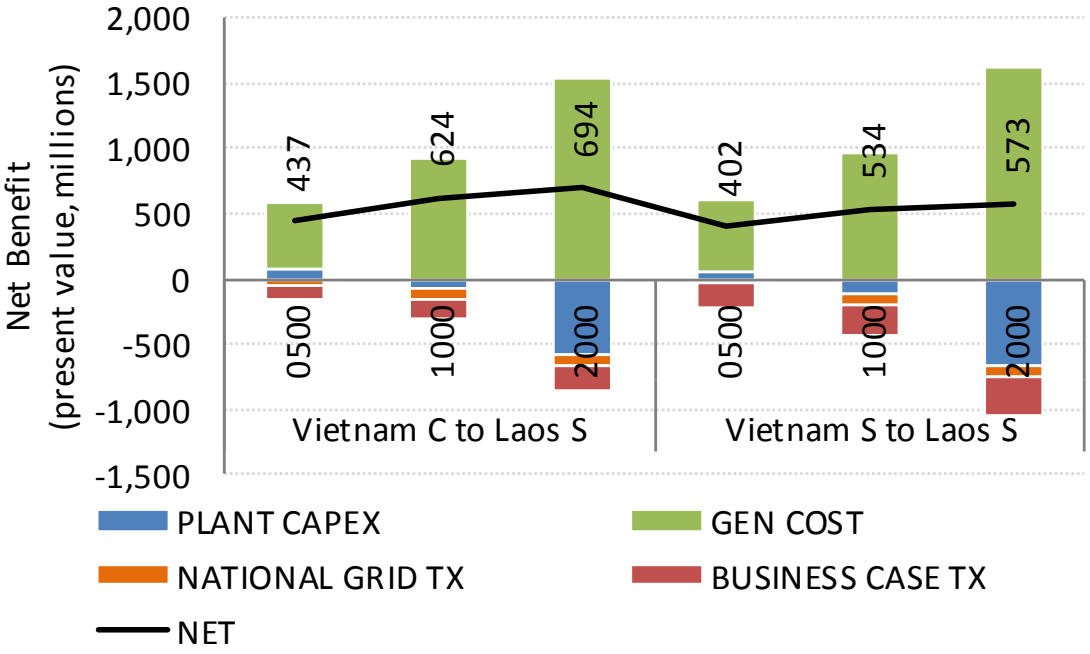


Figure 40 plots the net present value (at 2017 and discounted at 10% pa) of the benefits of both business cases for all of the option sizes studied. In all cases, avoided generation benefits exceed transmission capital and operational expenditures as hydro in Lao PDR substitutes for coal in Viet Nam. Both business cases have highest NPV for the 2000 MW link size.

Figure 40 Net Present Value (Business Case 1 and 3)



7.1.3 Key Insights

A summary of the key insights from the modelled results are provided in Table 18.

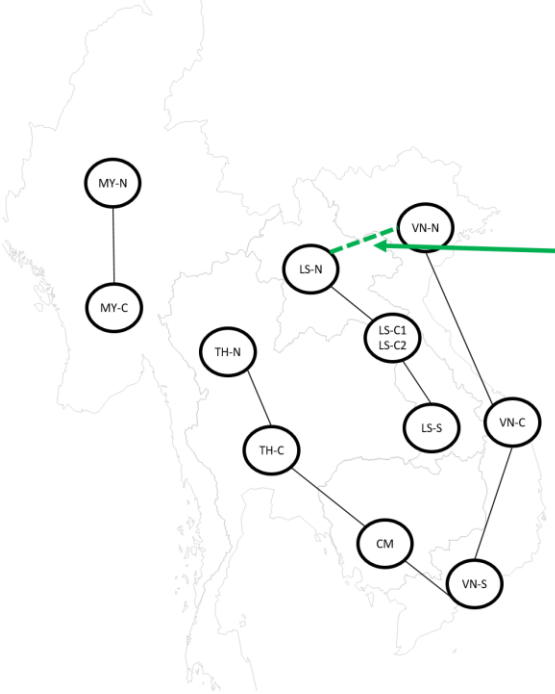
Table 18 Key Insights (Business Case 1 and 3)

General	Implications for Laos	Implications for Viet Nam	Other
Under the least-cost planning scenarios, development of hydro in Laos benefits Viet Nam	Significant export opportunities for Laos to develop hydro for exports into Viet Nam	BC1 requires a similar transmission development plan to Base case	To some extent BC1 and BC3 would be mutually exclusive investments
From 2020-25, generation from committed developments augments supplies in Viet Nam	National grid strengthening in Laos to better utilise storage Laos' hydro storages and to evacuate a growing surplus in northern Laos and hydro resources in the centre and south	BC3 defers 500 MW of augmentation from Central to South link from 2024 to 2033	Business Case 1 (Laos South to VN Central) observed to deliver the greatest NPV for 2000 MW size
Beyond 2025, Laos hydro developments (3300 in the South and 600 MW in central 2) defers the need for 1600 coal developments in Viet Nam South and 300 MW of gas in the North (Laos hydro substitutes for imported coal in VN)		Can avoid up to 2000 MW of coal investment (and some gas) with imported hydro power from Laos	Economics of hydro vs. coal important

7.2 Business Case 9: Laos North to Viet Nam North

This sub-section discusses the Business Case 9 (BC9) results against the Base Case. Business Case 9 is for the link from Xam Nau (Lao PDR) to Nho Quan (Viet Nam). The size options studied include 1500, 2500 and 3500 MW. This is shown in Figure 41 below with the corresponding assumed cost tabled in Figure 42.

Figure 41 Business Cases: Laos North to Viet Nam North



No.	Region (From)	Region (to)	Connection Points (From – To)	Length (km) & Sizes (MW)
9	Lao PDR (North)	Viet Nam (North)	Luang Prabang HPP ⇔ Xam Nau (Lao-N) ⇔ Nho Quan	400 km **(1500, 2500, 3500 MW)**

Examine different size interconnections

Figure 42 Business Case 9 Investment Cost

From	To	Size (MW)	Cost ($m's)
Lao PDR (North)	Vietnam (North	1,500	420
		2,500	640
		3,500	896

7.2.1 Capacity and Generation Outcomes

Figure 43 and Figure 44 plot the capacity development and generation differences between BC9 and the Base Case respectively (positive represents additional capacity/generation in the business case). In summary:

- There is an additional 6,000 MW of hydro built in Lao PDR by 2035 offsetting up to 4,000 MW of thermal generation in Viet Nam;
- Over the period from 2020 to 2025, hydro generation from Lao PDR displaces coal generation in Viet Nam North;
- From 2026, hydro investments in Lao PDR (North 1500 MW, Central 1 and 2 4100 MW and 600 MW in the South) displace investments in coal in Viet Nam (3000 MW deferred in VN from 2028 to 2032, 1900 MW avoided in VN Central, and 950 MW avoided in VN South). Hydro generation displaces Viet Nam coal generation; and
- From 2034, there are VN North gas investments and generation in Viet Nam replaced by the hydro developments in Lao PDR.

Figure 43 Business Case 9 Capacity Difference (Laos North to Viet Nam North)

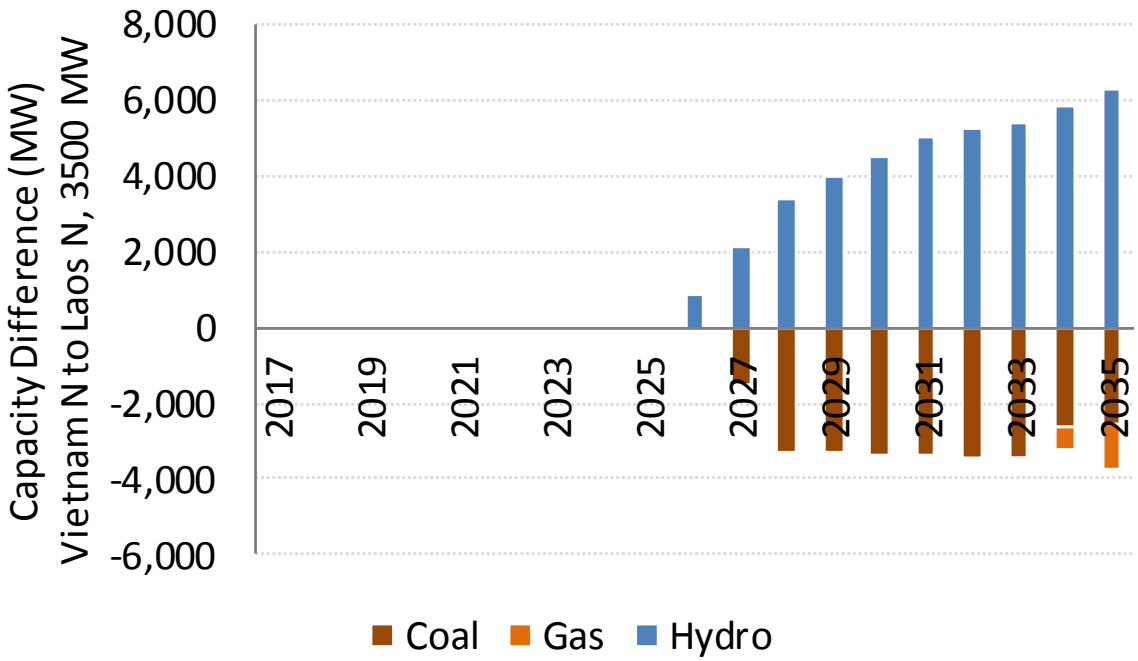
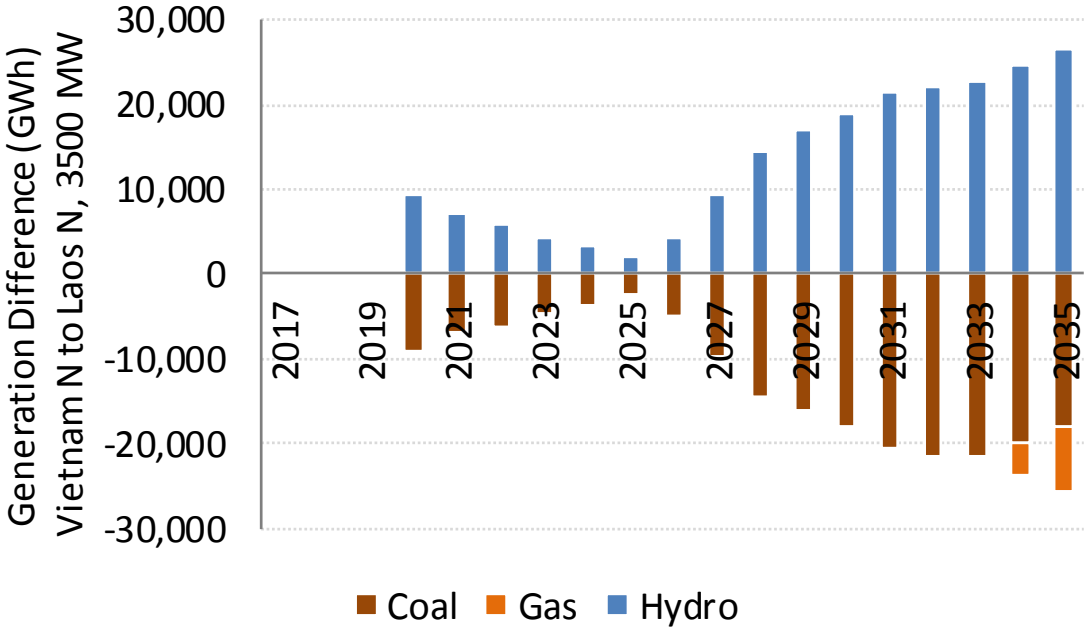


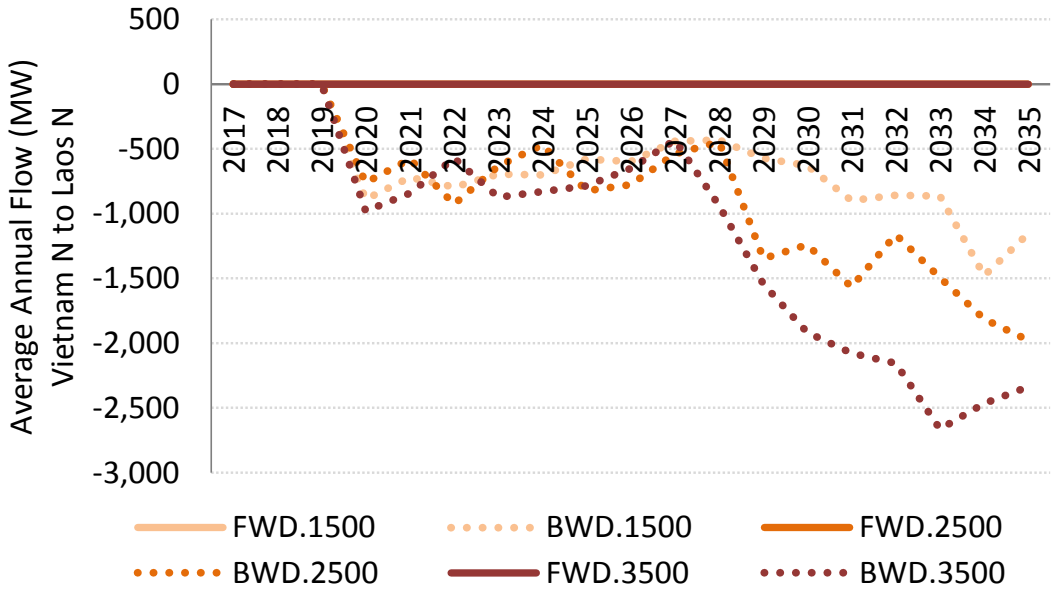
Figure 44 Business Case 9 Generation Difference (Laos North to Viet Nam North)



7.2.2 Power Flows

Figure 45 plots the annual average flow difference across the business case link for both forward (into Lao PDR) and backward flows (into Viet Nam) across all of the size options. The flows on the business link results in additional flows of up to 1,000 MW from Lao PDR into Viet Nam North from 2020 to 2025 as a result of generation cost differences between hydro (Lao PDR) and coal (Viet Nam). From 2027, flows increase as demand grows in Viet Nam and additional hydro is built in Laos (displacing coal developments in Viet Nam). The BC9 link sizes do not have a high utilisation until after 2032.

Figure 45 Business Case 9 Annual Flows (Laos North to Viet Nam North)



Monthly flows across the link for the 3,500 MW option is plotted in Figure 46 below. Flows on a monthly basis for the years 2020, 2025, 2030 and 2035 (for 2000 MW option) show a seasonal profile which dips during the wet season around August and peaks in the drier months of the year. The shape is driven by hydro developments in Lao PDR being coordinated and optimised with Viet Nam's existing hydro generation – Lao PDR hydro is modelled as being more flexible than Viet Nam hydro. Power flows in this business case are seasonal compared to BC1 and BC3 where power flows were more flat.

Figure 46 Business Case 9 Monthly Flows (Laos North to Viet Nam North)

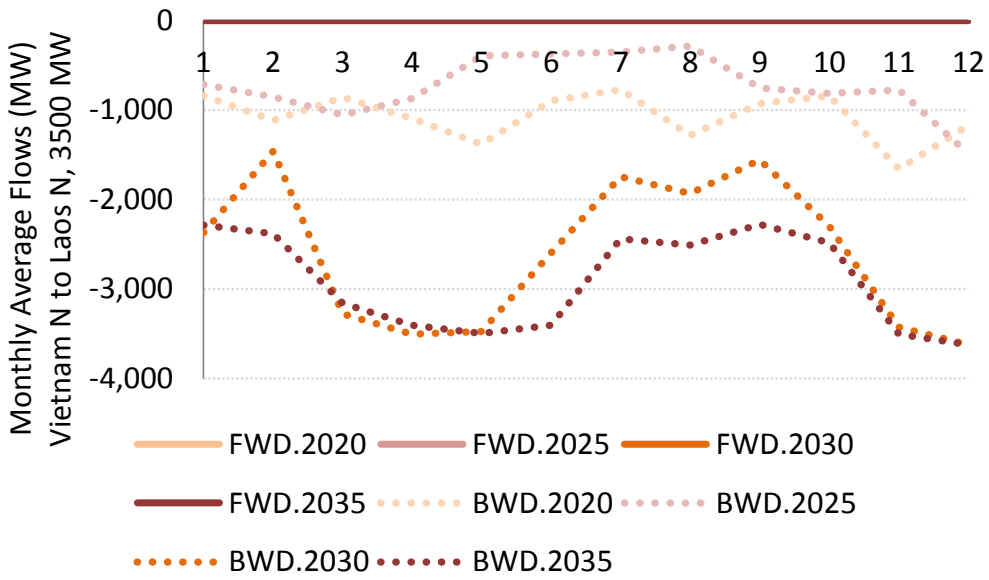


Figure 47 and Figure 48 plot the developed transmission capacities within the Lao PDR and Viet Nam national transmission systems respectively for both the Base and Business Case. Within Lao PDR, the Laos N to C1 link needs significant augmentation from 2030 coinciding with hydro built in Laos offsetting coal capacity in Viet Nam N. There is less national grid strengthening required from Viet Nam Central to the north as power flows from Laos North instead. Compared to BC1 and 3 there are augmentation savings as 1) only minor augmentations are required in the internal Laos grid. Up to 750 MW is required on the N to C1 link compared to 650-1000 MW required from 2020 in BC1 and BC3 on all links, and 2)

there is an immediate need for increases on existing link capabilities in BC1 and BC3 whereas the N to C1 link switches direction within existing limits (i.e. No additional cost) in BC9.

Figure 47 National Transmission Upgrades (Laos, 3500 MW BC option)

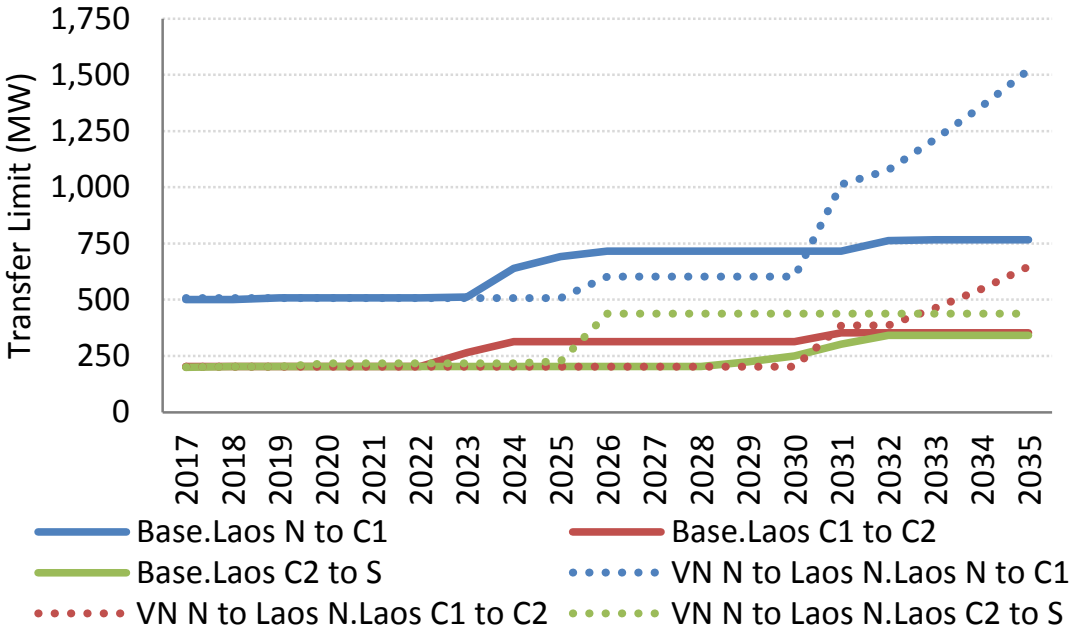
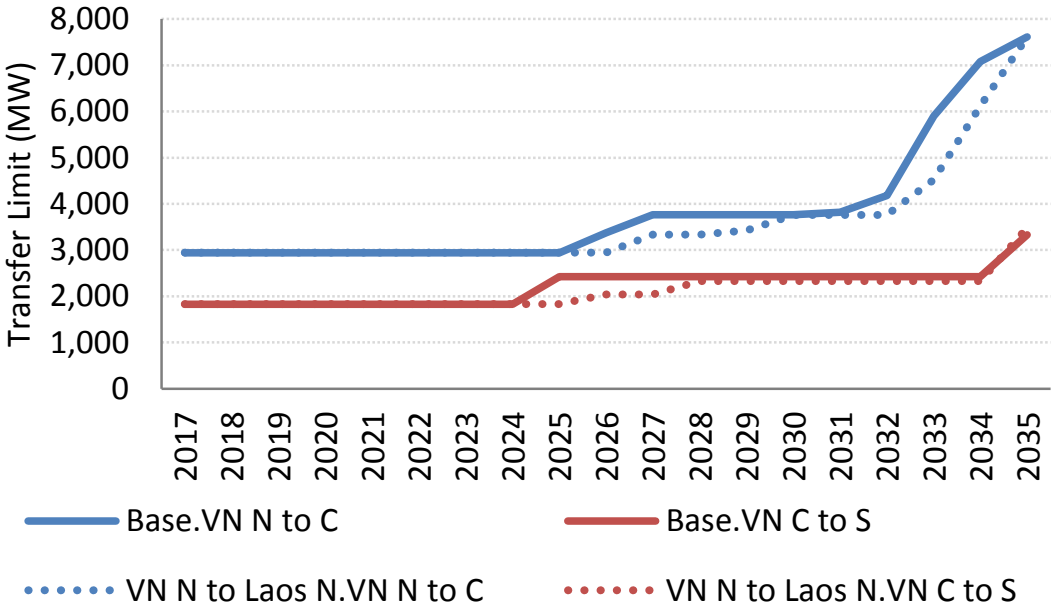


Figure 48 National Transmission Upgrades (Viet Nam, 3500 MW BC option)



7.2.3 Costs and Benefits

The annual benefits for the Viet Nam North to Laos North (BC9) business case (3500 MW option) is plotted in Figure 49. The result is similar to BC1 and BC3 with generation cost savings from 2020 decreasing towards 2025 and ramping back up in line with additional investments in Lao PDR hydro displacing coal capacity in Viet Nam. Annual benefits become significant with the additional capex in

hydro in Lao PDR offsetting fuel cost savings associated with displaced coal generation and gas to lesser extent towards 2035.

Figure 49 Costs and Benefits of BC9 against Base Case

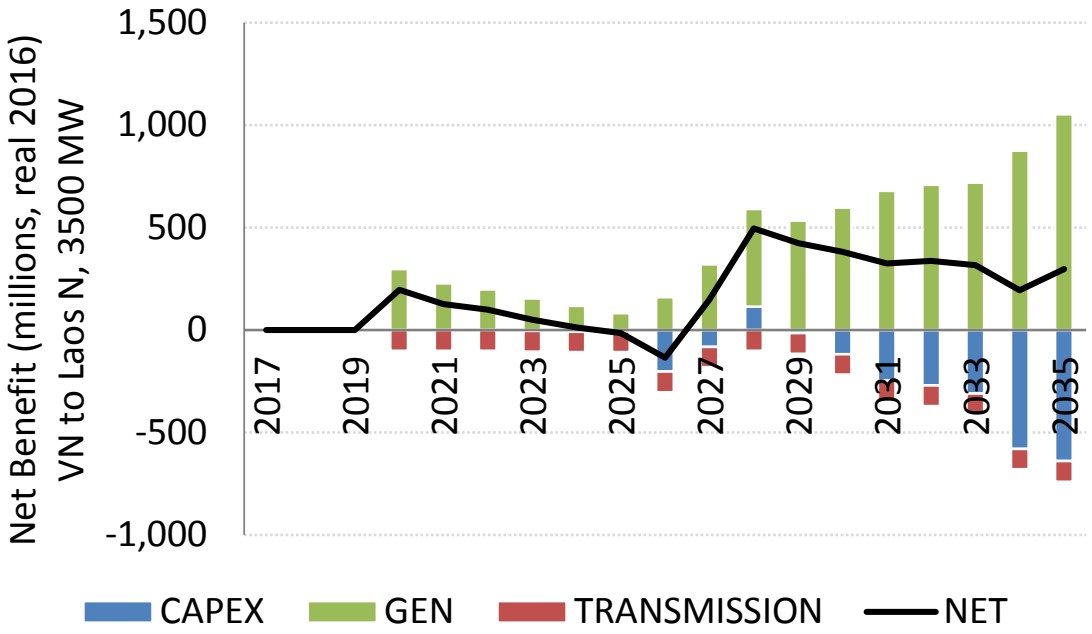
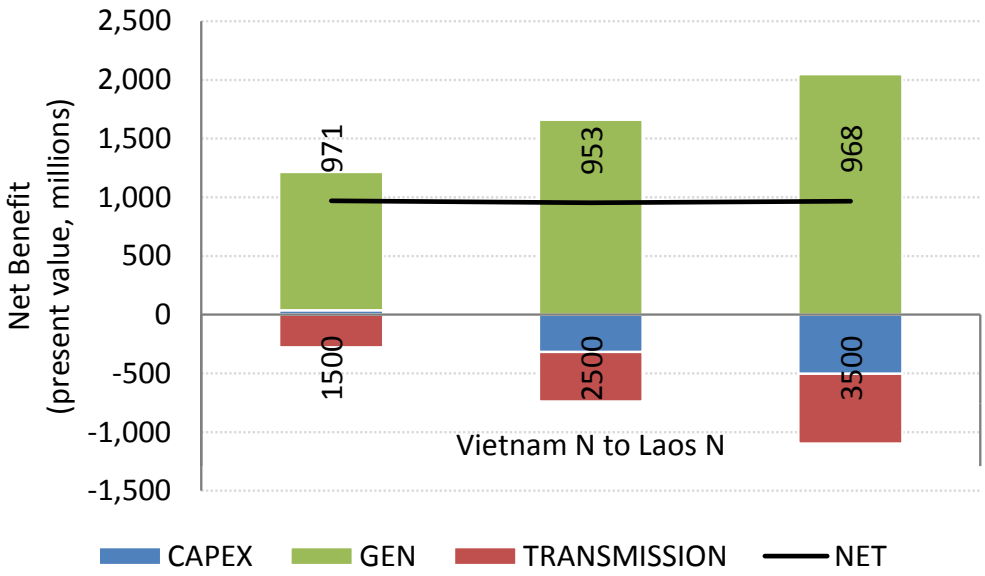


Figure 50 plots the net present value (at 2017 and discounted at 10% pa). In all cases, avoided generation benefits exceed costs of transmission, generation capital and operational expenditures as hydro in Lao PDR substitutes for coal in Viet Nam. Optimal sizing options for this business case appears to be 1500 MW although there is not much difference between the options.

Figure 50 Net Present Value (Business Case 9)



7.2.4 Key Insights

Summary of the key insights from the modelled results are provided in Table 19 below.

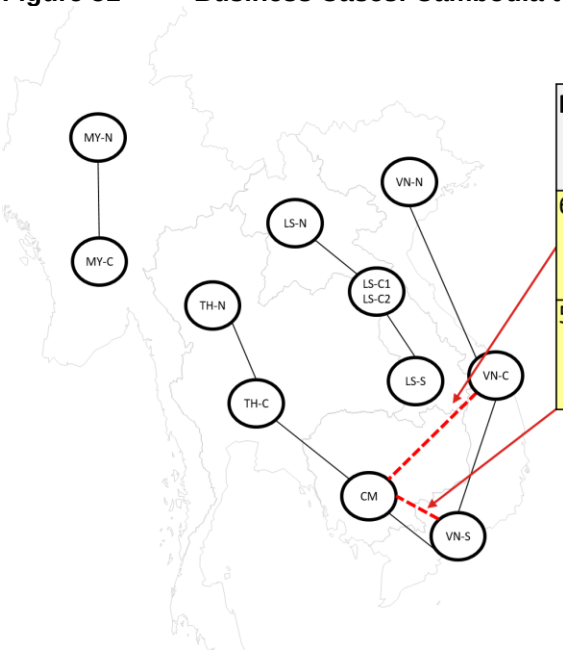
Table 19 Key Insights (Business Case 9)

General	Implications for Laos	Implications for Viet Nam	Other
Under the least-cost planning scenarios, development of hydro in Laos benefits Viet Nam	North to C1 link flows expected to switch back towards the North	Investments in coal in Viet Nam North are deferred initially (up to 3000 MW from 2028 to 2032) and coal in the central and south are avoided altogether by 2035 (1900 and 950 MW respectively). 1300 MW of gas capacity is avoided in 2034/35 in Viet Nam North	Link sizes examined each resulted in similar overall NPVs of net benefit
2020-25, generation from committed developments augments supplies in Viet Nam	Much less hydro development in the south of Laos	Requires slightly less national grid augmentation as the Base case	Power flows on the business case were of a more seasonal nature compared to BC1 and BC3
Export opportunity results in 6000MW of additional development of hydro in Laos in regions N/C1+C2/S (1500, 4100, 650 MW respectively)	BC9 requires less grid strengthening prior to 2030 in Lao PDR compared to in BC1/3 because power is evacuated from the north of Laos directly to VN North	Case results in joint optimisation of new Lao PDR hydro plants with storage and existing hydro in Viet Nam which has the effect of making the hydro generation in Viet Nam more “firm”. This will require coordination from Laos and Viet Nam	

7.3 Business Case 5 and 6: Cambodia to Viet Nam (Central and South)

This sub-section discusses Business Case 5 (BC5) and Business Case 6 (BC6) results against the Base Case. Business Cases 5 and 6 are of the transmission projects from Lower Se San 2 (Cambodia) to Pleiku (Viet Nam), and Kampong Cham (Cambodia) to Tay Ninh (Viet Nam) respectively. The size options studied are shown in Figure 51 below. BC5 is additional to the existing 200 MW interconnection between Phnom Penh to Viet Nam South. Figure 52 summarises the estimated cost of the projects.

Figure 51 Business Cases: Cambodia to Viet Nam



No.	Region (From)	Region (to)	Connection Points (From – To)	Length (km) & Size (MW)
6	Cambodia	Viet Nam (Central)	Lower Se San 2 HPP ⇔ Pleiku	230 km **(200, 400, 800 MW)**
5*	Cambodia	Viet Nam (South)	Kampong Cham ⇔ Tay Ninh	100 km **(200, 400, 600 MW)**

Examine different size interconnections

** In regional GMS model, BC5 is essentially additional to an existing 200 MW link from Phnom Penh to Vietnam South. Results are reported for the total flow.*

Figure 52 Business Case 5 and 6 Investment Cost

From	To	Size (MW)	Cost ($m's)
Cambodia	Vietnam (Central)	200	78
		400	156
		800	201
Cambodia	Vietnam (South)	200 (Additional)	68
		400 (Additional)	78
		600 (Additional)	87

7.3.1 Capacity and Generation Outcomes

Figure 53 and Figure 54 plot the capacity development and generation differences between BC5 (600 MW option) and the Base Case (positive represents additional capacity/generation in the business case). Compared to the Base Case, the changes in generation mainly reflect changes in investments. In summary:

- From 2020-25, uncommitted hydro in Cambodia is deferred because Cambodia imports surplus power from Viet Nam initially. This helps with the generation imbalance associated with excess hydro generation during the wet season and low inflows during the dry season.
- From 2026-2031, Cambodia develops hydro which defers Cambodia coal developments. Cambodia imports power from Viet Nam which builds some coal during this period to augment Cambodia's small reservoir hydros during the dry season.
- From 2032, coal in Cambodia is eventually built and reduces the need for gas developments in Viet Nam.

Figure 53 Business Case 5 Capacity Difference (Viet Nam South to Cambodia)

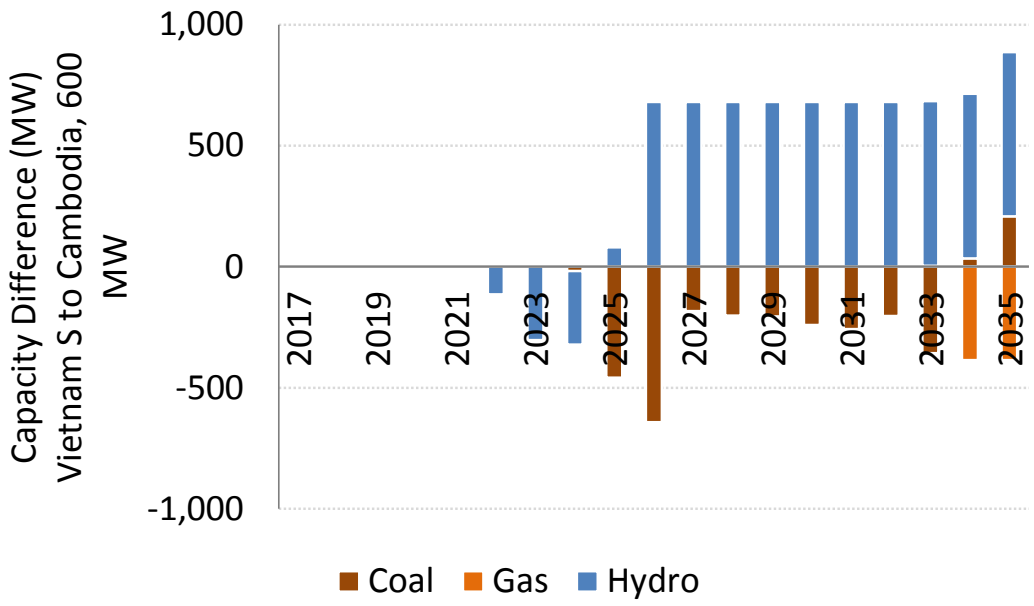


Figure 54 Business Case 5 Capacity Difference (Viet Nam South to Cambodia)

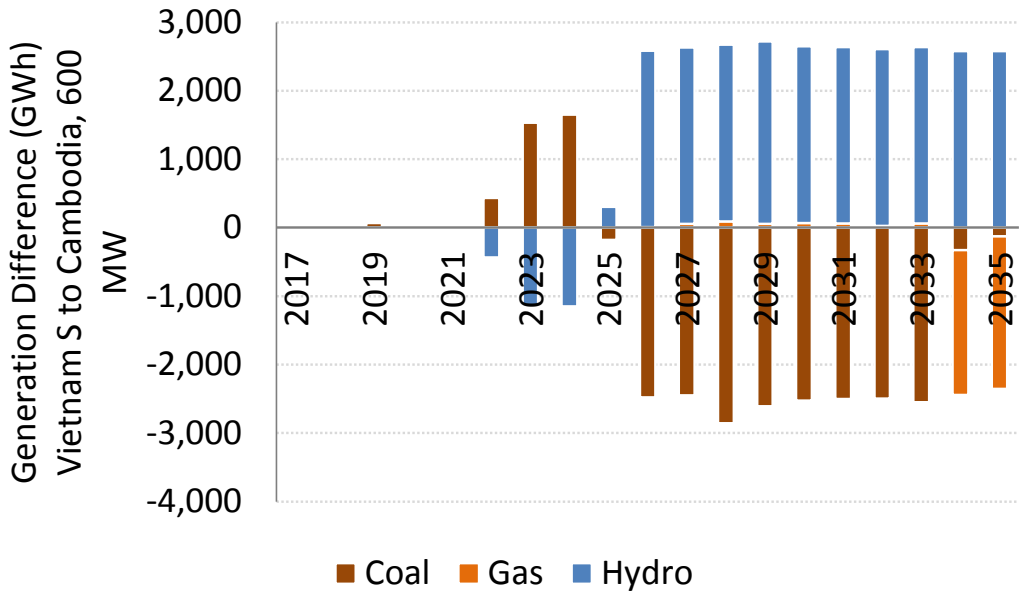


Figure 55 and Figure 56 plot the capacity development and generation differences between BC6 and the base case (positive represents additional capacity/generation in the business case). The results follow a similar story to BC5. In summary:

- From 2020-2025, uncommitted hydro in Cambodia is deferred because Cambodia imports surplus power from Viet Nam initially.
- From 2026-2031, Cambodia develops hydro (though less than in BC5) which defers Cambodia coal developments but imports power from Viet Nam to augment its hydro dry season dispatch. Viet Nam builds a smaller amount of coal during this period to support the power flows.
- From 2032, the coal capacity in Cambodia is eventually built and reduces the need for gas developments in Viet Nam.

Figure 55 Business Case 6 Generation Difference (Viet Nam Central to Cambodia)

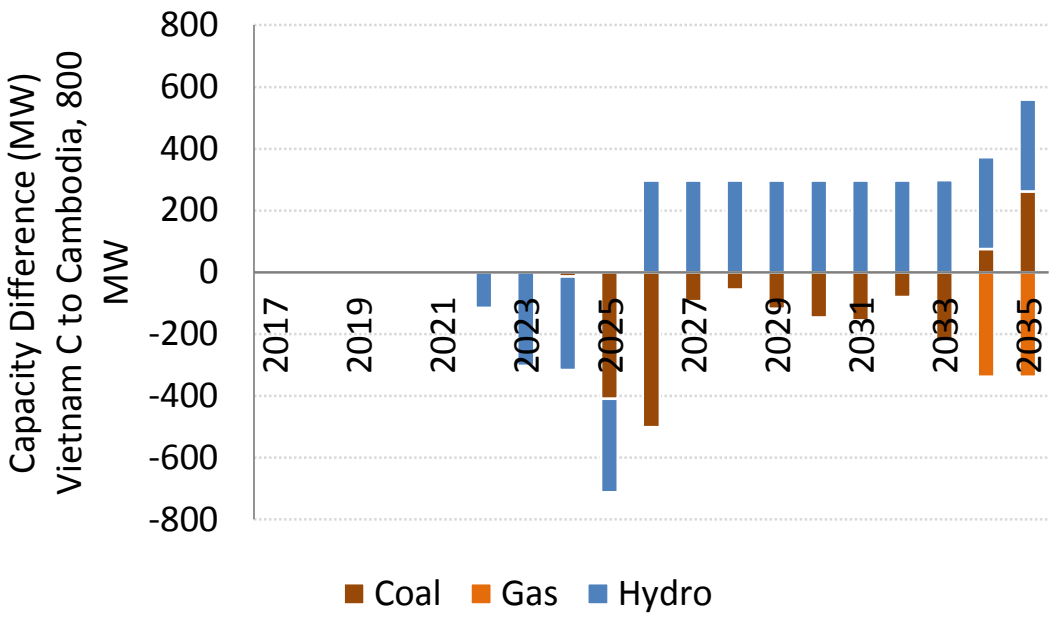
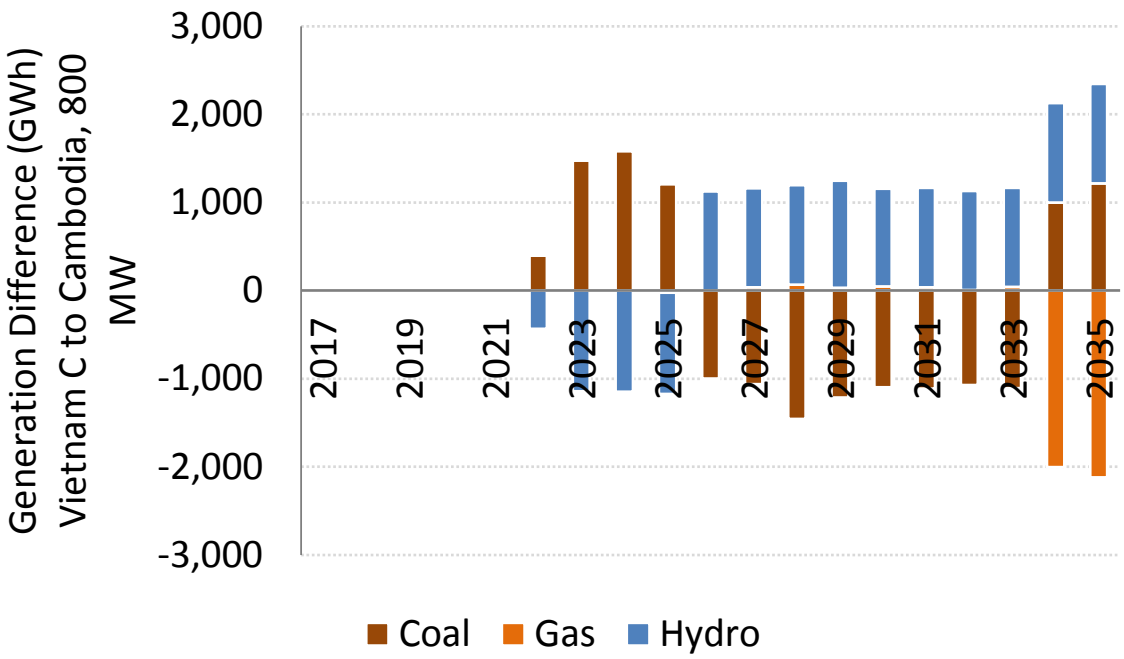


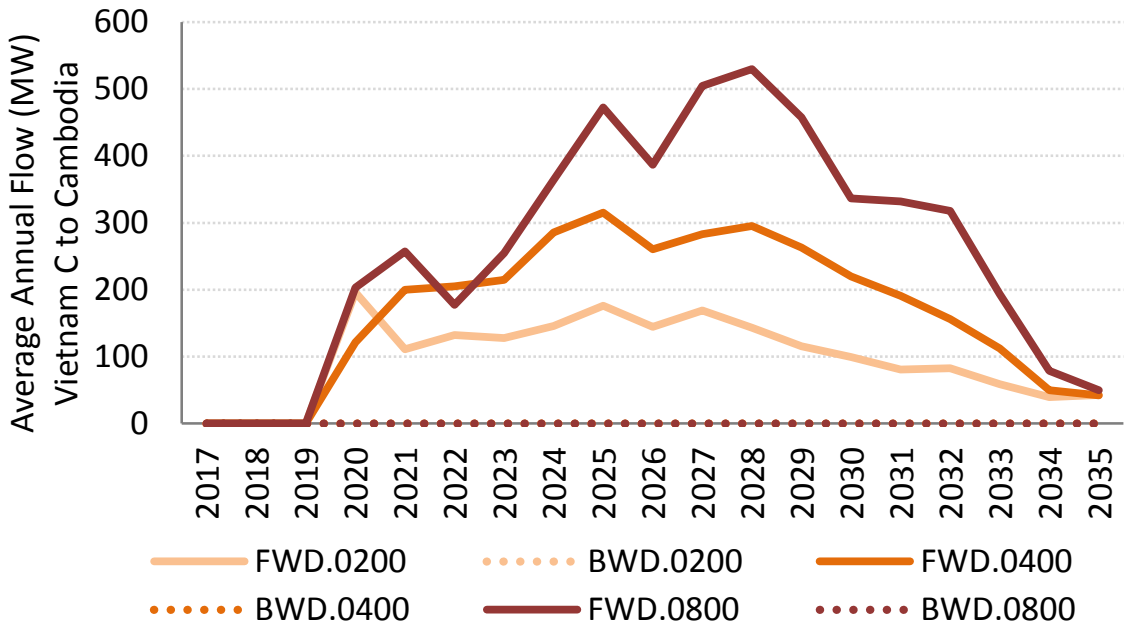
Figure 56 Business Case 6 Generation Difference (Viet Nam Central to Cambodia)



7.3.2 Power Flows

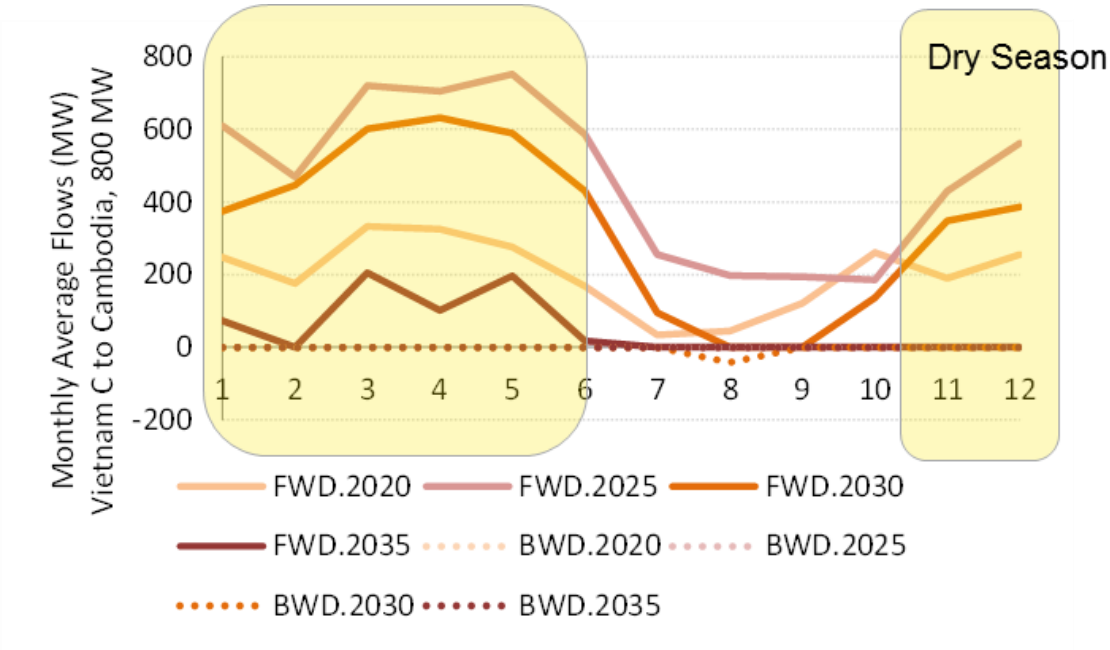
Results are similar across Business Case 5 and 6, and we present just the result for Business Case 6 (Viet Nam C to Cambodia) across the different link sizes. Figure 57 plots the annual average flow difference across BC6 for both forward (into Cambodia) and backward flows (into Viet Nam) across all of the size options. Power flows from Viet Nam to Cambodia and increases towards 2027 followed by a reduction. The trend is driven by hydro developments in northern Cambodia to 2025 (which requires dry season support), followed by thermal plant in southern Cambodia beyond 2025. The 800 MW option has the lowest utilisation out of the three size options.

Figure 57 Business Case 6 Annual Flows (Viet Nam Central to Cambodia)



Monthly flows across the link for the 800 MW option is plotted in Figure 58 below. Flows on a monthly basis for the years 2020, 2025, 2030 and 2035 show the seasonality of flows into Cambodia which dips during the wet season around August and peaks in the drier months of the year. During the wet season, months either side of August, Cambodia has sufficient capacity and energy to cover its own load whereas needs support during the dry season. Flows into Cambodia on the link are highest in 2025, when Cambodia has the highest proportion of hydro in its generation mix (which is assumed to have little storage capability).

Figure 58 Business Case 9 Monthly Flows (Viet Nam Central to Cambodia)



7.3.3 Costs and Benefits

The annual benefits for the Viet Nam C to Cambodia (BC6) business case (800 MW option) are plotted in Figure 59. There is an initial deferral of hydro capex to 2025 followed generator cost savings in the form of displaced coal, though after accounting for the cost of the transmission link results in marginally negative annual benefits – note the lower utilisation factor on the 800 MW line compared to the other options. BC5 costs and benefits are very similar to BC6 and is not shown here.

Figure 59 Costs and Benefits of BC6 against Base Case

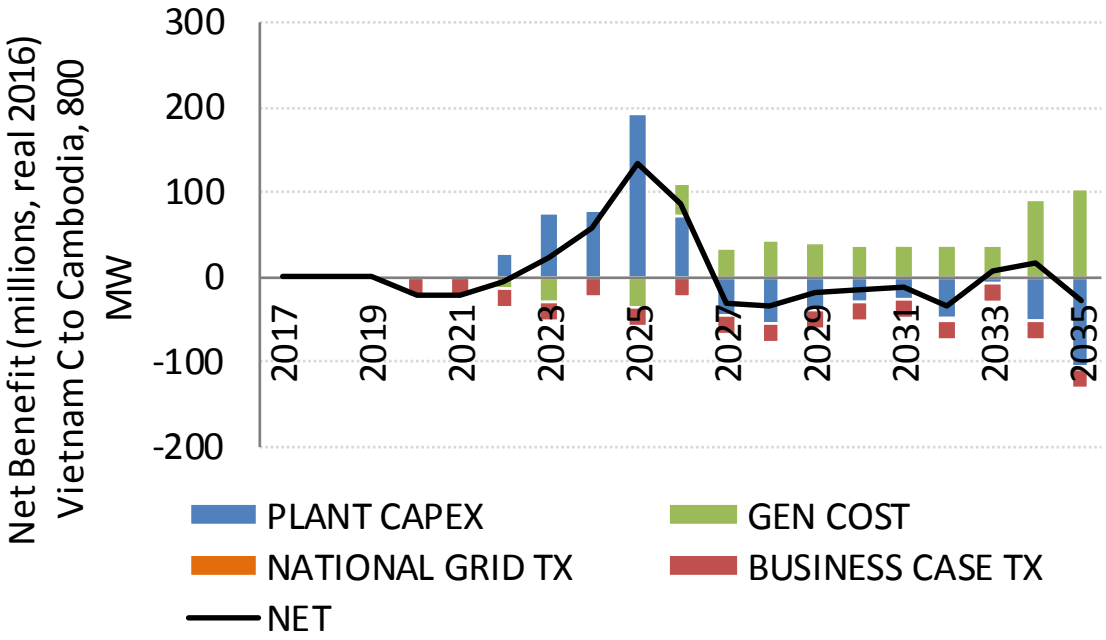
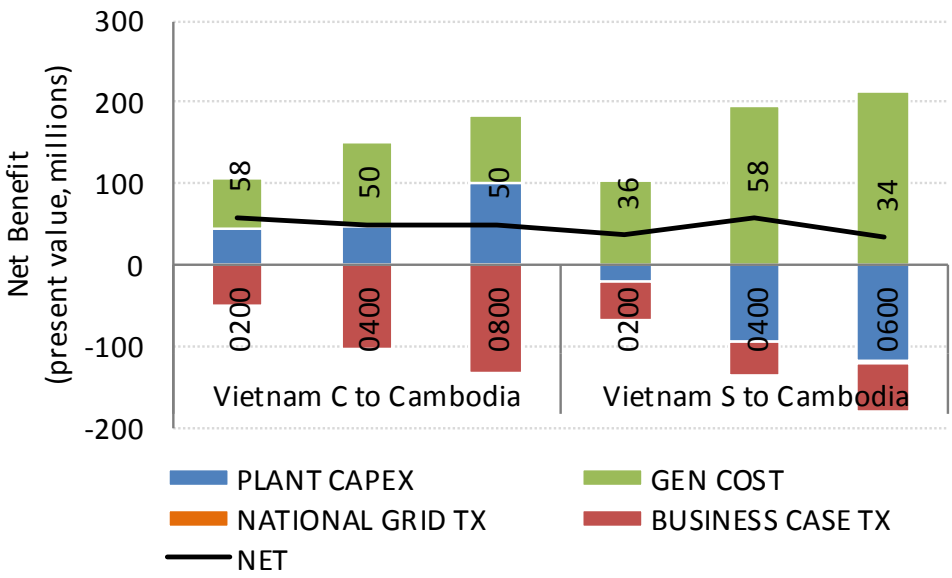


Figure 60 plots the net present value (at 2017 and discounted at 10% pa) of both business cases for all of the option sizes studied. Benefits aren't high as compared to the Laos Business cases for a variety of reasons, 1) the link options are smaller, 2) generation capacity is deferred, but not avoided, to augment hydro generation in Cambodia, and 3) Cambodia hydro does not have significant storage like in Lao PDR and has lower capacity factors in comparison. The optimal sizing options for each of the business cases is 200 MW for Viet Nam Central to Cambodia (BC6) and 400 MW for Viet Nam South to Cambodia (BC5).

Figure 60 Net Present Value (Business Case 5 and 6)



7.3.4 Key Insights

Summary of the key insights from the modelled results are provided in Table 20 below.

Table 20 Key Insights (Business Case 5 and 6)

General	Implications for Cambodia	Implications for Viet Nam	Other
Under the least-cost planning scenarios, development/augmentations of the BC links generally benefits Cambodia	Cambodia will need to develop its transmission network (north region for hydro and south for thermal)	Cambodia is relatively small and does not impact Viet Nam's grid strengthening	Business Case 5 and 6 each resulted in similar overall NPVs of net benefit
The benefits aren't as obvious given there is a deferral of capacity rather than outright displacement as seen in the business cases involving Lao PDR	Supports the existing power development plan to develop north region hydro. Hydro assumed to be relative inflexible with smaller storages and needs to develop its own coal resources	Cambodia will require power support from Viet Nam (dry season) in the medium term as it ramps up hydro developments	Efficient utilisation of resources (coal/gas/hydro) across Cambodia and Viet Nam
	Business case link helps support Cambodia's hydro development initially before building out the southern transmission corridor for thermal units in the Stung Hav node	Shift in coal development timings as a result of the Business Case links, but there are also benefits from avoiding gas investment towards 2035	Economics of hydro vs. coal important
	Cambodia coal and hydro capacity is deferred initially but extra hydro is built with the business case links		

7.4 Business Case 2: Myanmar to Thailand

This sub-section discusses the results of Business Case 2 compared to the Base Case. Business Case 2 studies the transmission project from Yangon area (Myanmar Central) to Mae Moh (Thailand North). The size of the cross-border option studied was 500 MW (350 km). This is illustrated in Figure 61 below with the corresponding assumed cost tabled in Figure 62.

The project itself may alleviate tightness / supply shortages in Myanmar in the short to medium term around the Yangon area, while in the longer-term the link could potentially support the development of power projects in Myanmar to export to Thailand. In summary the project:

- Possibly allows for a better utilisation of power plants in Northern Thailand (Mae Moh) and the Hong Sa power plant in Lao PDR by alleviating transmission congestion between north and central Thailand;
- Will enable effective resource sharing since the reserve margin in Thailand is estimated to be greater than 30% over the next fifteen years;
- Is unlikely to require significant upgrades of transmission networks in Thailand as Mae Moh is already a significant generation hub. It would, however require expansion of transmission and distribution networks in Myanmar; and
- Represents a considerable challenge from construction and operational and maintenance perspectives. Although the length of the transmission lines appears reasonable, they have to go through highly mountainous areas.

Figure 61 Business Cases: Myanmar to Thailand

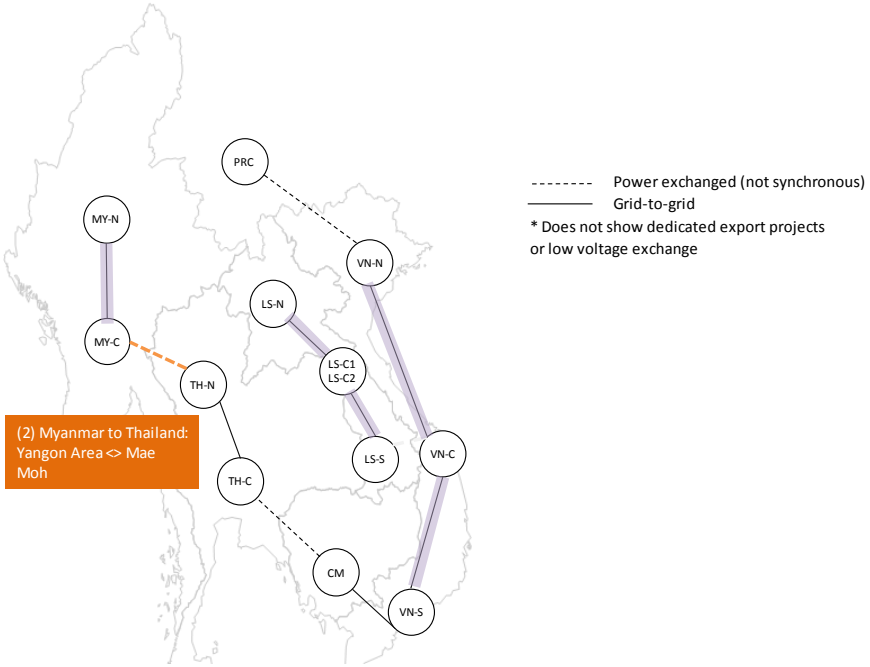


Figure 62 Business Case 2 Investment Cost

From	To	Size (MW)	Cost ($m's)
Myanmar (Central)	Thailand (North)	500	298
		1,000	382
		2,000	490

7.4.1 Capacity and Generation Outcomes

Figure 63 plots the capacity development differences between the business case and the base case (positive represents additional capacity in the business case). In summary:

- Coal capacity in Thailand is deferred 10 years and is substituted with about 500 MW of coal in Myanmar from 2028;
- There is gas capacity in both countries that is avoided altogether from 2030. By 2035 there is a net decrease in capacity required amongst both countries which highlights diversity benefits; and
- There are reserve sharing opportunities due to diversity in load shape and hydro generation sources. This is most apparent in the earlier years with the deferral of coal projects in both Myanmar and Thailand from 2022 to 2027.

Figure 63 Business Case 1 Capacity Difference (Myanmar to Thailand North)

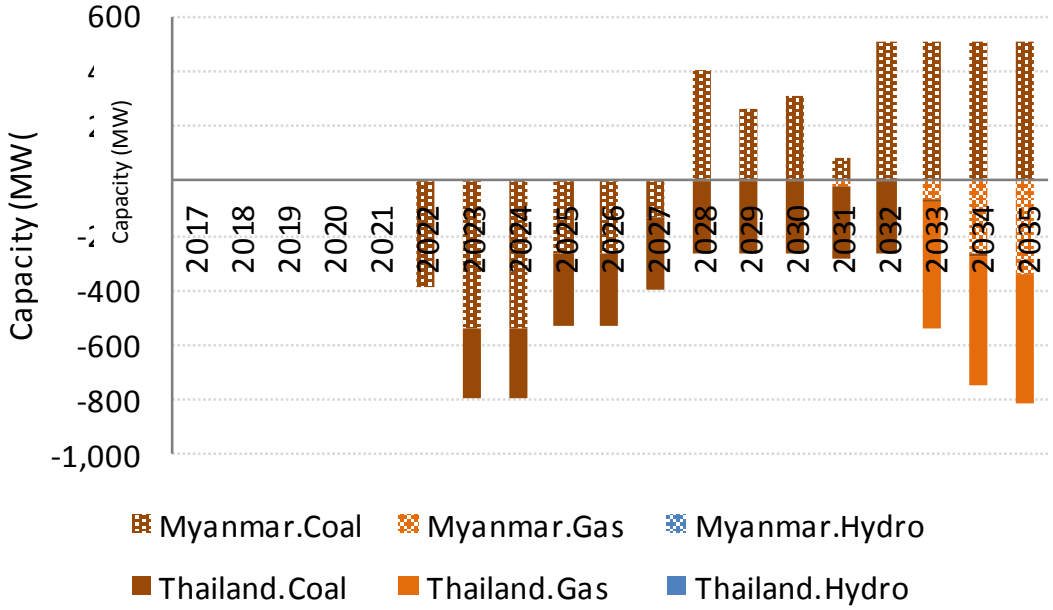
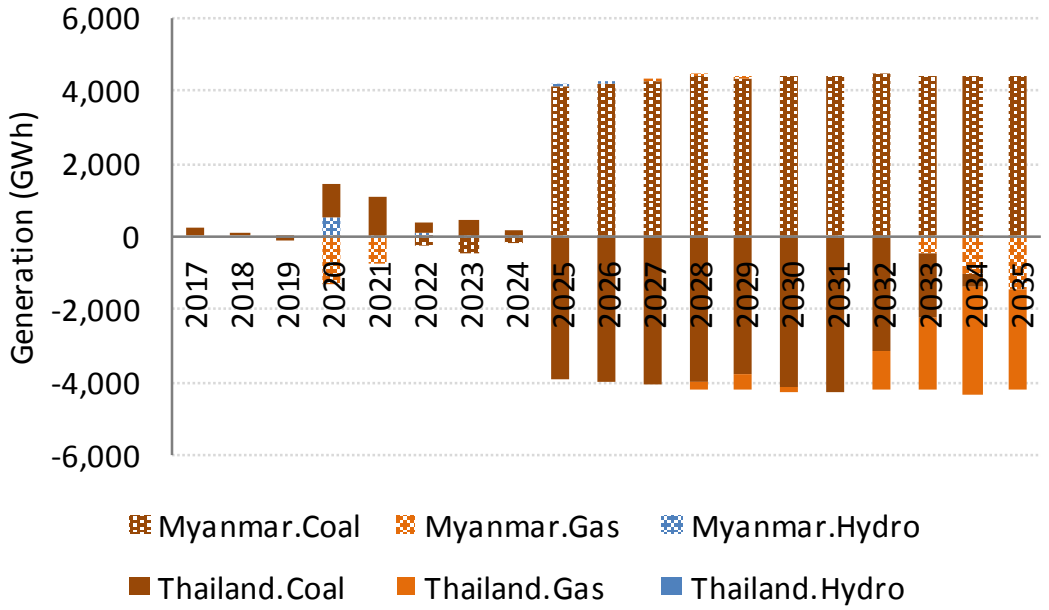


Figure 64 plots the generation differences between the business case and the Base Case (positive represents additional generation in the business case). In summary:

- There is little generation that is displaced in the earlier years as Myanmar itself has a tight supply and demand balance. Myanmar imports up to 1,000 GWh from Thailand in 2020/21with the commissioning of the business case (BC) link for baseload support and to minimise generation costs; and
- From 2025, coal generation in Myanmar displaces coal generation in Thailand (+4,000 GWh), and gas generation in both countries from 2032.

Figure 64 Business Case 1 Generation Difference (Myanmar to Thailand North)



7.4.2 Power Flows

Figure 65 plots the annual average flow across the BC link into Myanmar (positive flows represents flows from Thailand into Myanmar). The BC link initially provides support to Myanmar up to 2024 but switches direction from 2025 as Myanmar develops additional generation capacity over and above supplying its domestic demand for export to Thailand. The link is then fully utilised to maximise benefits resulting from lower generation costs in Myanmar displacing more expensive generation in Thailand.

Figure 65 Business Case Annual Flows (Myanmar to Thailand)

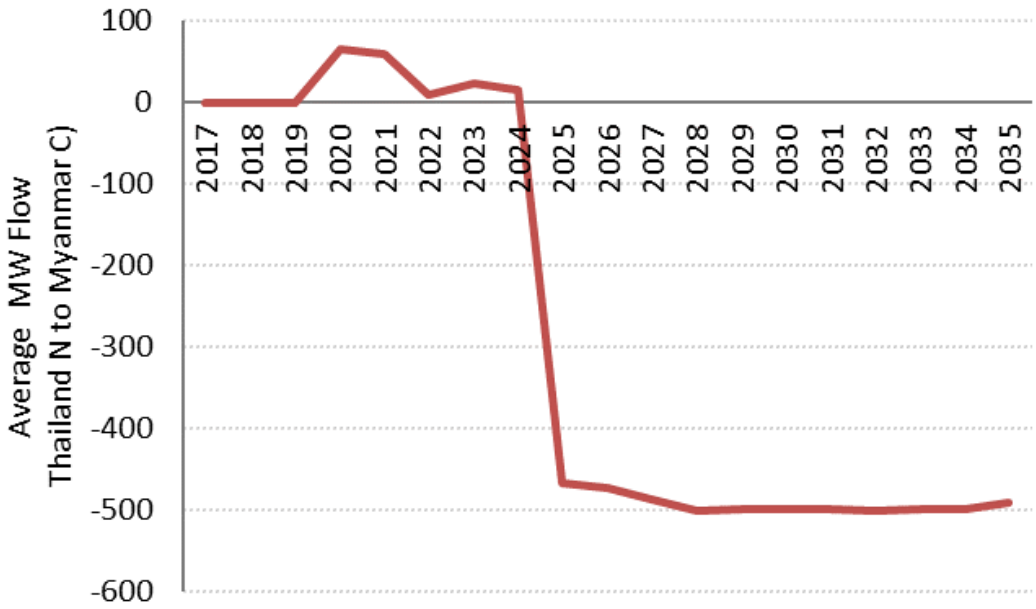


Figure 66 and Figure 67 plot the power transmission flows and augmented capacities within the Myanmar national transmission system for both the business case and Base Case. Positive flows indicate net flows into Myanmar Central. The average flows are from North into Central initially, driven by the delay in committed coal and hydro projects. As the committed projects come online, combined with additional prospective projects, the flows reverse direction (into the North). The BC connects into Myanmar Central and requires earlier augmentations to the national network but reaches 1,500 MW at the same time as the base case in 2030.

Figure 66 National Transmission Flows (Myanmar North to Central)

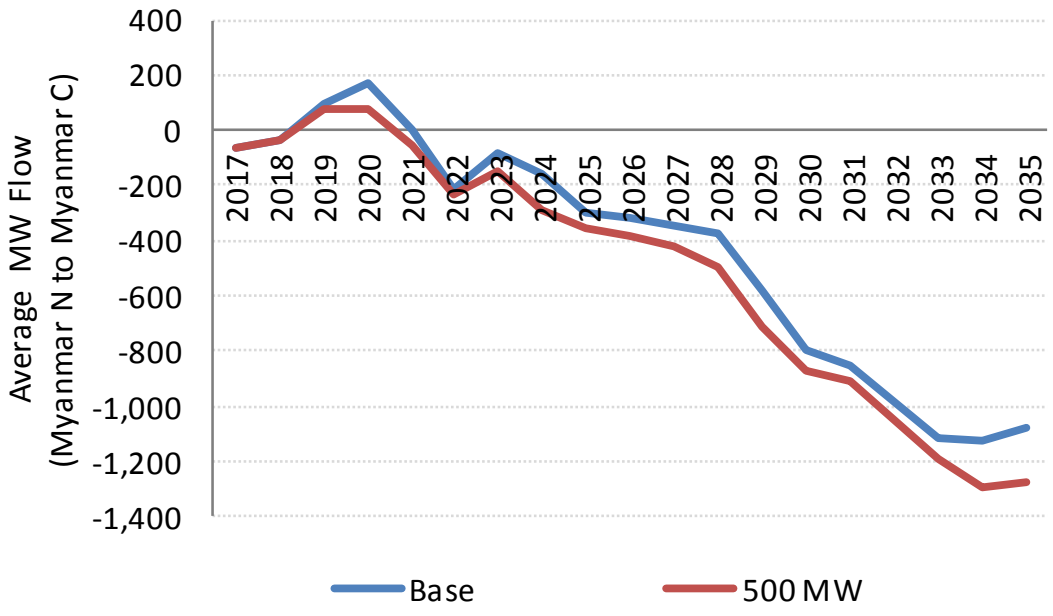
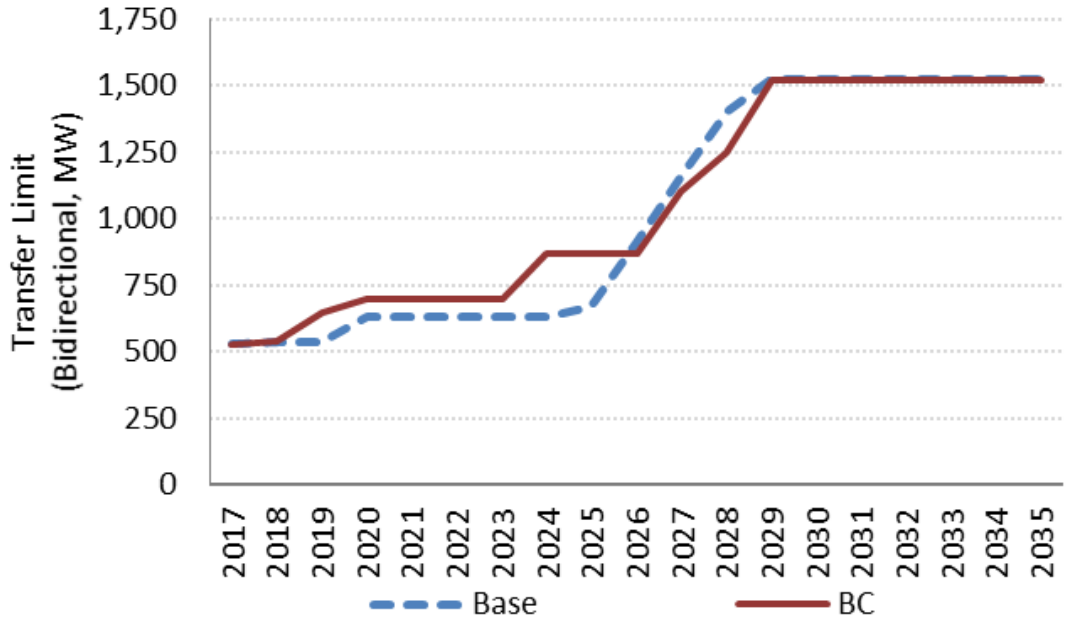


Figure 67 National Transmission Upgrades (Myanmar North to Central)



7.4.3 Costs and Benefits

The annual benefits for the Myanmar to Thailand business case (BC2) are plotted in Figure 68. Annual benefits become are the highest during the earlier years when capacity is deferred in both Myanmar and Thailand as a result of reserve sharing. Towards 2035, generation savings arise due to the displacement of gas generation from additional Myanmar coal developments.

Figure 68 Costs and Benefits of BC against Base Case

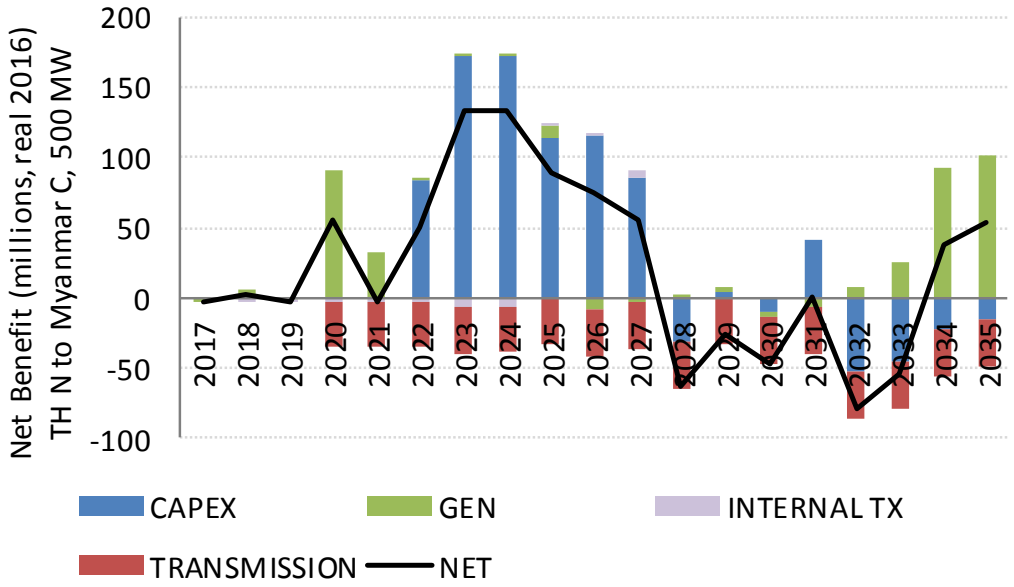
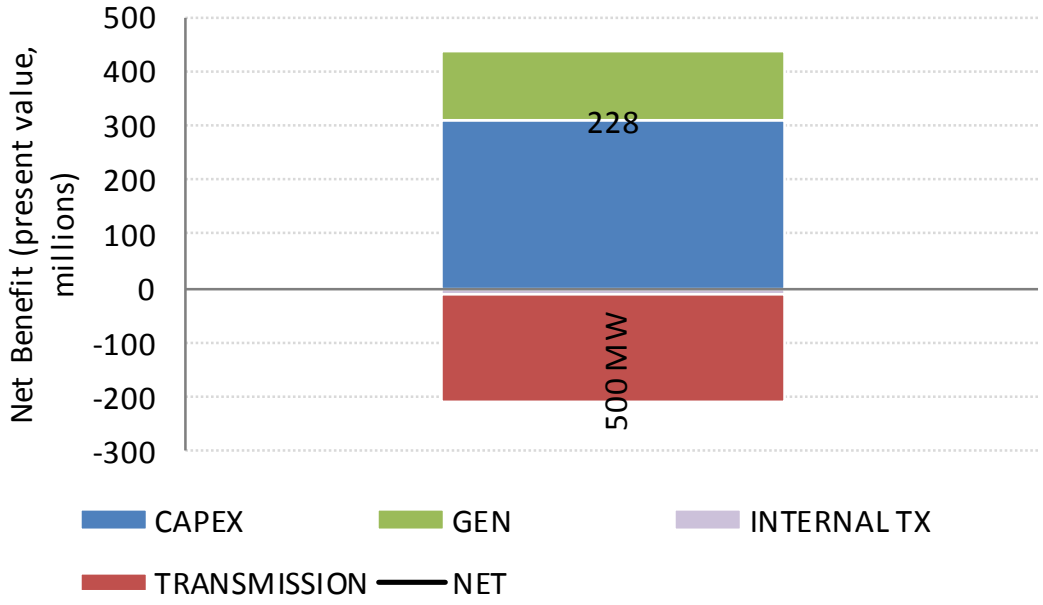


Figure 69 plots the net present value (at 2017 and discounted at 10% pa) of the benefits of both business cases for all of the option sizes studied. The overall $228m net present value comprises positive avoided generation ($124) and capital investment ($311m) costs and exceeds the cost of the BC link cost and national transmission augmentation ($208m combined).

Figure 69 Net Present Value



7.4.4 Key Insights

A summary of the key insights from the modelled results is summarised in Table 21.

Table 21 Key Insights (Business Case 2)

General	Implications for Myanmar	Implications for Thailand	Other
From 2020-25, generation from Thailand augments supply in Myanmar with the delay in committed hydro and coal projects	Myanmar does not need to build generators as quickly, instead they benefit from power imports from Thailand. If the business case is intended to be a stop-gap measure in Myanmar to overcome tightness in supply then it is critical that the link be supported by grid reinforcement within Myanmar to transfer power from Thailand to the north of Myanmar via the Yangon load centre.	"NPV positive" as a consequence of the near-term benefits of Thailand evacuating surplus power to address supply shortages in Myanmar.	Diversity in conditions / different technology mixes in the two power systems.
Beyond 2025, Myanmar has the potential to develop additional capacity to reduce generation costs in Thailand.	Longer-term "swapping" of generation build in Thailand with generation build in Myanmar and has Myanmar as an exporter.	Can avoid up to 800 MW of gas investment with imported coal generation from Myanmar.	Different costs of generation (Thailand is gas based vs. Myanmar coal + hydro).

7.5 Business Case 7: Myanmar to Lao PDR

This sub-section discusses the Business Case 7 (BC7) results against the Base Case. Business Case 7 is for the link from Mandalay (Myanmar North) to Luang Namtha (Laos North). The size options studied were 500, 1000 and 2000 MW (150 km). The business case is illustrated in Figure 70 with the corresponding assumed cost tabled in Figure 71.

The project is intended to ease the power supply shortage in Yangon region, which accounts for more than 50% of the country's electricity demand. The issues of power supply shortage and low electricity access have been highlighted by not only Myanmar officials but also other international organisations including ADB, IEA and APERC. It has the following potential:

- Potential to facilitate effective resource sharing between Lao PDR and Myanmar given their different energy sources and geographical locations;
- Since the majority of generation sources in Lao PDR are hydro, this transmission link will be an additional source of electricity supply, and greater reliability, for Lao PDR;
- Myanmar will also benefit from importing low-cost electricity generated by hydro plants in Lao PDR; and
- This line can potentially contribute towards increased electricity access in both Myanmar and Lao PDR.

Figure 70 Business Case 7: Myanmar North to Laos North

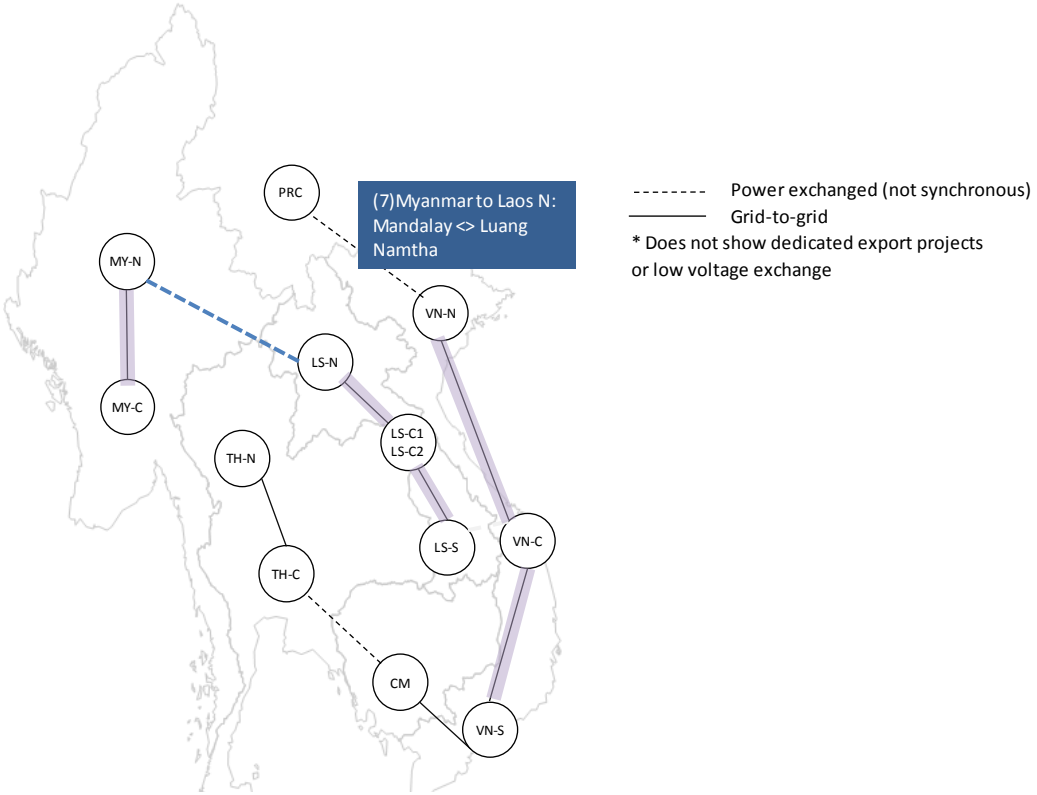


Figure 71 Business Case 7 Investment Cost

From	To	Size (MW)	Cost ($m's)
Myanmar (North)	Lao PDR (North)	500	510
		1,000	654
		2,000	840

7.5.1 Capacity and Generation Outcomes

Figure 72 to Figure 74 plot the capacity development differences between the BC7 options and the Base Case (positive represents additional capacity in the business case). In summary:

- Coal from Myanmar Centre region and gas developments from the North is offset from the introduction of surplus hydro imported from Laos North;
- Additional hydro is developed in Laos (commensurate with the sizing of the interconnector) to offset additional coal and gas generation;
- The capacity between hydro and coal/gas which is avoided is roughly at a ratio of 2 to 1 consistent with the relative capacity factors of the underlying technologies.

Figure 72 BC7 Capacity Difference (Myanmar North to Laos North, 500 MW option)

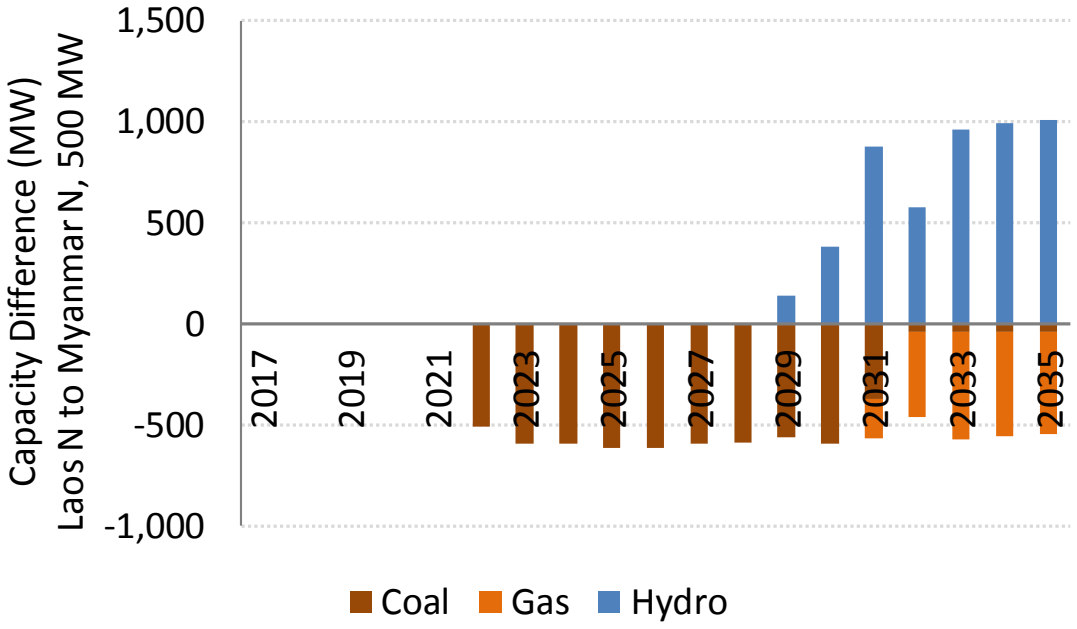


Figure 73 BC7 Capacity Difference (Myanmar North to Laos North, 1000 MW option)

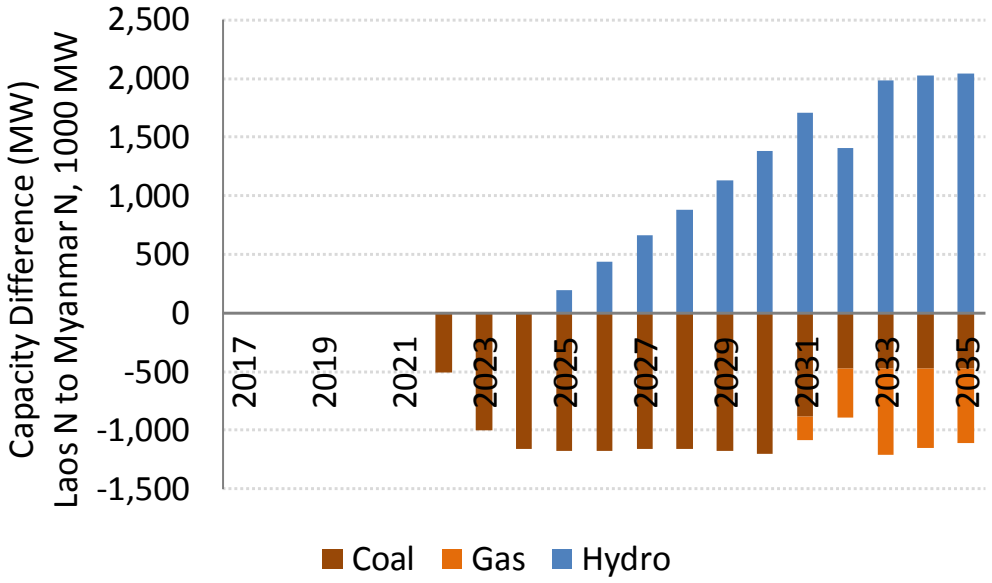


Figure 74 BC7 Capacity Difference (Myanmar North to Laos North, 2000 MW option)

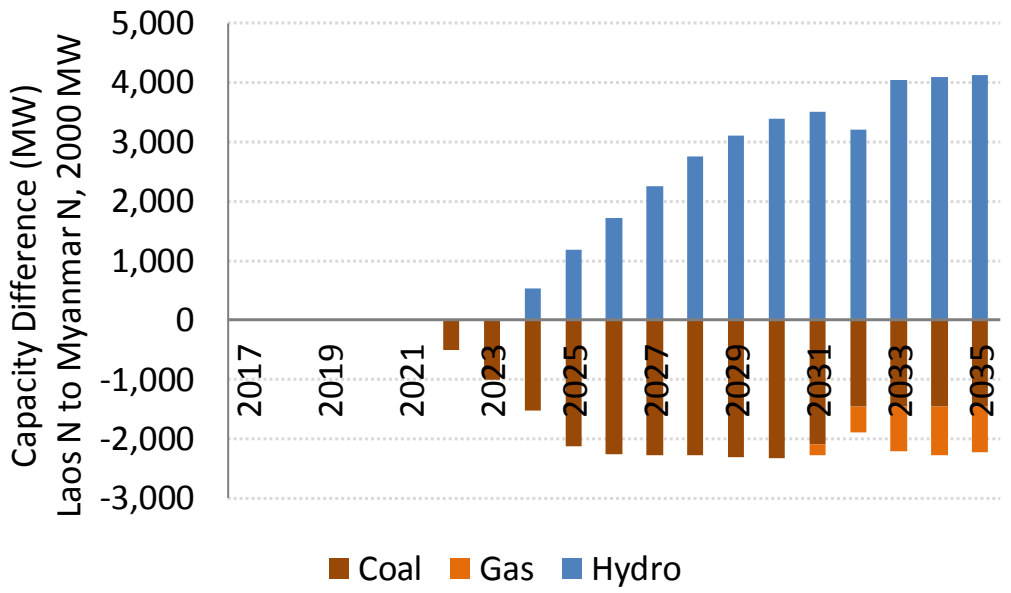


Figure 75 to Figure 77 plot the generation development differences between the BC7 options and the Base Case (positive represents additional generation in the business case). In summary:

- Generation in Myanmar is offset by hydro generation from Laos;
- There is less displacement of gas in Myanmar as a consequence of Take or Pay assumptions;
- The larger the business case link the higher the thermal generation that is displaced in Myanmar and flow across the link.

Figure 75 BC7 Generation Difference (Myanmar North to Laos North, 500 MW option)

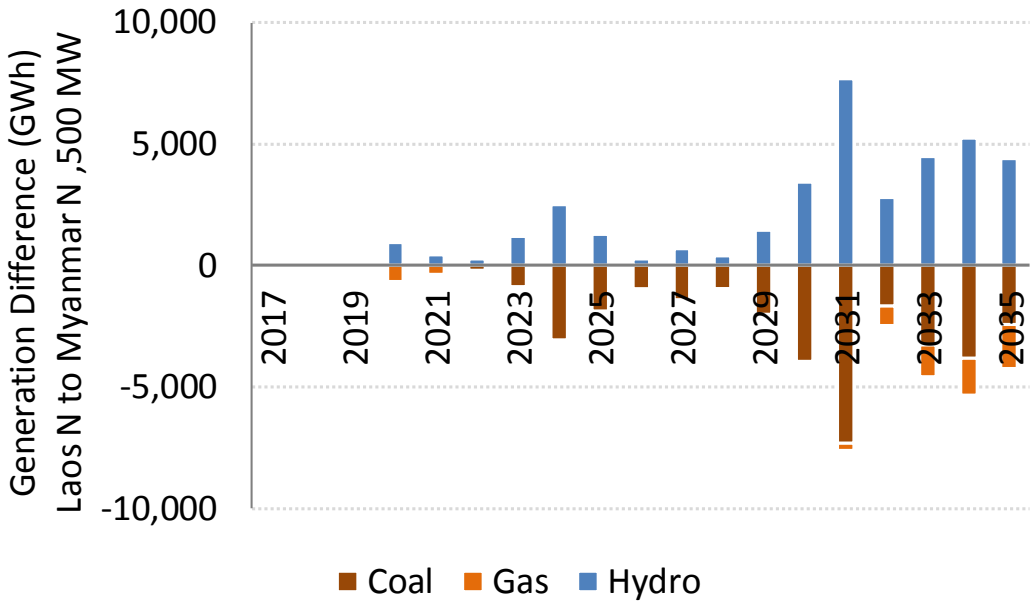


Figure 76 BC7 Generation Difference (Myanmar North to Laos North, 1000 MW option)

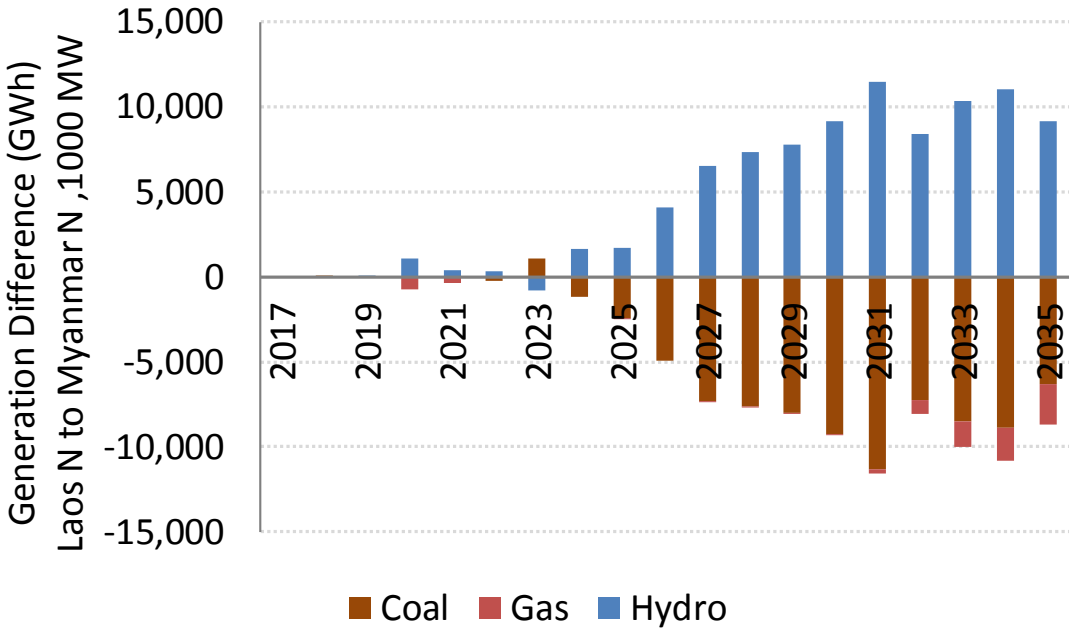
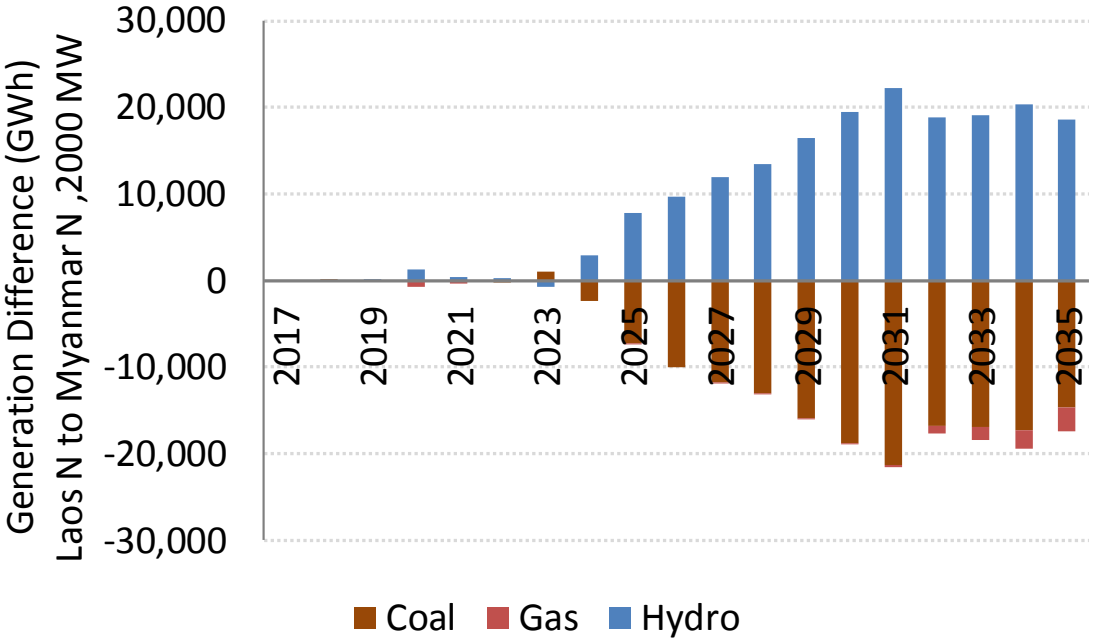


Figure 77 BC7 Generation Difference (Myanmar North to Laos North, 2000 MW option)



7.5.2 Power Flows

Figure 78 plots the annual average flow across the business case link across all of the size options.

- Flows across the 500 MW option business case link reach full utilisation immediately;
- However the 1000 MW & 2000 MW options do not become fully utilised until 2025/2030; and
- 500-1000 MW option is a good match for near-term requirements.

National power flows between Myanmar North and Central are plotted in Figure 79 (positive flows are flows from the north to central region). The impact of the business case link is:

- Under the Base Case the flows are, on average, from Myanmar North to Central because of delays in projects, but switch directions from central to north as projects come online mainly in the central region;
- The business case link introduces additional supply into Myanmar north region (Mandalay) which is exported into the central region resulting in flows from the north to central; and
- Imported power from Laos North mainly replaces coal developments in the central region of Myanmar.

Figure 78 Business Case 7 Annual Flows (Laos North to Myanmar North)

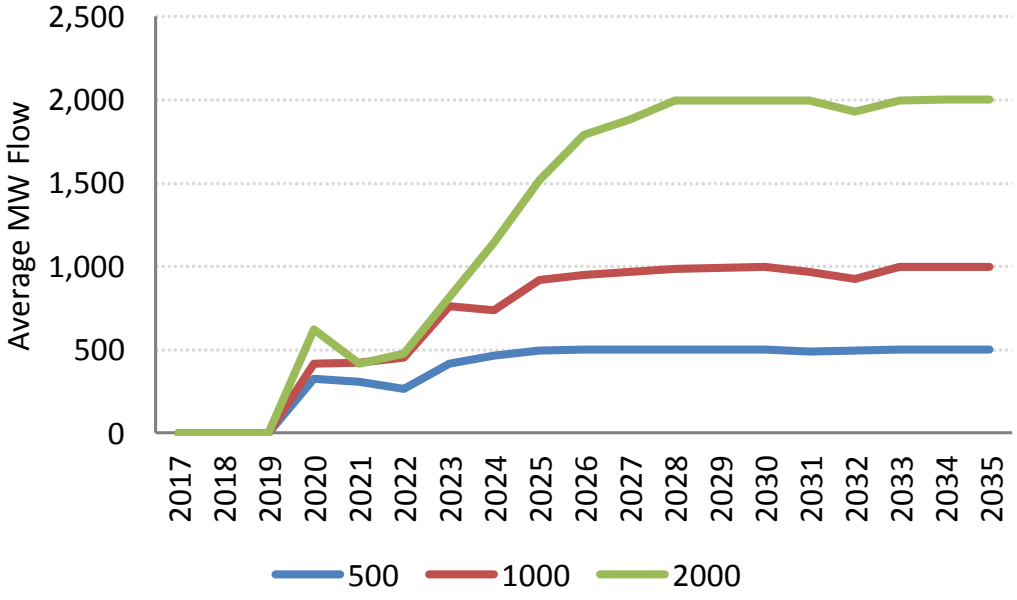


Figure 79 Business Case 7 Myanmar National Flows (Flows from North to Central)

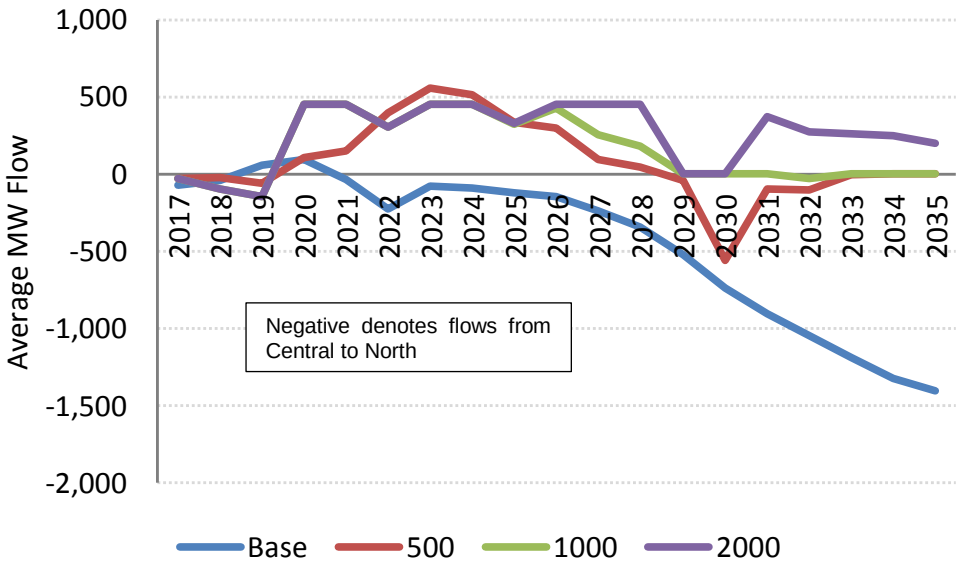
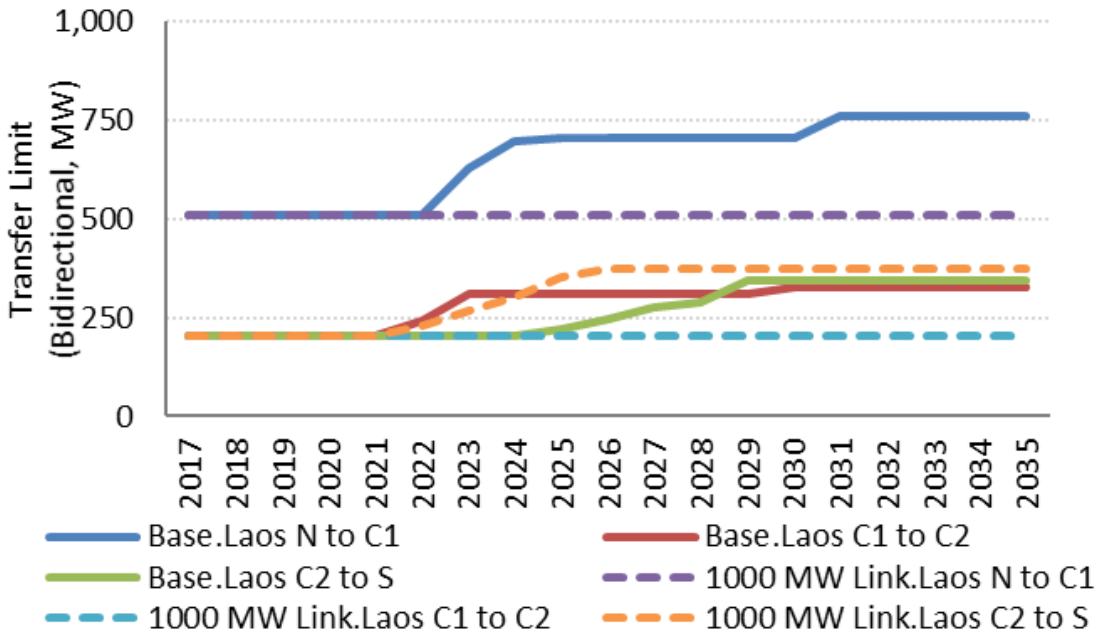


Figure 80 and Figure 81 plot the developed transmission capacities within the Lao PDR and Myanmar national transmission systems respectively for both the Base and Business Case (1000 MW option plotted only as they all follow similar trends). In summary:

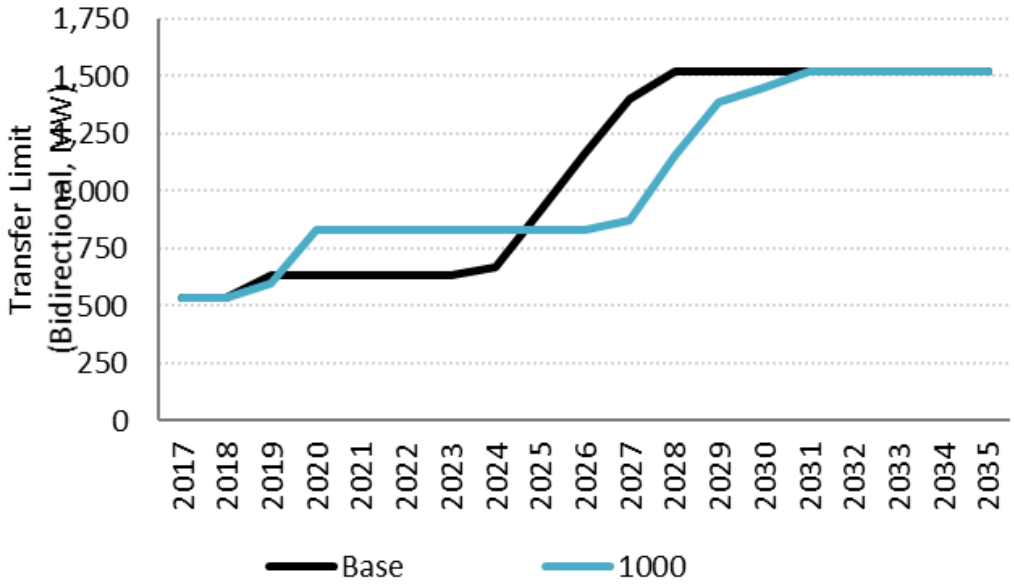
- Augmentation of the intra-regional Laos links is not required for the N to C1 and C1 to C2 links, and only slightly higher for the C2 to S link compared to base case assumption27;
- The reduction in internal transmission augmentation requirements in Laos is because surplus hydro power is instead evacuated to Myanmar via the business case link;
- The flows from Laos into the North of Myanmar require the Myanmar intra-regional link to be augmented earlier compared to the Base case to allow for higher flows into the Myanmar central region from the north;
- However, the need to augment the link from Central to North, as additional projects are developed in the central region, is deferred because of imports into the Myanmar north region from Laos.

Figure 80 National Transmission Upgrades (Lao PDR, 1000 MW BC option)



[27] Laos is modelled as 4 separate regions, North 1 (N), Central 1 (C1), Central 2 (C2) and South (S).

Figure 81 National Transmission Upgrades (Myanmar, 1000 MW BC option)



7.5.3 Costs and Benefits

The annual benefits for the Myanmar North to Laos North (BC7) business case (1000 MW option) are plotted in Figure 82. The 500 and 2000 MW options follow a similar trajectory.

Figure 83 plots the net present value (at 2017 and discounted at 10% pa) across all three business case options. In summary:

- In the period to 2030, there are significant benefits with reduction in both capex initially followed by and generation costs. Post 2030, additional hydro is developed in Laos to offset more coal and gas projects in Myanmar (mainly in the centre region).
- The cost of transmission (including intra-regional augmentations) is relatively small compared to the generation benefits.
- Across the 3 options, 2000 MW presents the highest NPV at $1,208m.
- The 2000 MW option opens up further opportunities for Laos to develop its hydro resources and trade possibilities beyond 2030.

Figure 82 Costs and Benefits of BC7 against Base Case

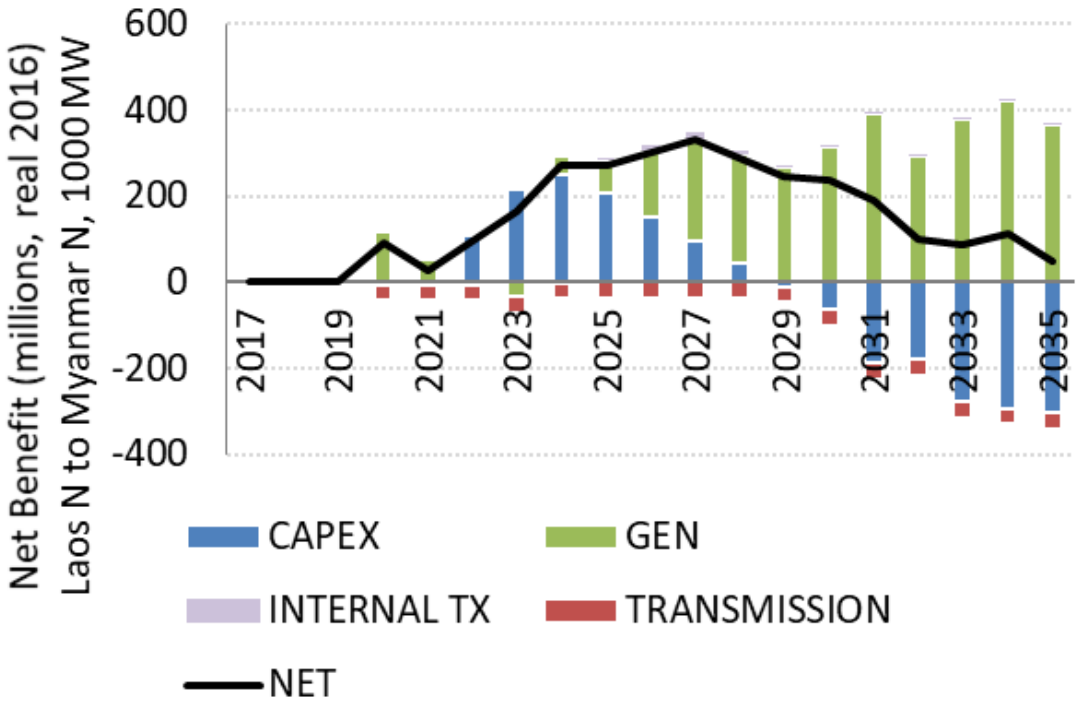
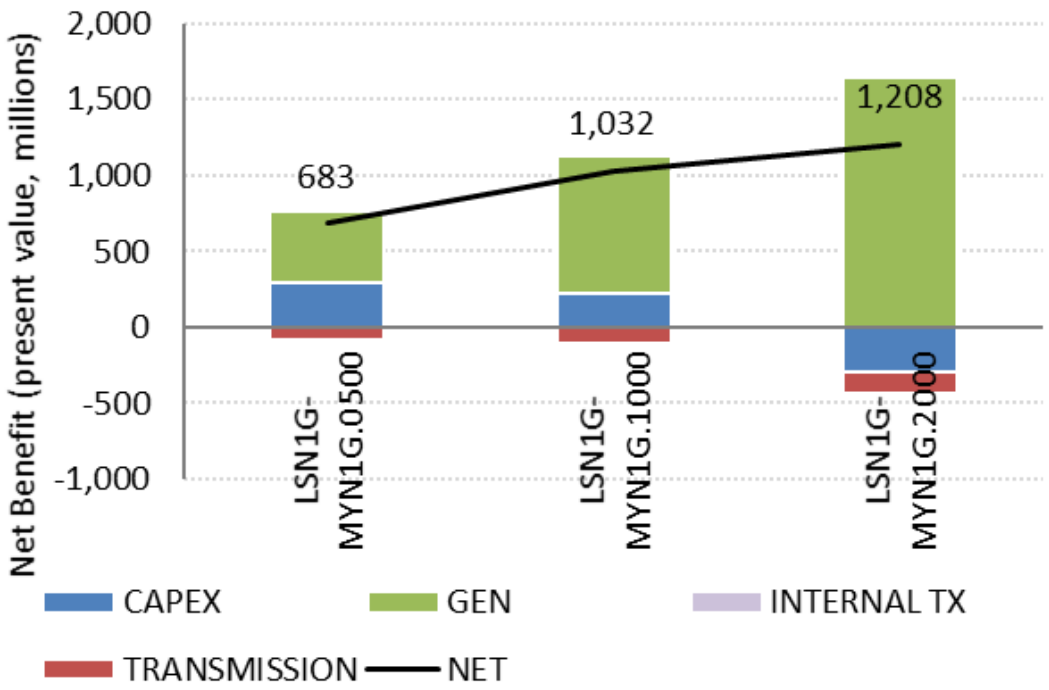


Figure 83 Net Present Value (Business Case 7)



7.5.4 Key Insights

The main insights from the modelled work have been summarised in Table 22.

Table 22 Key Insights (Business Case 7)

General	Implications for Laos	Implications for Myanmar	Other
Under the least-cost planning scenarios, development of hydro in Laos benefits Myanmar	Internal links from North to C1 link flows expected to switch back towards the North	Some investments in coal in Myanmar are deferred and/or avoided altogether by 2035. Gas capacity is also avoided from 2033.	Link sizes examined each resulted in similar overall NPVs of net benefit.
2020-25, generation from committed developments in Laos augments supplies in Myanmar	Requires slightly less national grid strengthening because power is evacuated from the north of Laos directly to Myanmar North	Opportunity to reduce capital investment if national link is augmented to allow for flows from Laos via Myanmar north region (from 2020)	Smaller BC link (500-1000 MW) would be appropriate in the shorter term.
Export opportunity results in 1 – 4 GW of additional development of hydro in Laos	Benefits from monetising excess hydro reserves, and opportunity to foster significant cross-border trading	Results in joint optimisation of new Lao PDR hydro plants with storage and existing hydro in Myanmar allowing for better reserve sharing and optimisation	Over the longer-term the augmentation of national link can be deferred as the north region can be supplied via imports from Laos. Business link could be increased to 1000-2000 to support increasing demands in Myanmar

7.6 Business Case 8: Myanmar to PRC

This sub-section discusses Business Case 8 against the Base Case. Business Case 8 studies two (2) transmission projects connecting from PRC (Yunnan), into Myanmar North (Mandalay) and into Myanmar Central (Yangon). China would be interested to provide export power via an HVDC line of up to 2000 MW, with 1000 MW for Myanmar and 1000 MW for Bangladesh (wheeled through Myanmar's power system). However, for Myanmar to fully gain the benefit of this, it would be essential for Myanmar internally upgrade their 500 kV network to support this. An alternative proposal would be for 1000 MW to go directly into Yangon.

In this analysis, we therefore consider the pros and cons of two sub-cases (Figure 84):

- 8a: 1000 MW to Myanmar's power system into Mandalay (350 km); or
- 8b: 1000 MW to Myanmar's power system into Yangon (800 km).

Figure 85 summarises the estimated project cost.

Figure 84 Business Case 8a and 8b: Myanmar North and Central to PRC

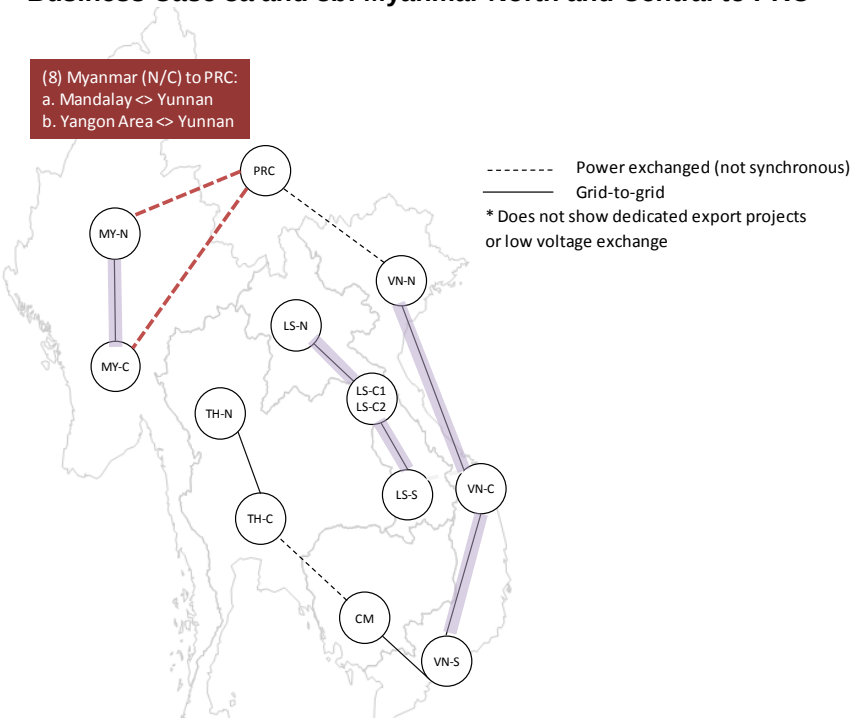


Figure 85 Business Case 8a and 8b Investment Cost

Business Case	From	To	Size (MW)	Cost ($m's)
8a	Myanmar (North)	PRC	1,000	327
8b	Myanmar (Central)	PRC	1,000	872

7.6.1 Capacity and Generation Outcomes

Figure 86 and Figure 87 plot the capacity development differences and Figure 88 and Figure 89 plots the generation differences between the Base Case and BC 8a and 8b respectively (positive represents additional capacity in the business case). Compared to the Base Case, the introduction of the business case link substitutes roughly 1000 MW from China for 1000 MW of coal (and some gas) in Myanmar – both capable of providing baseload power. Generation differences are consistent with the capacity charts.

Figure 86 Business Case 8a Capacity Difference (Myanmar North to PRC)

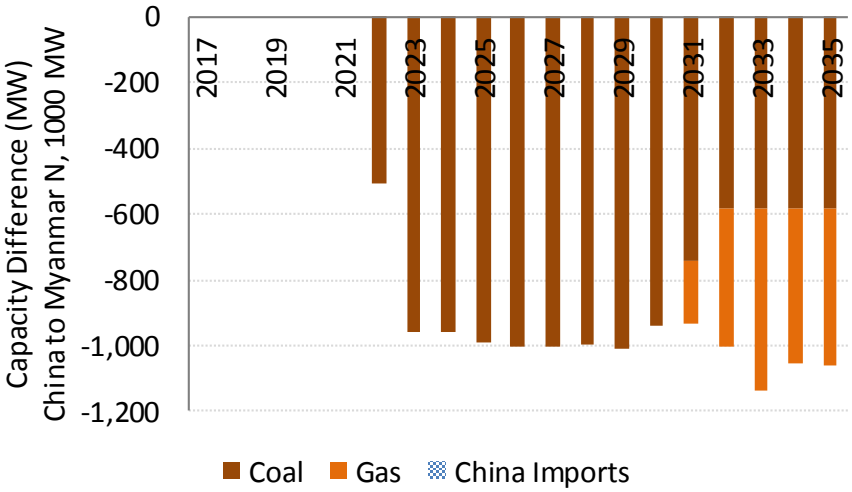


Figure 87 Business Case 8b Capacity Difference (Myanmar Central to PRC)

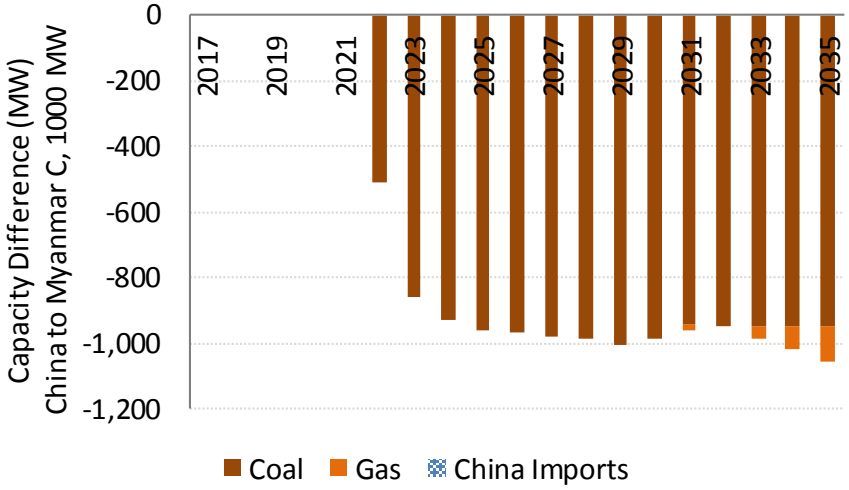


Figure 88 Business Case 8a Generation Difference (Myanmar North to PRC)

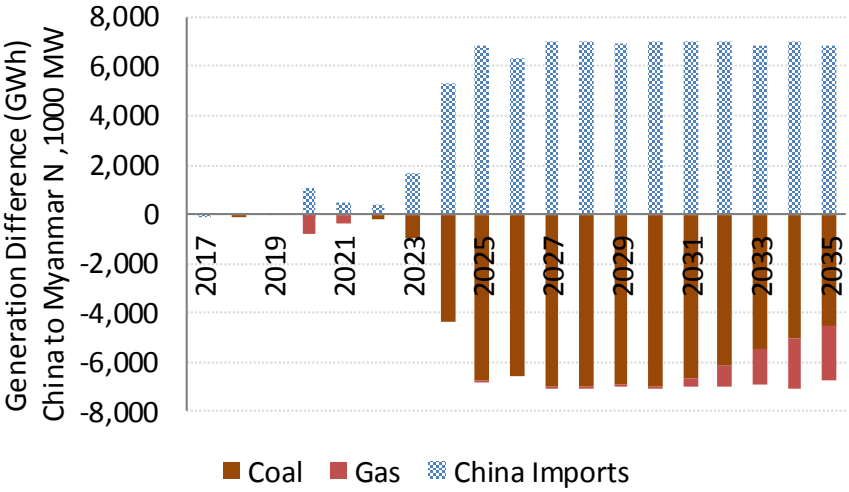
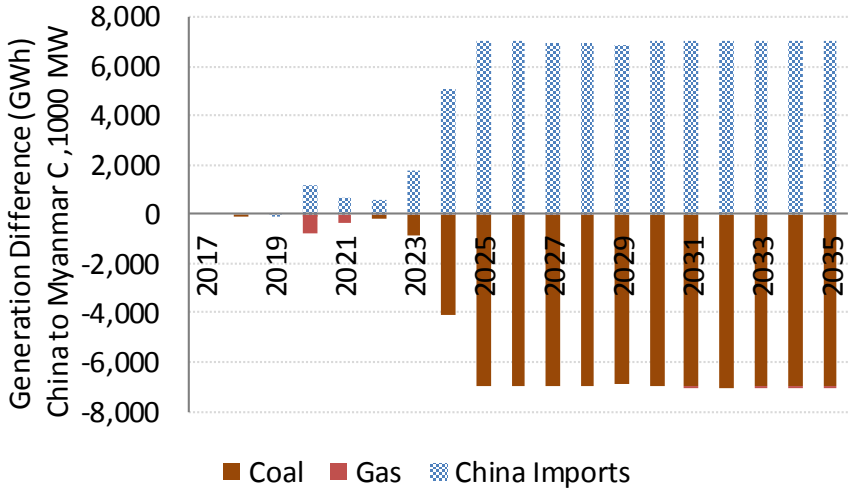


Figure 89 Business Case 8b Generation Difference (Myanmar Central to PRC)



7.6.2 Power Flows

Figure 90 plots the annual average flow across BC 8a and 8b. Under both business cases, the link in conjunction with surplus power from PRC is able to deliver significant flows and utilise the link at a high capacity factor due to the ability to provide baseload power (surplus power from China). The surplus power has been valued at a low marginal cost (e.g. zero opportunity cost of surplus power because of its consideration as a sunk investment).

Figure 90 Business Case 8a and 8b Annual Flows

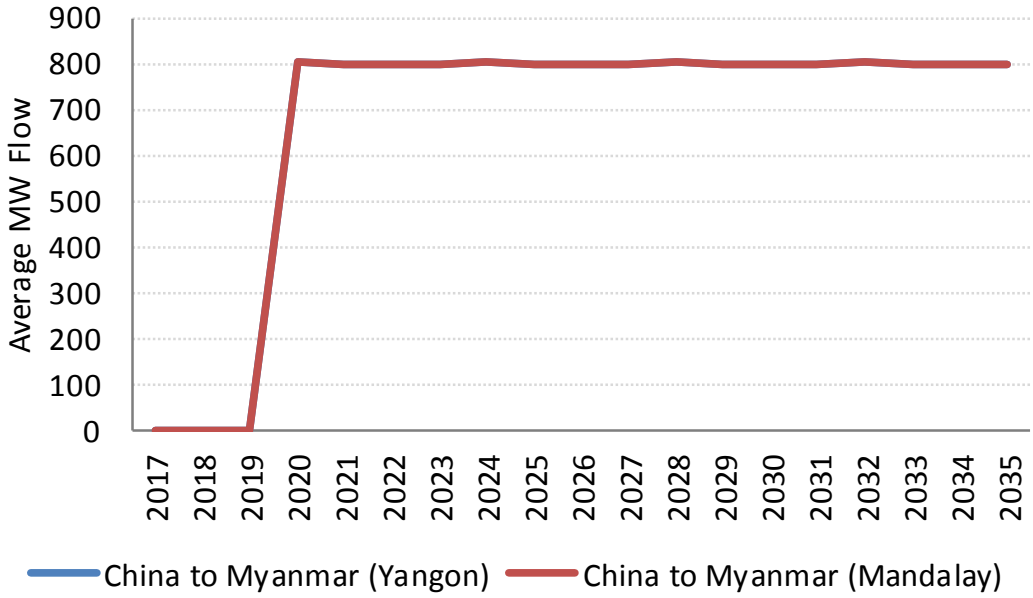


Figure 91 and Figure 92 plot the flows on the national transmission line and the required augmentations across the base case and BC 8a and 8b. Flows across the Myanmar link (North to Centre) initially from N to C in the short term (tight demand and supply in the centre region) then switches to C to N because of significant thermal project developments in south of Myanmar from 2022 onwards. BC Link into Myanmar N (8a) offsets the coal generation required from the centre region to support the north region over the longer term.

Delay of plants means both N and C regions are tight, whereas additional generation from China results in additional reserve sharing between the regions (i.e. augmentation of national link occurs earlier).

Figure 91 Business Case 8a and 8b Myanmar National Flows (Flows from North to Central)

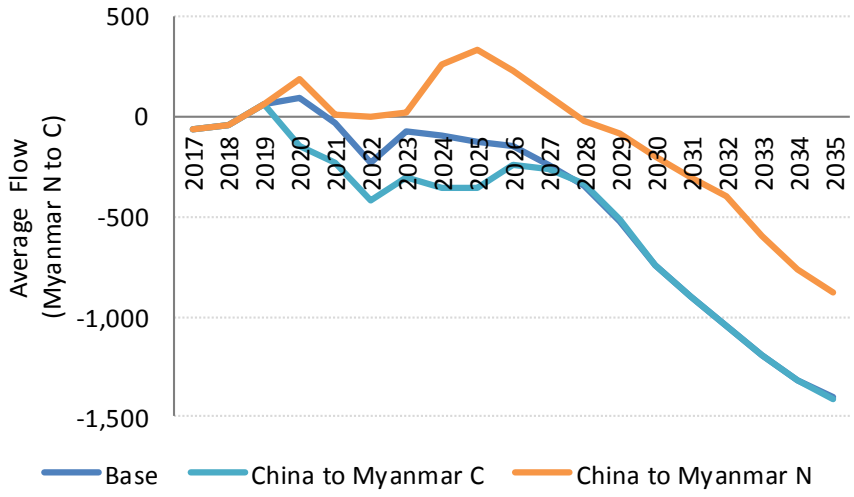
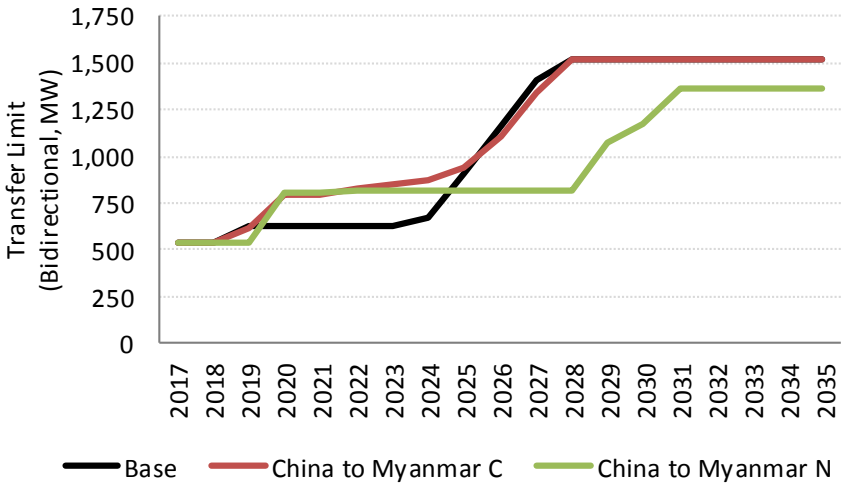


Figure 92 National Transmission Upgrades (Myanmar North to Central)



7.6.3 Costs and Benefits

The annual benefits for business case 8a and 8b are plotted in Figure 93 and Figure 94. The initial two years from 2020-2021 result in avoided generation costs, followed by significant avoidance of capacity investment and generation cost. The benefits are relatively stable from 2023 given the high utilisation of the business case link in both cases. Significant generation cost benefits arise due to no value/cost attributed to the imports from China (surplus energy).

Figure 95 plots the net present value (at 2017 and discounted at 10% pa) of both business cases. The NPV shows positive generation cost and capacity investment benefits. The main differences lie in the cost of the transmission project as China to Mandalay is significantly cheaper than into the Yangon area. Figure 96 plots the impact of the net benefit against a range of import costs for the two interconnector options ($30-60/MWh range) and shows Imports into Mandalay is break-even around $60/MWh, and $45/MWh into Yangon.

Figure 93 Costs and Benefits of BC 8a against Base Case

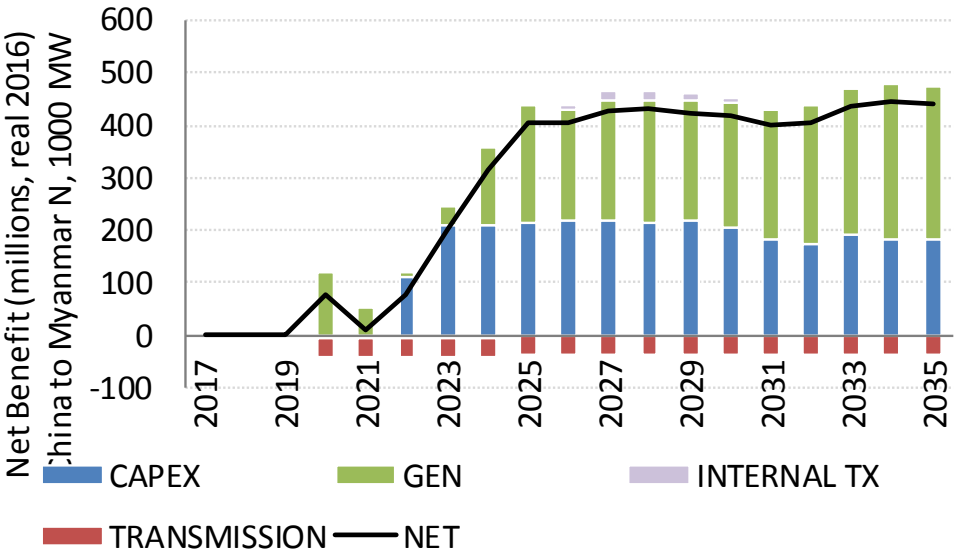


Figure 94 Costs and Benefits of BC 8b against Base Case

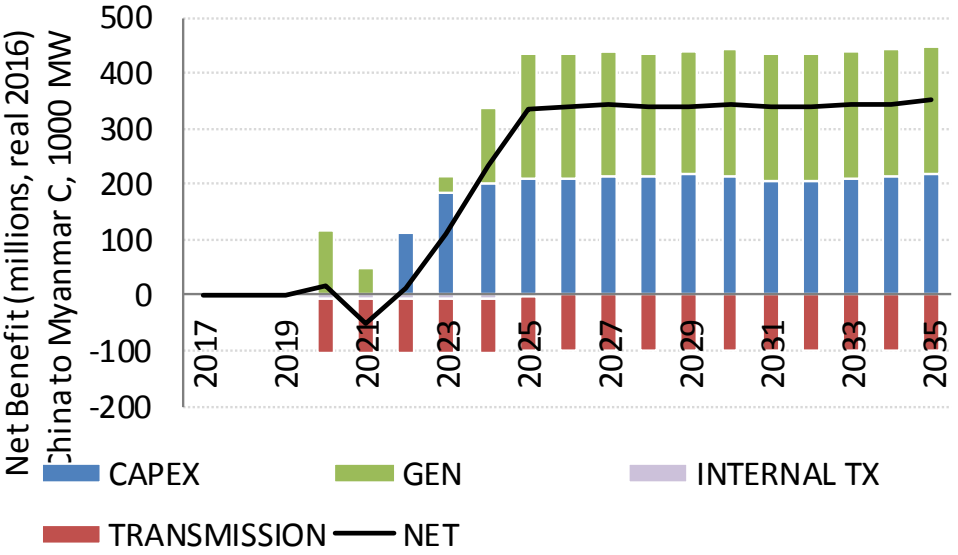


Figure 95 Net Present Value (Business Case 8a and 8b)

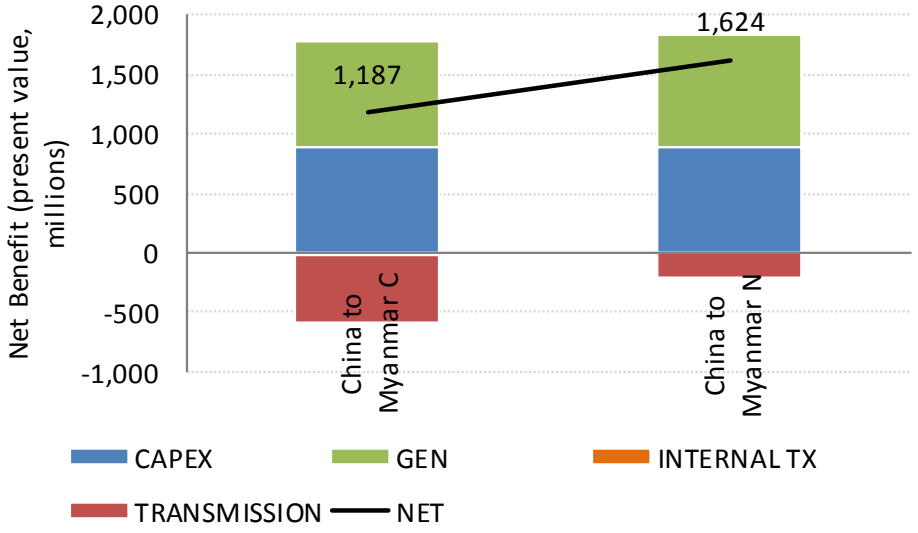
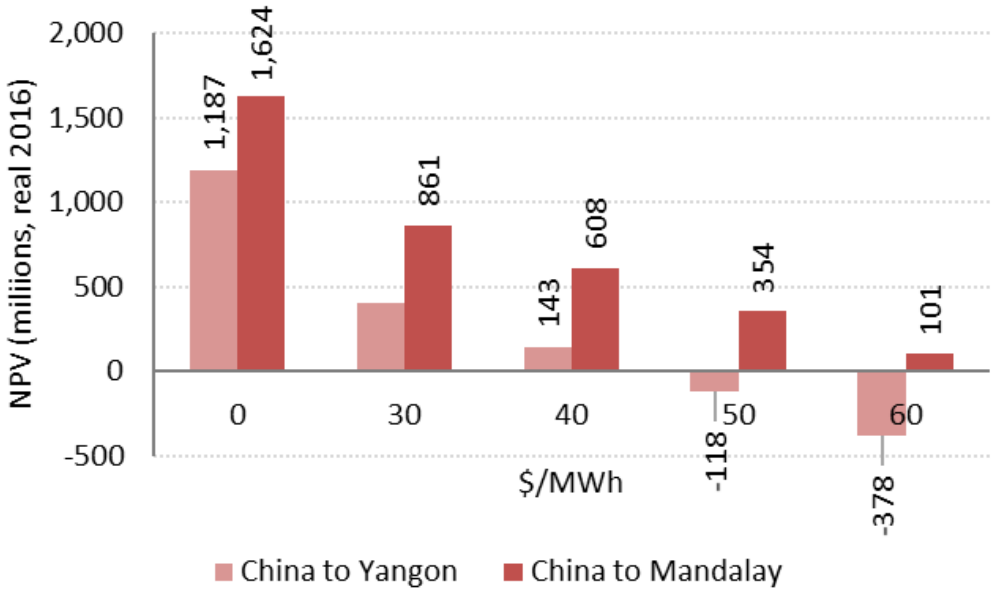


Figure 96 Net Present Value Sensitivities against Cost of Import



7.6.4 Key Insights

The key insights from the modelled results are given in Table 23.

Table 23 Key Insights (Business Case 8a and 8b)

General	Implications for Myanmar	Implications for China	Other
Under the least-cost planning scenarios, development/augmentations of the BC links generally benefits Myanmar	For Myanmar to benefit it would require transmission upgrades of about 800 MW (post contingency) between Mandalay and Yangon and be commissioned successively by 2020-22	Opportunity to export surplus power into Myanmar with opportunity to sell power to Bangladesh	Myanmar still requires transmission upgrades up to 1500 MW over the period 2026-30, deferred for the Mandalay Gateway case Base Case also requires these upgrades to be in place by 2028 as a consequence of significant thermal power project developments in the south
Diversification of Myanmar's generation sources and reduce reliance on its hydro power stations especially in times of drier conditions	Both projects would enable Myanmar to have higher levels of renewable energy and provide hedge against dry seasons	Would have to price the imports. The project delivers greatest benefit for Myanmar with levelised avoided cost of 60 $/MWh for option 8a vs. 45 $/MWh for option 8b	Reduces the requirement to develop thermal generation

8 Integrated Case

The Integrated case combines the benefits of all the underlying business cases – jointly optimising generation and transmission to determine the highest priority projects by allowing each of the business case links to be upgraded as required to support a cost-efficient generation planning outlook across the region. The GMS network is plotted here in Figure 97 showing all of the business case links. Figure 98 summarises the business case links and the earliest commissioning date based on current expectations.

Figure 97 Network Map of all Business Cases Included in Integrated Case

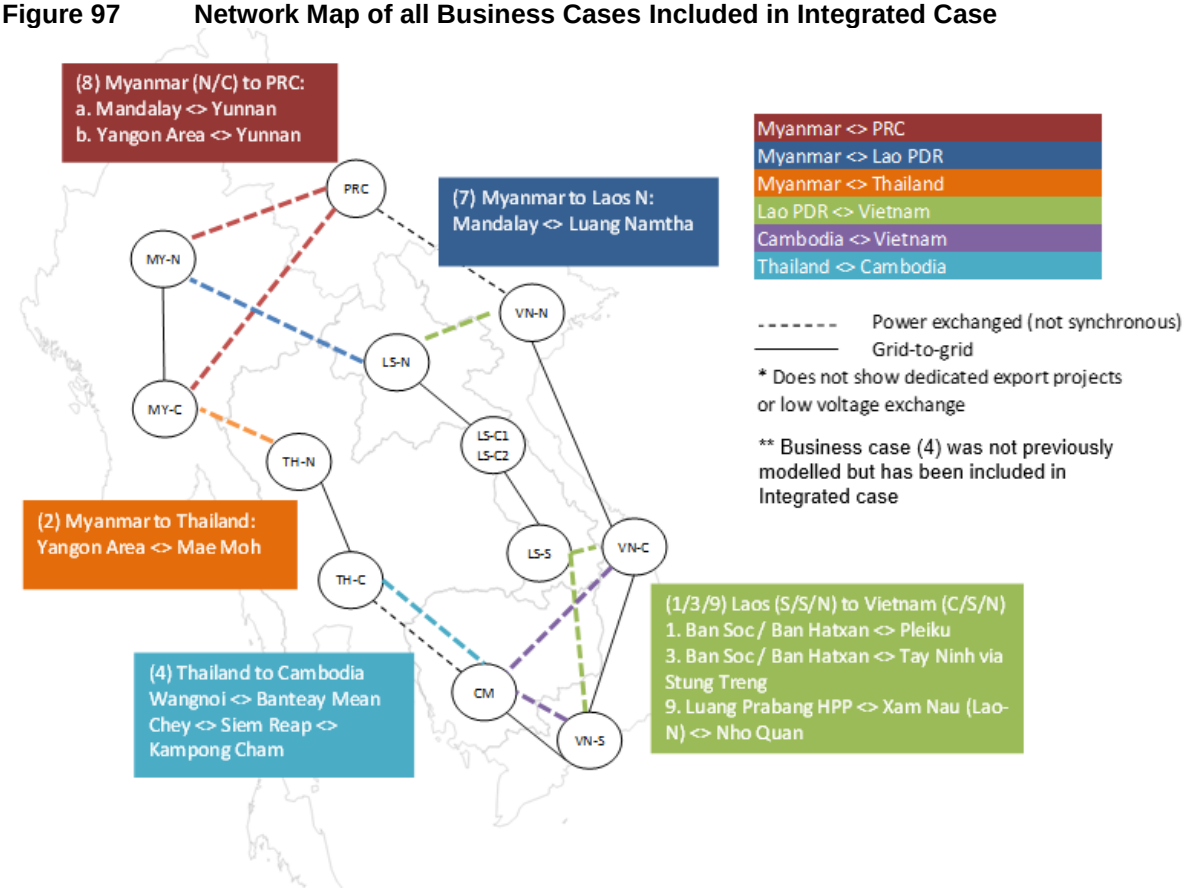


Figure 98 Business Cases Modelled and Earliest Commissioning Year (Integrated Case)

BC No.	Region (From)	Region (To)	Connection Points (From – To)	Earliest Year Allowed
1	Lao PDR (South)	Viet Nam (Central)	Ban Soc / Ban Hatxan ⇔ Pleiku	2022
2	Myanmar	Thailand (North)	Yangon area ⇔ Mae Moh	2025
3	Lao PDR (South)	Viet Nam (South)	Ban Soc / Ban Hatxan ⇔ Tay Ninh via Stung Treng	2025
4	Thailand (Central)	Cambodia	Wangnoi ⇔Banteay Mean Chey ⇔ Siem Reap ⇔ Kampong Cham	2025
5	Cambodia	Viet Nam (South)	Kampong Cham ⇔ Tay Ninh	2022
6	Cambodia	Viet Nam (Central)	Lower Se San 2 HPP ⇔ Pleiku	2025
7	Lao PDR (North)	Myanmar (North)	Conceptual link (specific connection points not determined)	2022
8a	Myanmar (Mandalay)	PRC	Mandalay ⇔ Yunnan	2025
8b	Myanmar (Yangon)	PRC	Yangon ⇔ Yunnan	2025
9	Lao PDR (North)	Viet Nam (North)	Luang Prabang HPP ⇔ Xam Nau (Lao-N) ⇔ Nho Quan	2025

Laos ⇔ Viet Nam	**Cambodia ⇔ Viet Nam or Thailand**	**Myanmar ⇔ Lao PDR, PRC or Thailand**

The optimised cross-border transmission plan (Integrated Case) follows that of the Base case and individual business case studies with differences listed below. This provides insight into optimal development of generation and transmission in the region, including the prioritisation of the transmission projects.

- All candidate cross-border transmission projects are available as options that the model could develop and let it decide which business case projects to build with the earliest commissioning date set for each business case link;
- Allow all national transmission links to be upgraded as required to support regional trade; and
- All cross-border transmission projects are modelled as continuous i.e. no lumpy investment – this is to understand the "optimal" sizes.

8.1 Regional Transmission Expansion Plan

Figure 99 summarises the business case expansion limits that resulted from the Integrated Case modelling. The overall sequencing by period of time that resulted from the Integrated Case is summarised in Table 24. The table shows for each period the business cases (defined by "From Region" and "To Region"), the resulting capacity expansion for the cross-border link and associated cost. Priority business case augmentation timings are also noted in the table (based on size and benefit of link). Figure 100 plots the total transmission investment requirements over time excluding costs associated with augmentations of the various national grids.

To quickly visualise the findings, we provide the following figures:

- Figure 101 shows the regional expansions of the Integrated case for 2022-24;
- Figure 102 shows the regional expansions of the Integrated case for 2025-26;
- Figure 103 shows the regional expansions of the Integrated case for 2027-30; and
- Figure 104 shows the regional expansions of the Integrated case for period beyond 2030.

Figure 99 Business Case Link Timing Assumption and Expansion Summary

BC No.	Region (From)	Region (To)	Regional Transmission Expansion	Earliest Year Allowed
1	Lao PDR (South)	Viet Nam (Central)	• 1200 MW developed in 2022 • 1200 MW => 1400 MW by 2030 • 1400 MW => 2000 MW by 2035	2022
2	Myanmar	Thailand (North)	• 550 MW in 2025 • 1550 MW developed by 2030 • 2000 MW developed by 2035	2025
3	Lao PDR (South)	Viet Nam (South)	• 800 MW in 2025 • 800 MW => 2000 by 2028	2025
4	Thailand (Central)	Cambodia	• 100 MW => 300 MW in 2027 • 300 MW => 700 MW in 2032	2025
5	Cambodia	Viet Nam (South)	• 200 MW => 470 MW in 2023 • 470 MW => 600 MW by 2033	2022
6	Cambodia	Viet Nam (Central)	• 250 MW by 2026/27	2025
7	Lao PDR (North)	Myanmar (North)	• 1100 MW in 2023 • 1100 MW => 2000 MW by 2033	2022
8a	Myanmar (Mandalay)	PRC	• 800 MW developed from 2025 • Expanded to 1000 MW in the longer-term	2025
8b	Myanmar (Yangon)	PRC	• Not developed	2025
9	Lao PDR (North)	Viet Nam (North)	• 570 MW developed in 2025 • 2500 MW in place by 2029	2025

Laos ⇔ Viet Nam	**Cambodia ⇔ Viet Nam or Thailand**	**Myanmar ⇔ Lao PDR, PRC or Thailand**

Table 24 Summary of Regional Expansion – Chronological Sequencing

Period	Priority Business Case Augmentation	From Region	To Region	Expansion From (MW)	Expansion To (MW)	Estimated Cost ($m)
2022-24	✓	Lao PDR (South)	Viet Nam (Central)	0	1200	154
		Cambodia	Viet Nam (South)	200	470	29
	✓	Lao PDR (North)	Myanmar (North)	0	1100	466
2025-27	✓	Lao PDR (North)	Viet Nam (North)	0	1400	365
	✓	Myanmar (Mandalay)	PRC	0	800	168
	✓	Myanmar	Thailand	0	670	163
	✓	Lao PDR (South)	Viet Nam (South)	0	1700	385
		Cambodia	Viet Nam (Central)	0	250	63
		Thailand (Central)	Cambodia	80	270	101
2028-30	✓	Myanmar	Thailand (North)	670	1550	215
		Lao PDR (South)	Viet Nam (Central)	1200	1400	31
		Lao PDR (South)	Viet Nam (South)	1700	2000	62
	✓	Lao PDR (North)	Viet Nam (North)	1400	2400	255
Beyond 2030	✓	Lao PDR (South)	Viet Nam (Central)	1400	2000	79
	✓	Myanmar	Thailand (North)	1550	2000	111
	✓	Lao PDR (North)	Myanmar (North)	1100	2000	373
	✓	Myanmar (Mandalay)	PRC	800	1000	30
		Thailand (Central)	Cambodia	270	730	252
		Cambodia	Viet Nam (South)	470	600	14

Figure 100 Total Transmission Investment Requirements over Time (Excludes National Grid Augmentations)

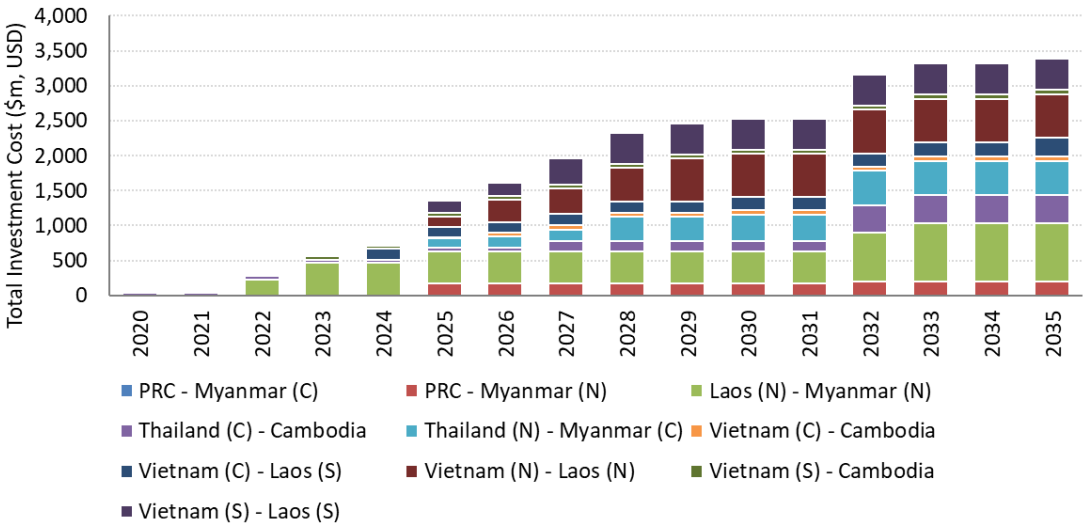


Figure 101 Regional Expansions in Period 2022-24

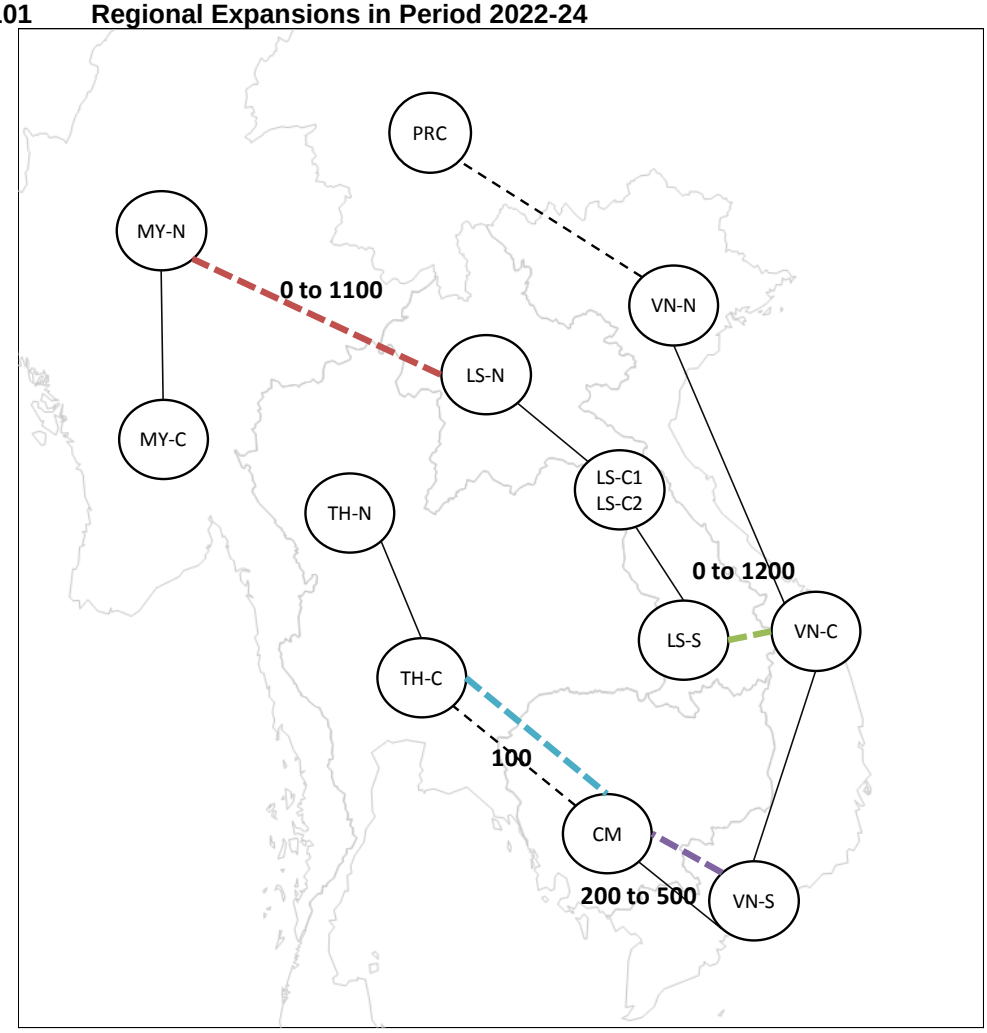


Figure 102 Regional Expansions in Period 2025-27

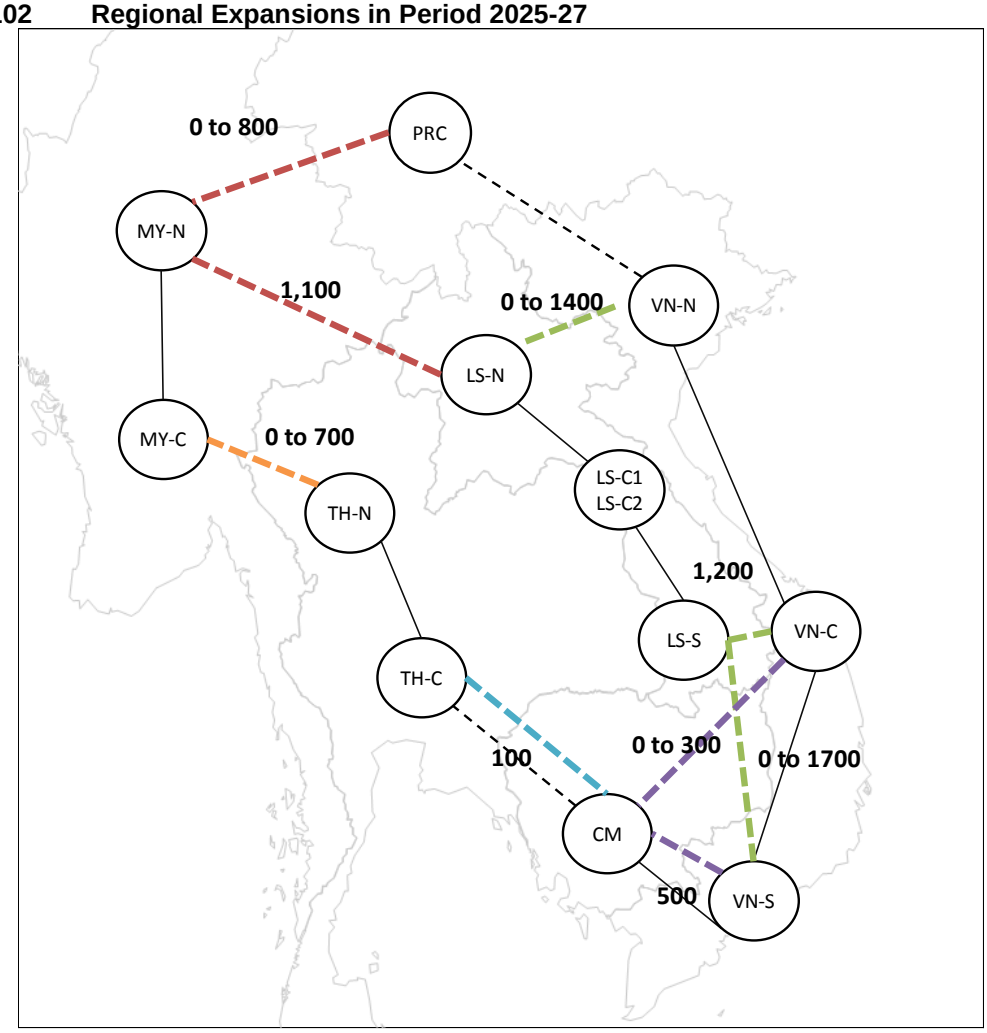


Figure 103 Regional Expansions in Period 2028-30

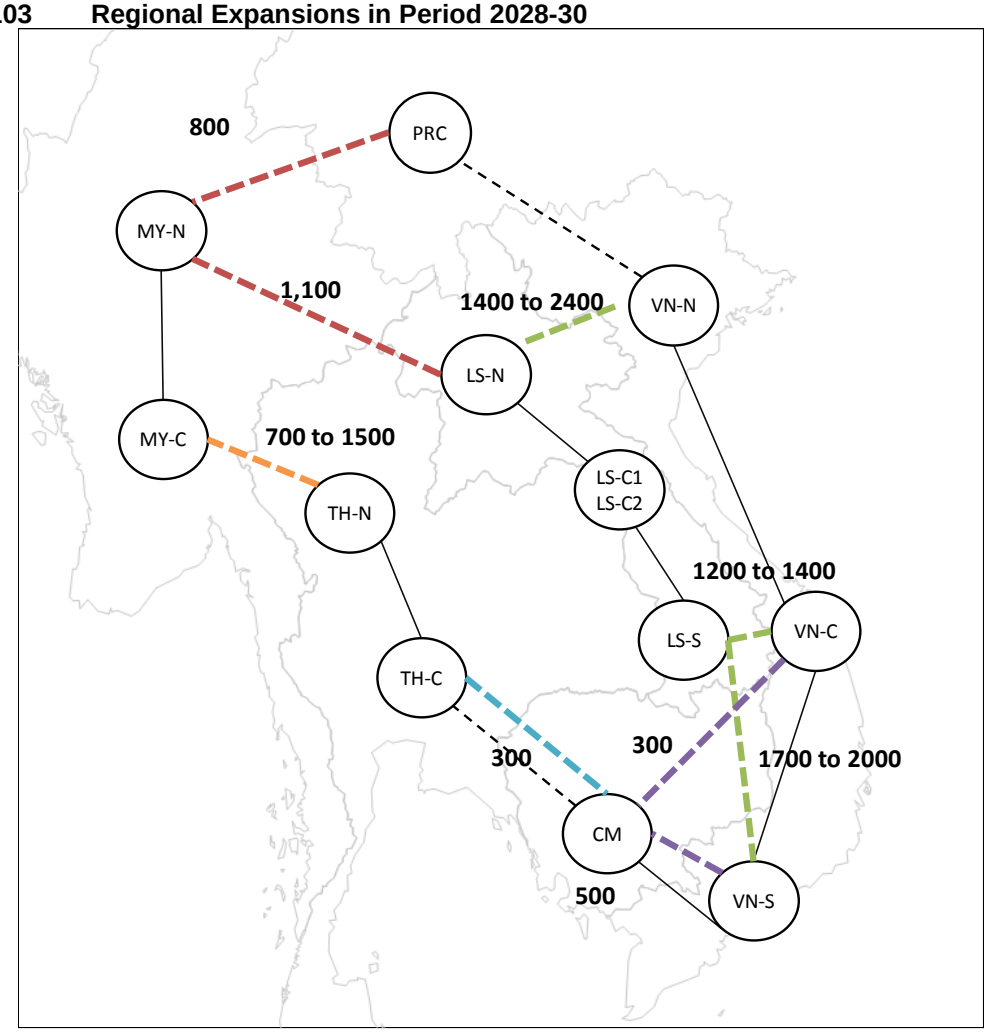


Figure 104 Regional Expansions in Period Beyond 2030

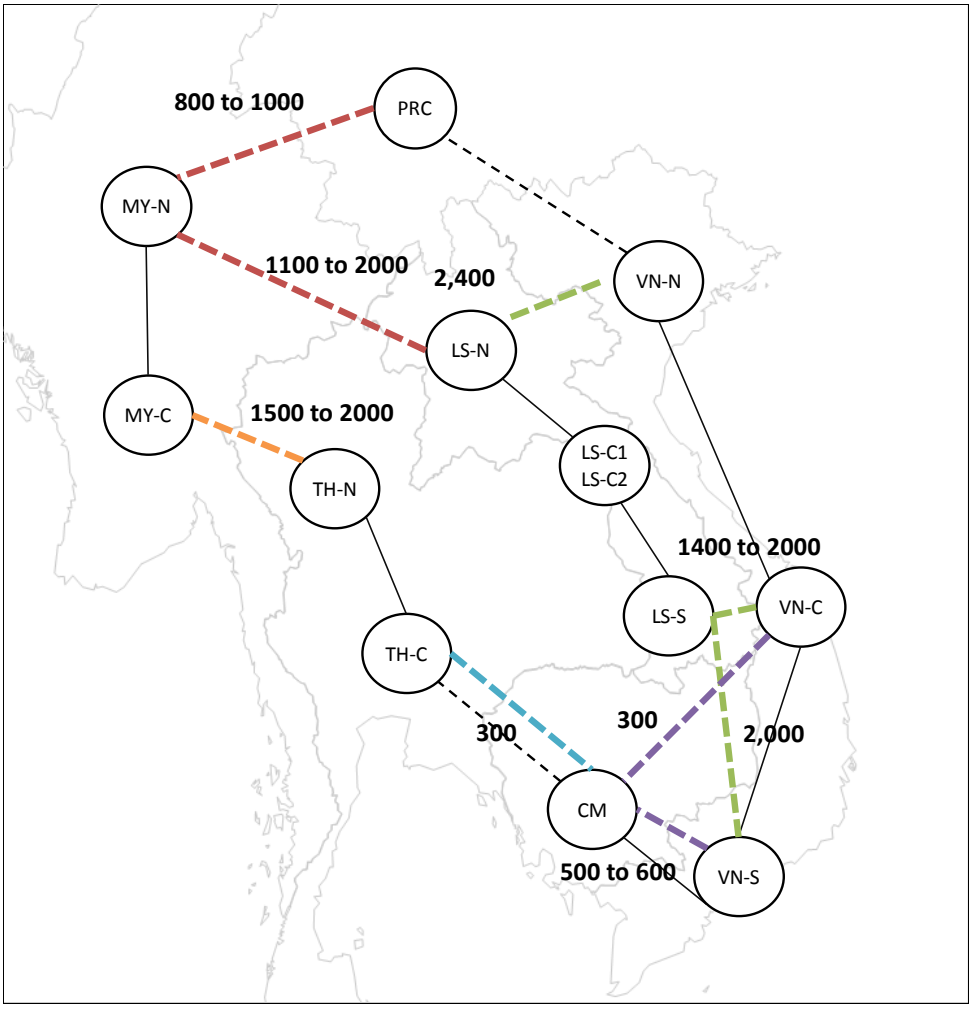


Figure 105 to Figure 107 plot the transmission expansion capacity from 2017-2035 divided into links connected to Vietnam, Cambodia and Myanmar. Figure 108 to Figure 110 plot the average flows where a positive flow on a link denoted as Country A – Country B means power flows from A to B. Vietnam is a net importer from Laos (hydro) whereas Cambodia imports power from Vietnam to support its dry season power requirements, and exports to Thailand at other times. Myanmar imports low cost surplus power from China and Laos, and exports a significant amount to Thailand in the longer term. As highlighted earlier, most of the augmentations hit the upper size limit option modelled.

Figure 105 Business Case Transmission Expansion (Laos to Vietnam BC Links)

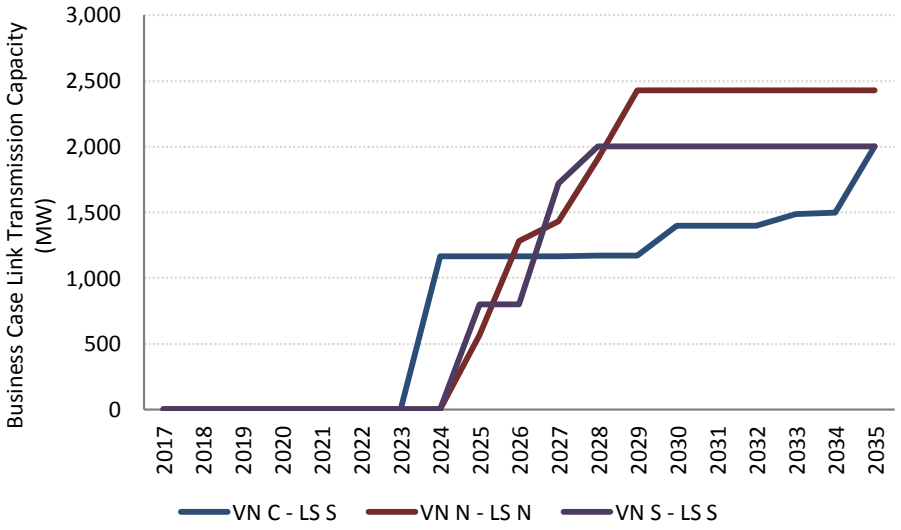


Figure 106 Business Case Transmission Expansion (Cambodia BC Links)

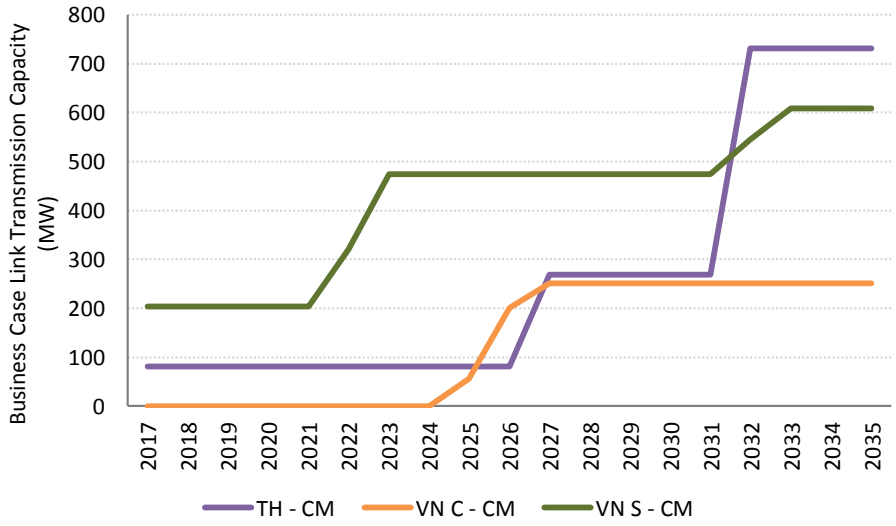


Figure 107 Business Case Transmission Expansion (Myanmar BC Links)

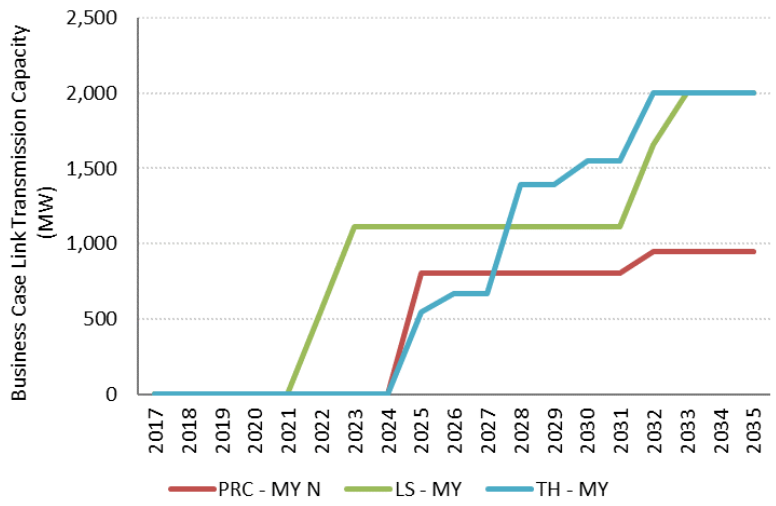


Figure 108 Average Flows across Business Case Link (Laos to Vietnam BC Links)

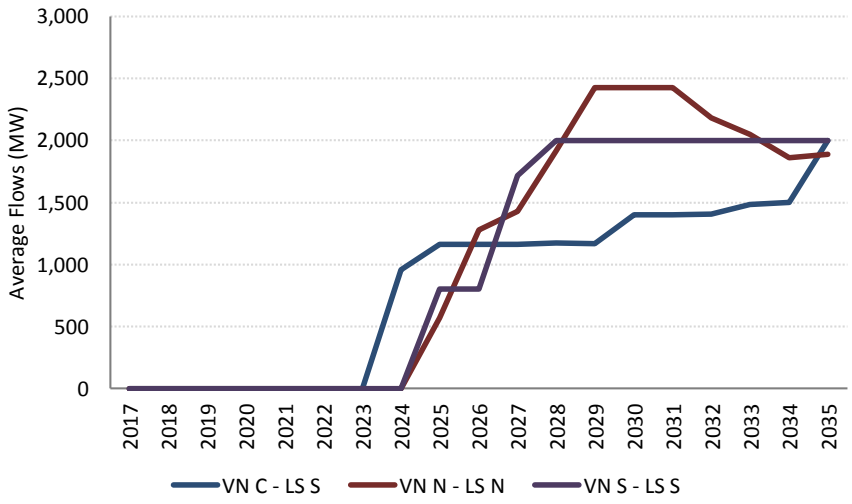


Figure 109 Average Flows across Business Case Link (Cambodia BC Links)

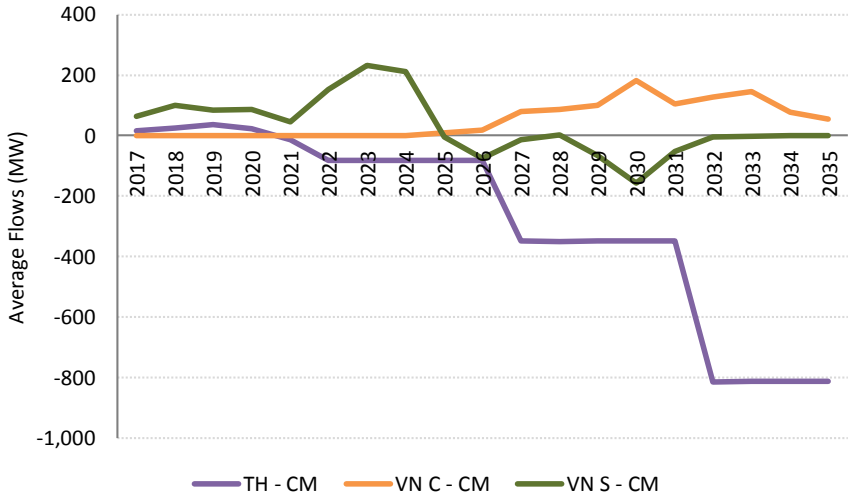
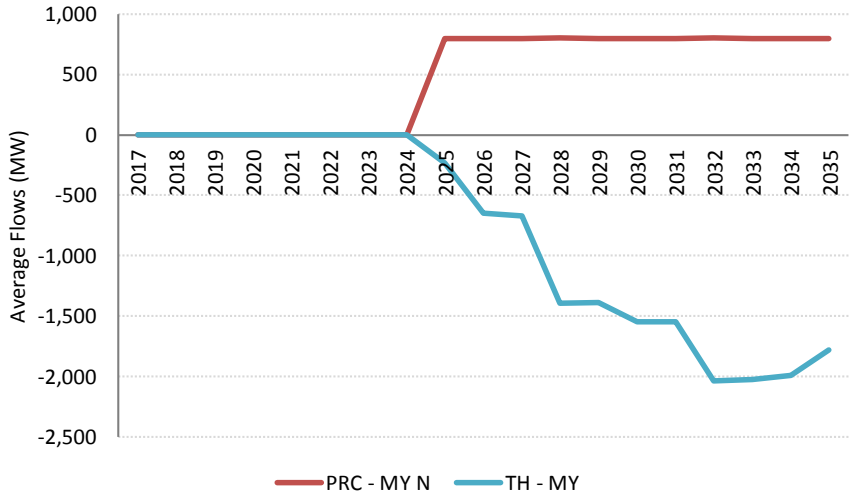


Figure 110 Average Flows across Business Case Link (Myanmar BC Links)



8.2 National Transmission Augmentation to Support Transmission Plan

To open up cross-border power trading, the various national transmission networks need to undergo internal augmentations to facilitate the required power flows. These links (Vietnam, Laos and Myanmar networks) have been modelled as available options from 2020 and are charted in Figure 111 to Figure 113 (Base case included for comparison).

The Vietnam internal transmission augmentations are avoided or delayed with imports from Laos (North and South) into the respective Vietnam regions, removing the need to wheel as much power within the country. Lao PDR has slight timing differences on the links with the main change being the addition of significant transmission limits from C2-S to support power flows into Vietnam south.

Myanmar requires earlier augmentation from North to Central given the additional (surplus) power from PRC and to relieve the supply issues related to the delay in committed plants in the Central region. In the long-term, it also significantly reduces the need for the Central region to export back to the North.

Figure 111 National Transmission Augmentation (Vietnam)

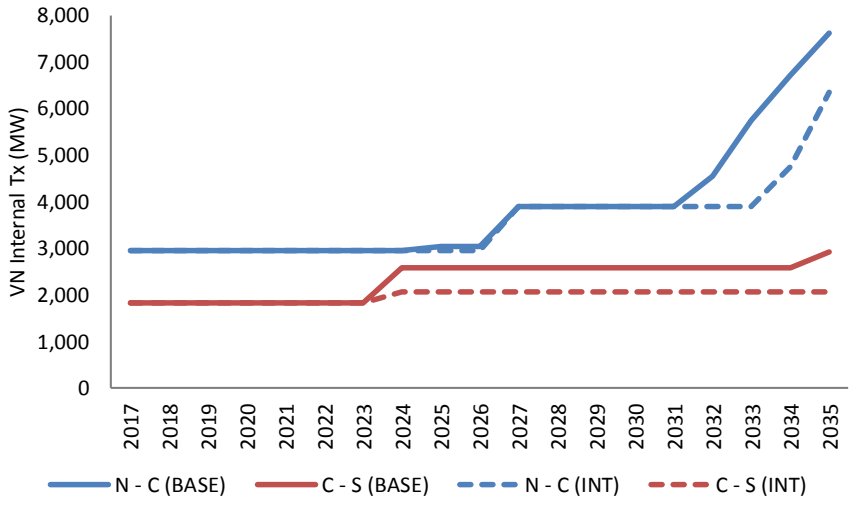


Figure 112 National Transmission Augmentation (Laos)

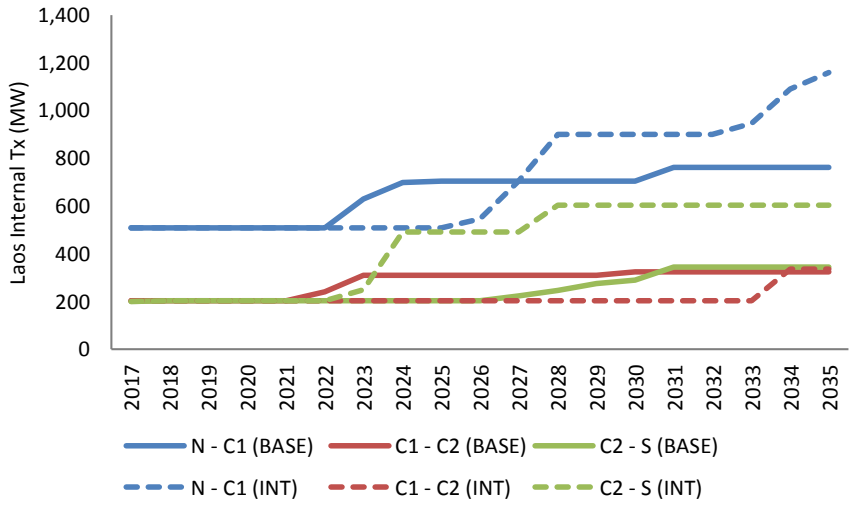


Figure 113 National Transmission Augmentation (Myanmar)

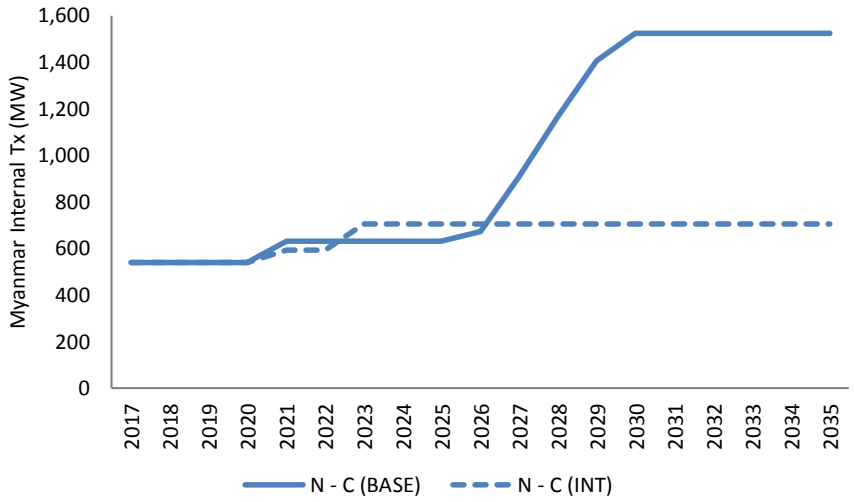


Figure 114 to Figure 116 plot the average transmission flows across the internal links for the Base and Integrated Case. The average net flows do not change significantly for the N-C link in Vietnam. However, the higher flows from C-S result from additional hydro generation from Laos. Laos internal flows change significantly with N to C1 flows reversing in the Integrated case to support flows into Vietnam N, and the Laos C2 flows into Laos S to export into Vietnam S. Over the long-term, Myanmar power tends to flow from Mandalay (north) to Yangon (central) more than in the Base case (power tends to flow in the opposite direction from Yangon to Mandalay).

Figure 114 National Transmission Flows (Vietnam)

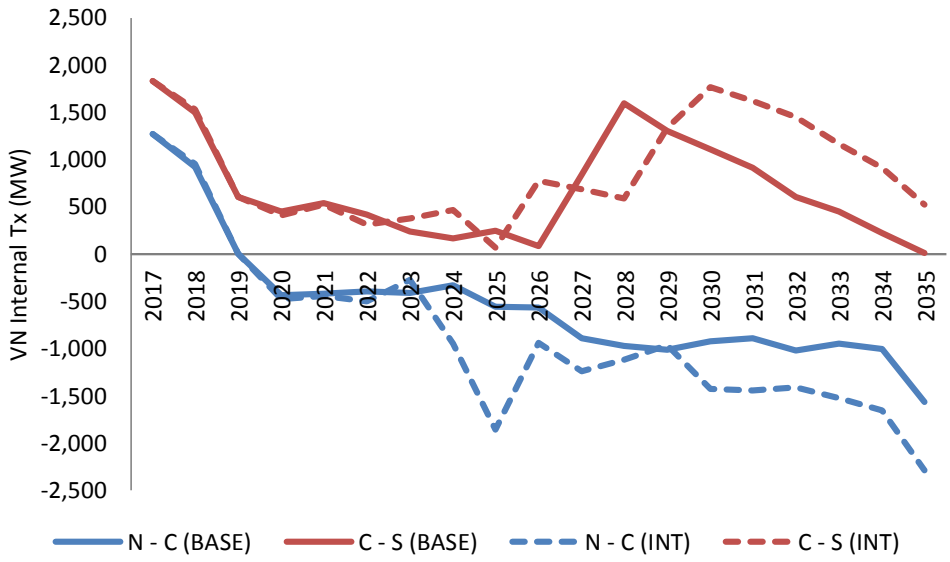


Figure 115 National Transmission Flows (Laos)

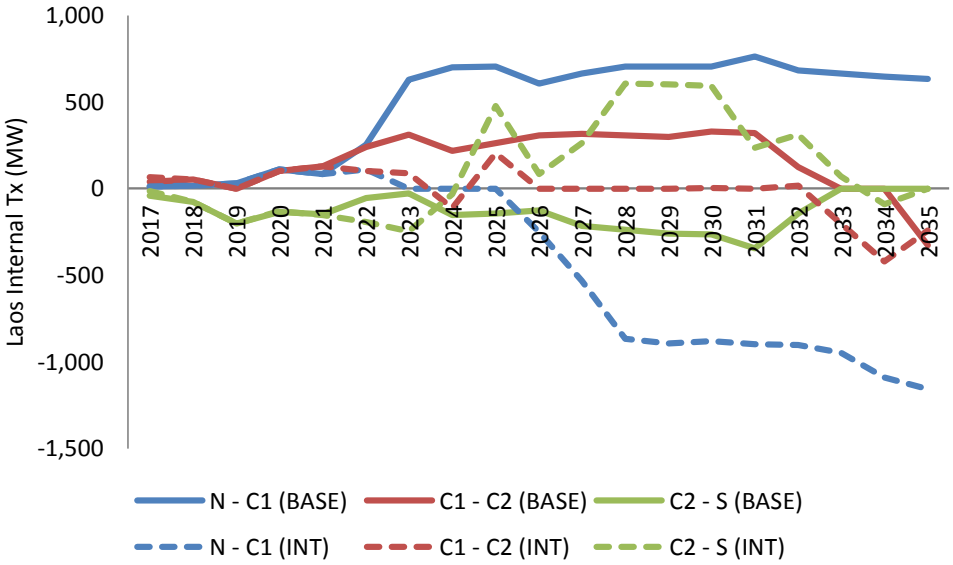
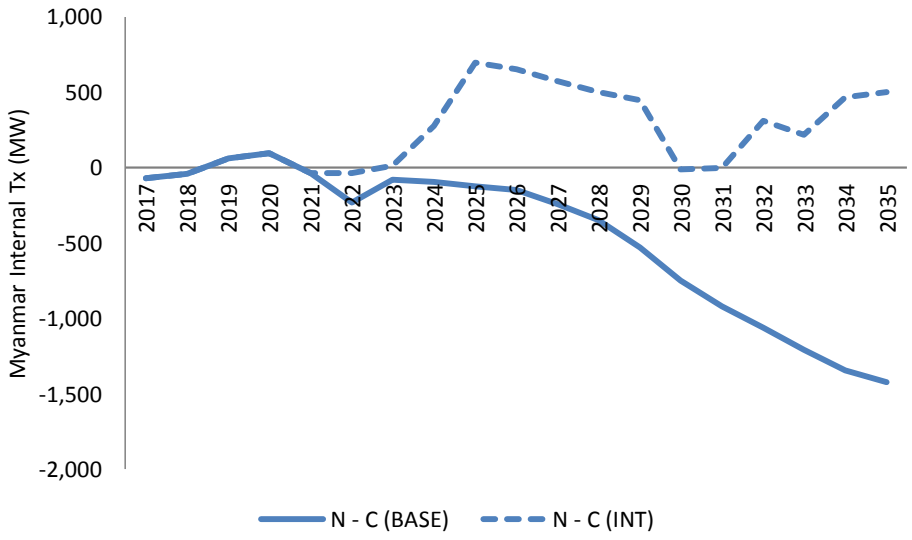


Figure 116 National Transmission Flows (Myanmar)

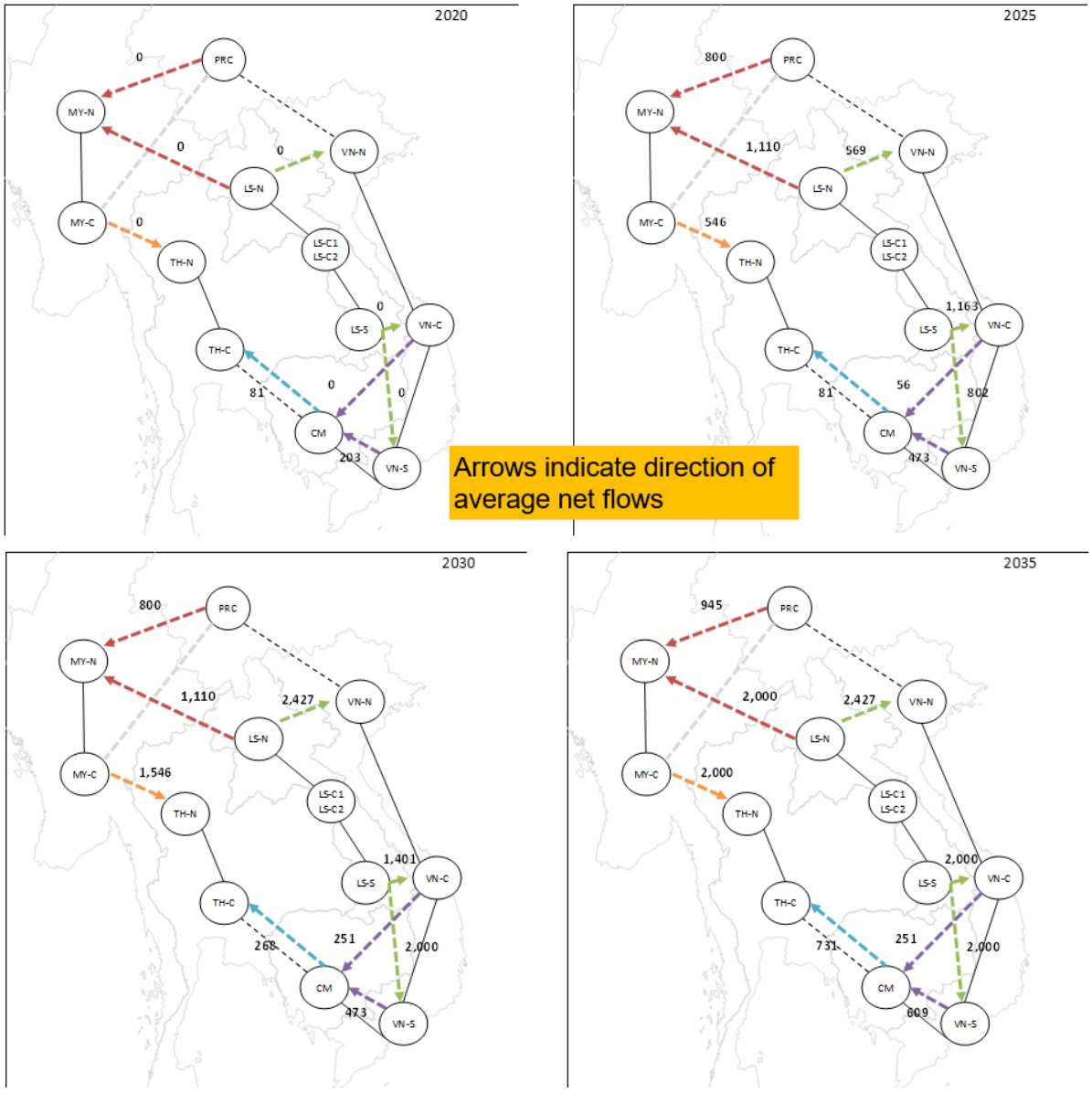


8.3 Regional Power Flows under Integrated Case Regional Transmission Expansion

Figure 117 summarises the flow direction (arrows) and augmented business case link capacities (numbers) for 2020/2025/2030/2035 snapshot years. Most business case links are built from the first allowable year suggesting an immediate benefit and importance (from a least cost perspective) from the integration of the GMS[28]. The integrated GMS entails Vietnam having significant connections to Laos and Cambodia, and Myanmar to PRC and Thailand, essentially connecting all of the GMS countries. By 2035, most of the Business Case links are augmented up to the maximum size option studied with the exception of PRC to MY-C which is not needed with the other available options. The arrows indicate the flow direction and show Vietnam and Thailand as importers across their related business case links.

[28] Capacities in 2020 relate to existing connections.

Figure 117 Business Case Transmission Upgrades and Flow Direction



8.4 Capacity and Generation Outcomes

Figure 118 and Figure 119 plot the installed capacity outlook and differences between the Base and Integrated case respectively. The Base case has little cross-border trading and the increasing demands across the GMS are predominantly met by coal and gas over the long-term in Vietnam, Thailand, Myanmar and Cambodia. However, the Integrated case allows for up to 10 GW of additional hydro from Lao PDR with avoided coal capacity of 8 GW in Vietnam and Thailand, and up to 5 GW of gas by 2035 in Vietnam, Thailand and Myanmar, supported by the building and upgrading of all business case links to facilitate cross-border trading.

Figure 118 Coal, Gas and Hydro Capacity Outlook (Base and Integrated Case)

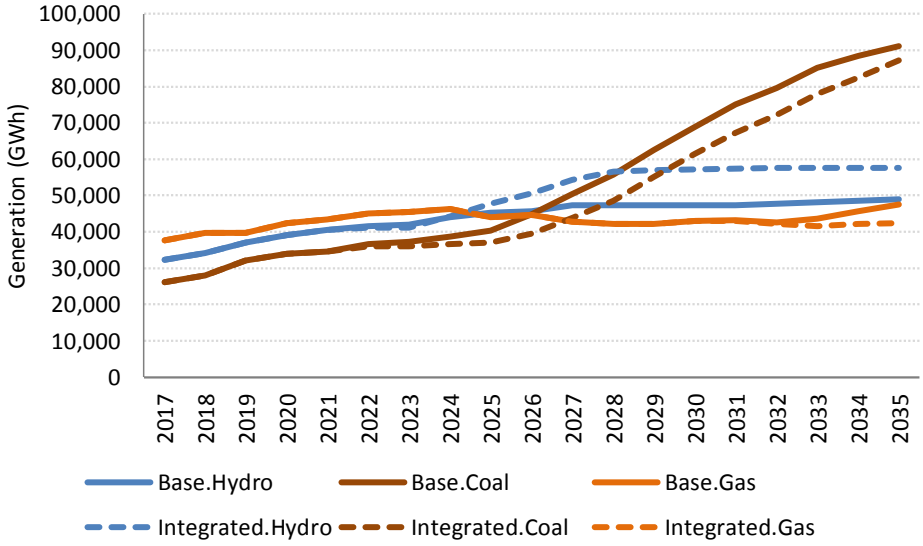


Figure 119 Coal, Gas and Hydro Capacity Outlook (Base and Integrated Case Difference)

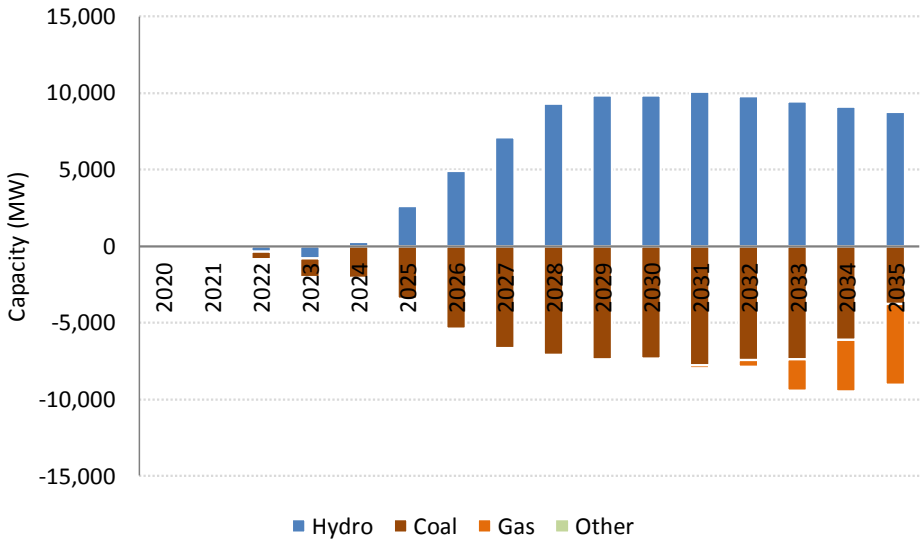


Figure 120 to Figure 123 plot the capacity outlook by country and by fuel types and show an extra 10 GW of hydro power developed in Laos displacing coal and to a smaller extent, gas developments. The capacity development differences relate to the overall reduction in generation costs associated with hydro in Laos compared to thermal options available in the standalone planning outlooks in Vietnam and Thailand in the Base case. Moreover, the amount of displaced coal and gas capacity is roughly equivalent to hydro by 2035 even with hydro energy constraints (roughly 40-50% capacity factor in Laos) highly suggesting better utilisation of generation resources and benefits associated with reserve sharing – this is generally expected with varying demand profiles and hydro availabilities across the GMS countries which are all interconnected in the Integrated Case.

Figure 120 Capacity Outlook by Country (Base and Integrated Case Difference)

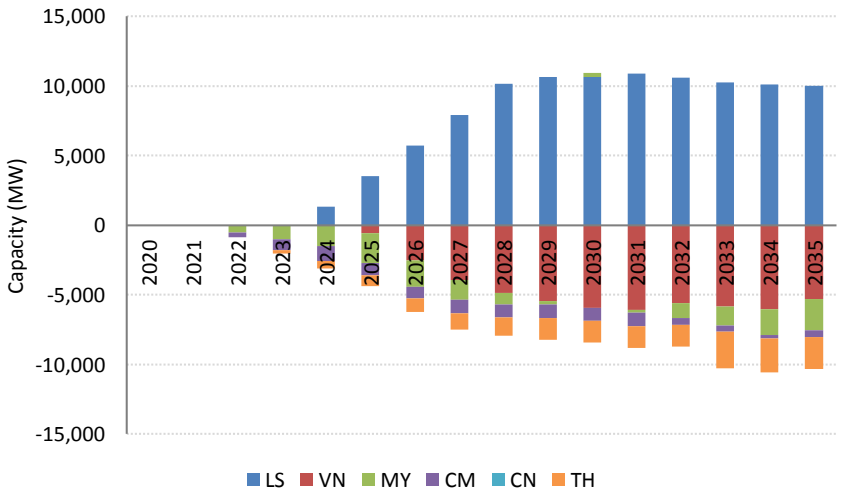


Figure 121 Hydro Capacity Outlook by Country (Base and Integrated Case Difference)

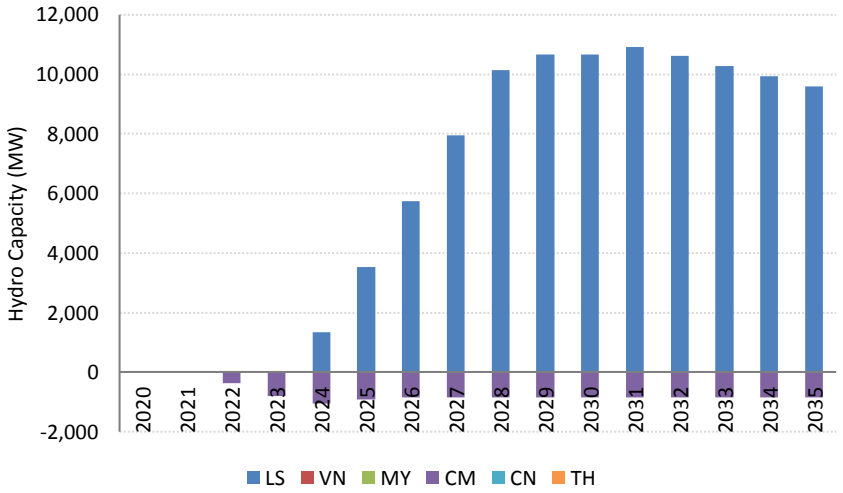


Figure 122 Coal Outlook by Country (Base and Integrated Case Difference)

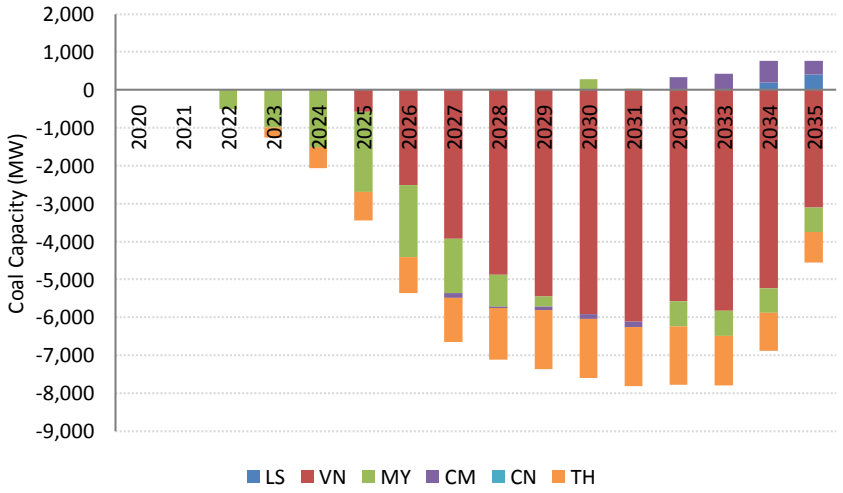
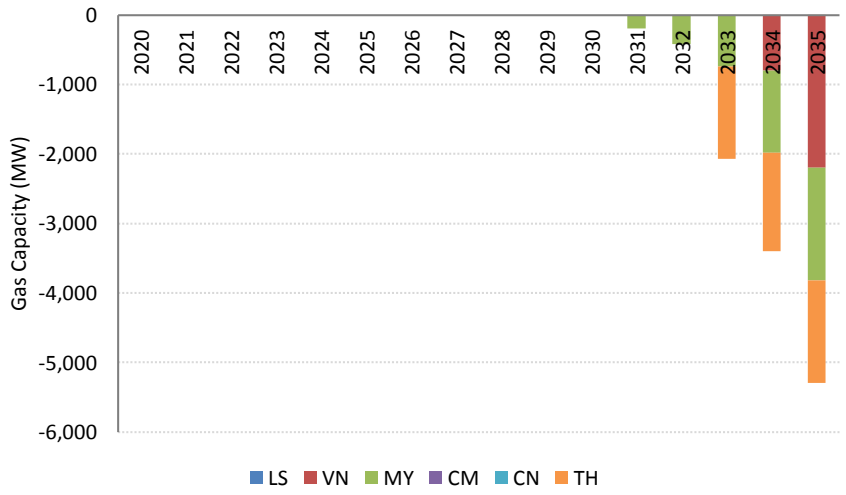


Figure 123 Gas Capacity Outlook by Country (Base and Integrated Case Difference)



The generation differences as plotted in Figure 124 and Figure 125 follow that of the capacity outlook. The additional hydro capacity generates an additional 70 TWh, displacing coal and gas over the long-term in Vietnam and Thailand. However, the outlook for the GMS even with cross-border trading is still dominated by coal generation. The hydro share increases above gas generation post 2026. Figures Figure 126 to Figure 129 plot the generation differences by country and fuel type.

Figure 124 Coal, Gas and Hydro Generation Outlook (Base and Integrated Case)

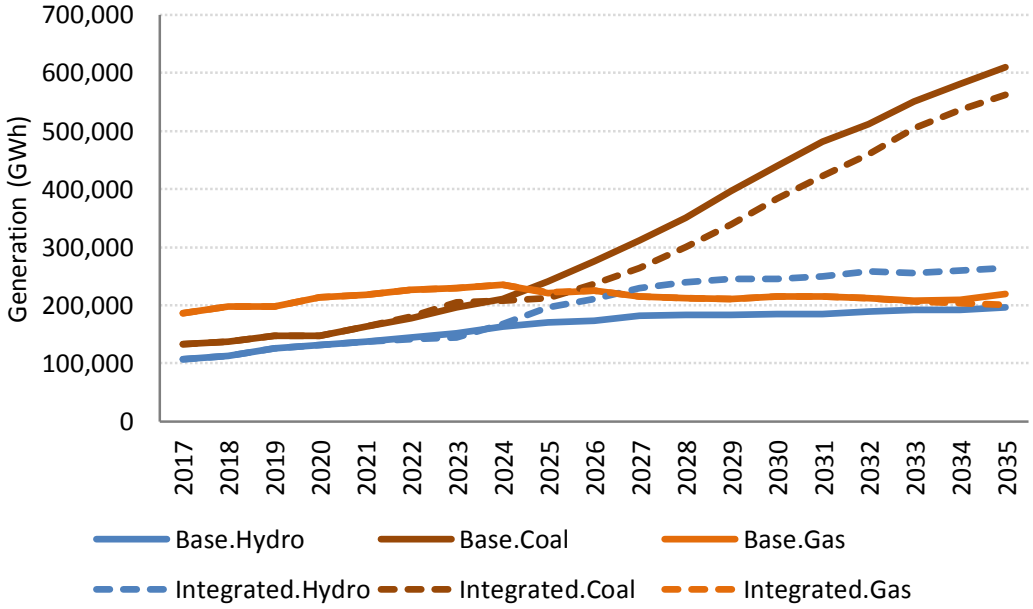


Figure 125 Coal, Gas and Hydro Generation Outlook (Base and Integrated Case Difference)

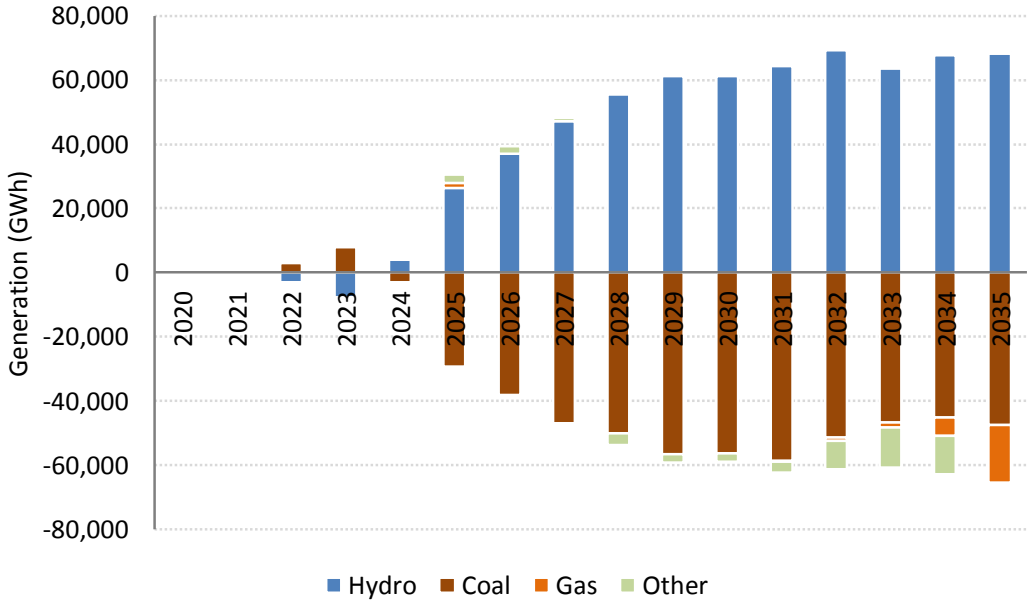


Figure 126 Generation Outlook by Country (Base and Integrated Case Difference)

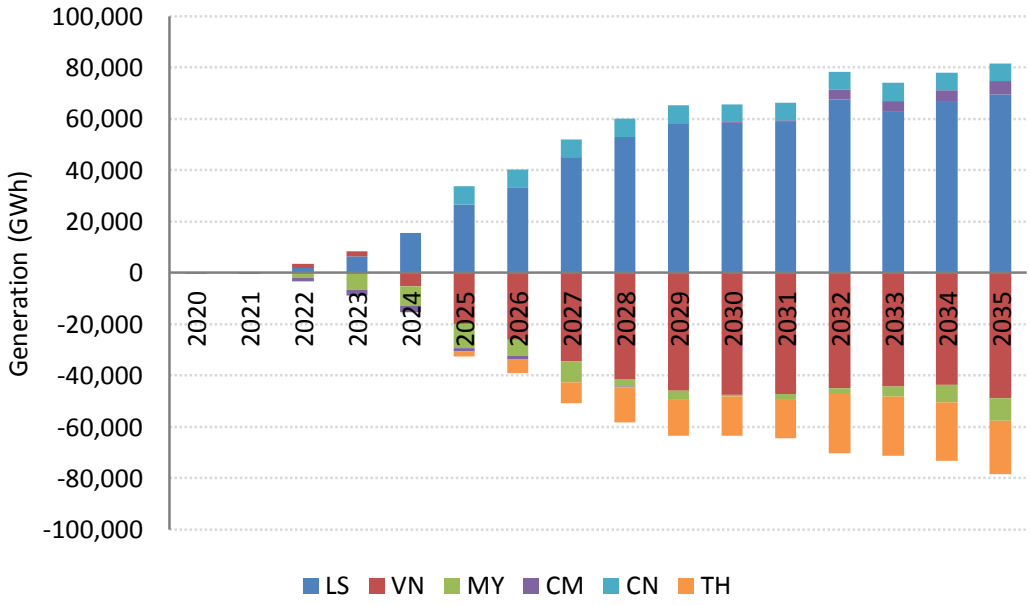


Figure 127 Hydro Generation Outlook by Country (Base and Integrated Case Difference)

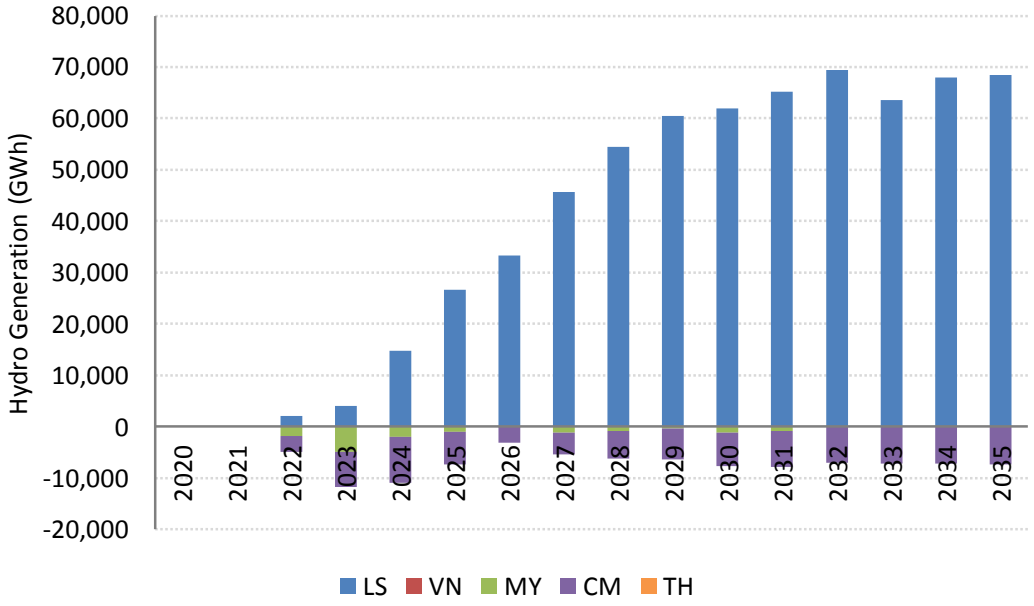


Figure 128 Coal Generation Outlook by Country (Base and Integrated Case Difference)

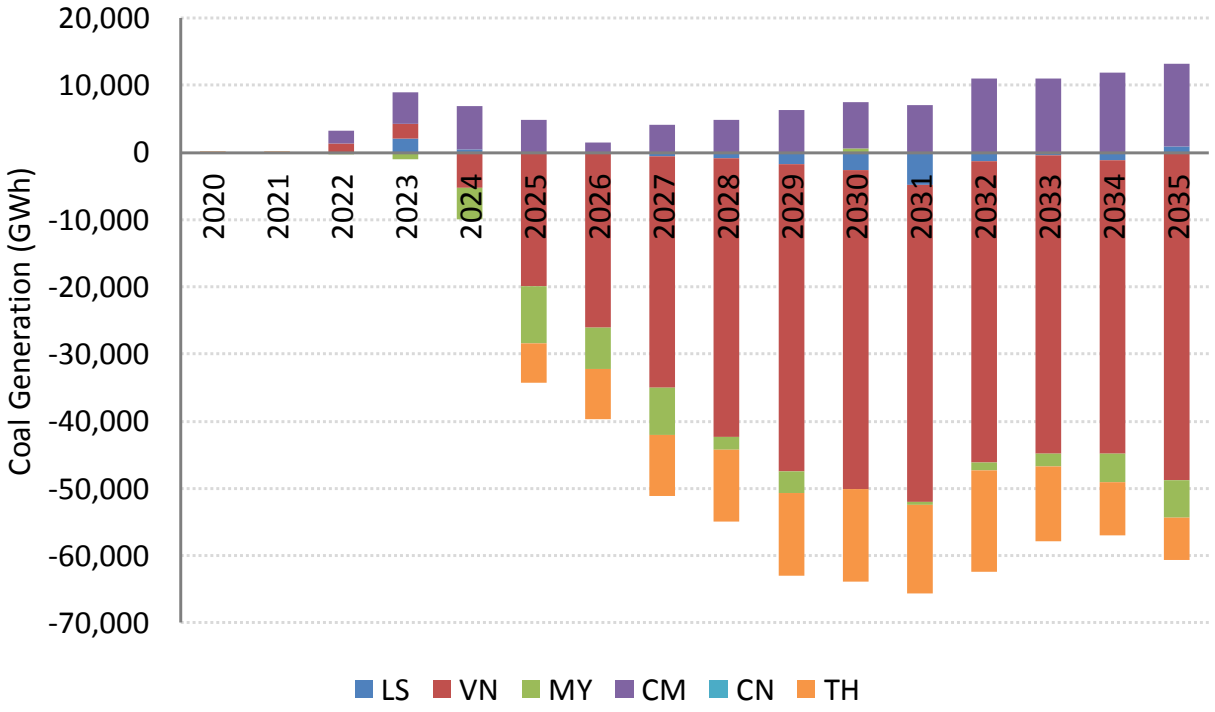
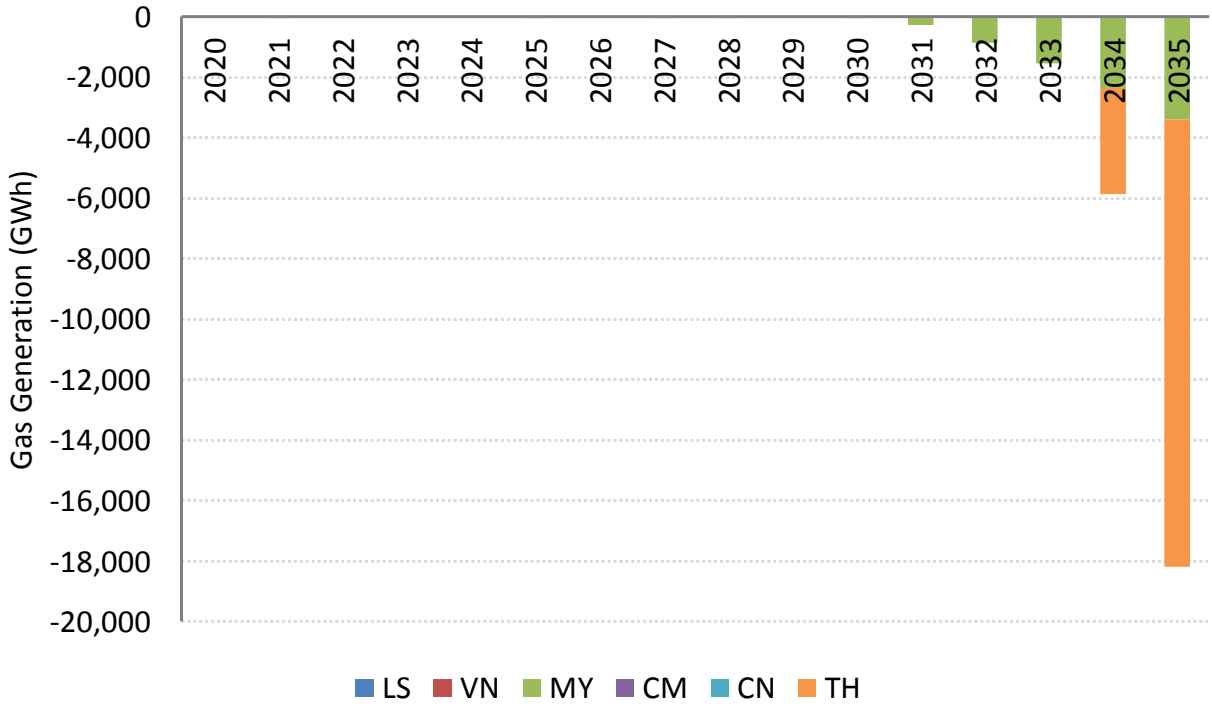


Figure 129 Gas Generation Outlook by Country (Base and Integrated Case Difference)



8.5 Costs and Benefits

The net benefits plotted below (Figure 130) and associated with the integrated case, are significant and are entirely accounted for by generation cost benefits (hydro displacing coal and gas generation). A portion of the generation benefit includes imports from China which has been valued at $0/MWh, however, Figure 131 adjusts the cost and benefit calculation based on valuing the imports at $50/MWh (approximate break-even level for the PRC to MY-N business case). At a high level:

- There is an associated negative capex benefit (from additional capex spend, as opposed to an overall deferral or avoidance of capital expenditure compared to the Base case);
- The cost of internal transmission augmentations to support the Integrated case is negligible; and
- NPV for Integrated case assuming no cost to China imports is $3.5 billion, and the NPV assuming a $50/MWh import cost from China is $2.4 billion.
- The Integrated case has a total NPV that is lower than the sum of the individual Business Cases as the benefits are not independent of each other.

Figure 130 Net Present Value by Component (Integrated Case, China Imports @ $0/MWh)

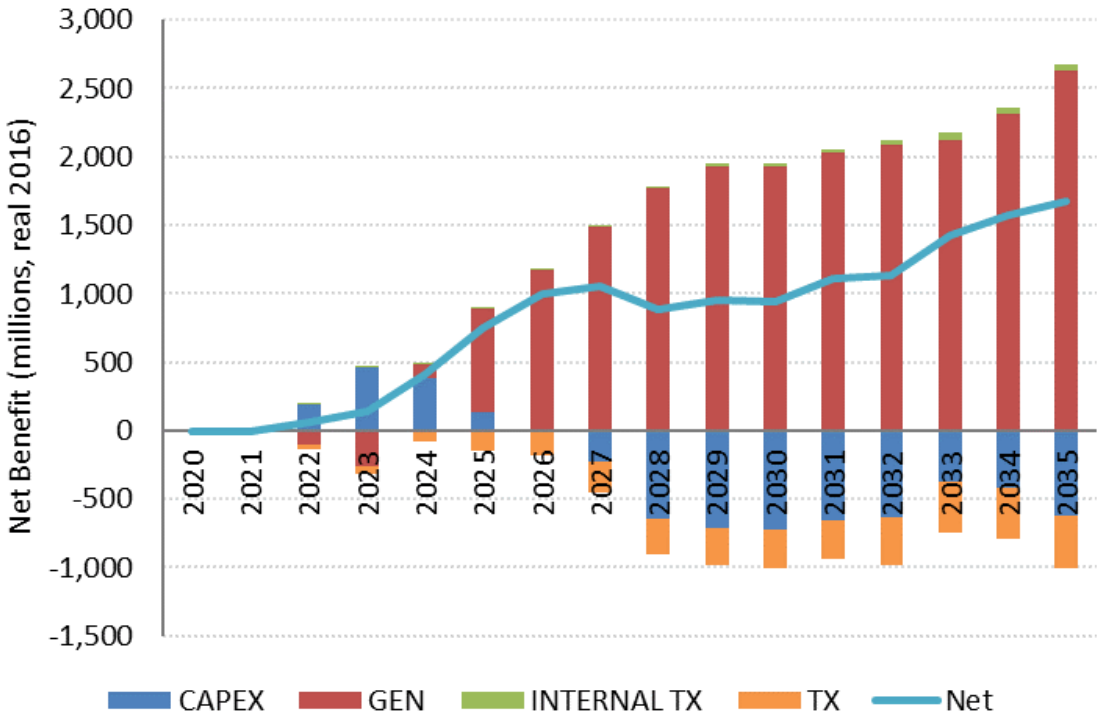
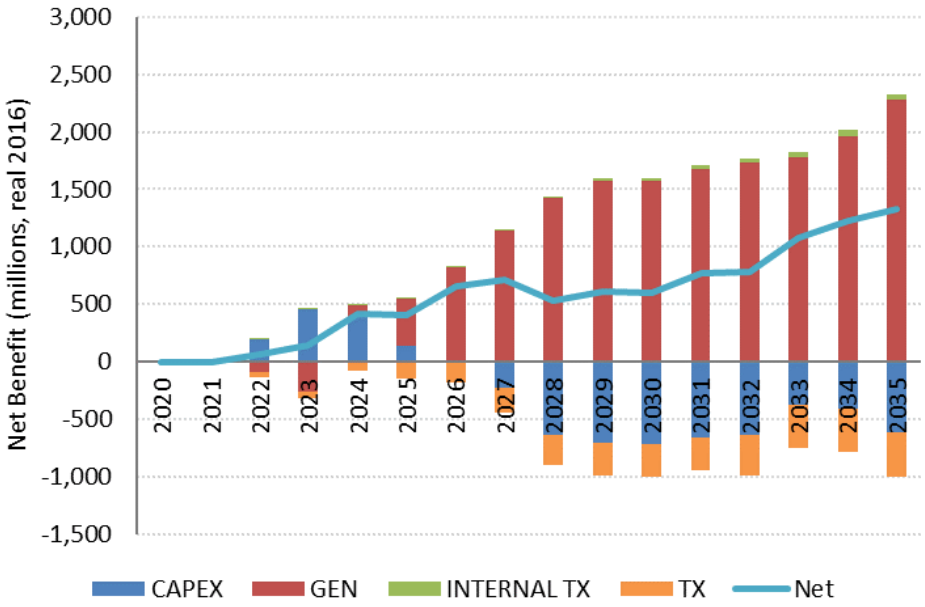


Figure 131 Net Present Value by Component (Integrated Case, China Imports @ $50/MWh)



The following figures (Figure 132 to Figure 134) divide the generation capex and generation fuel costs between the GMS countries[29]. The cost and benefit differences are consistent with the overall picture where extra investment is required in Laos with slight increases in Myanmar to support increasing power demands in Vietnam and Thailand. In overall terms, the higher capex costs in Laos and Myanmar are more than offset by the generation benefits in Vietnam and Thailand. As a result, the overall Integrated case benefits can be attributed to a subset of all Business cases studied i.e. ones that involve additional flows of lower-cost generation (PRC and Laos) displacing higher-cost generation (Thailand and Vietnam).

[29] On an amortised basis. Transmission investment costs are not included here.

Figure 132 Capex Difference by Country (Base and Integrated Case)

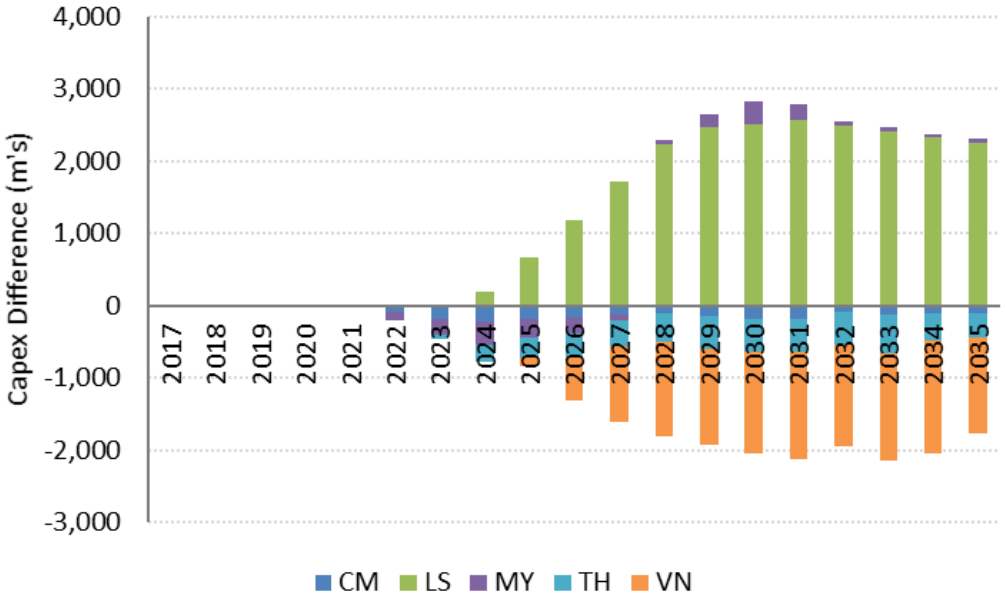


Figure 133 Generation Cost Difference by Country (Base and Integrated Case)

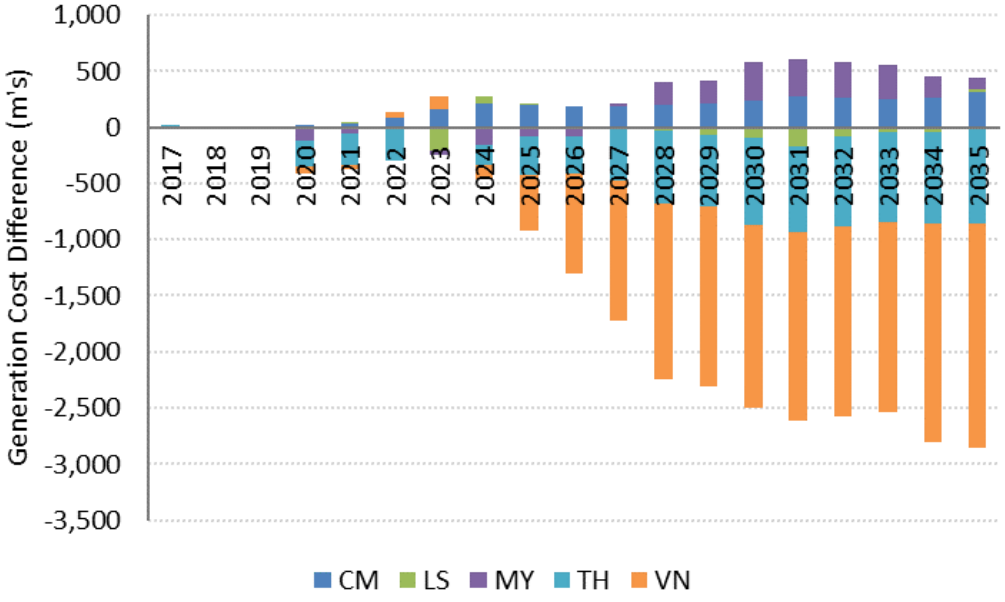


Figure 134 Total Cost Difference by Country (Base and Integrated Case)

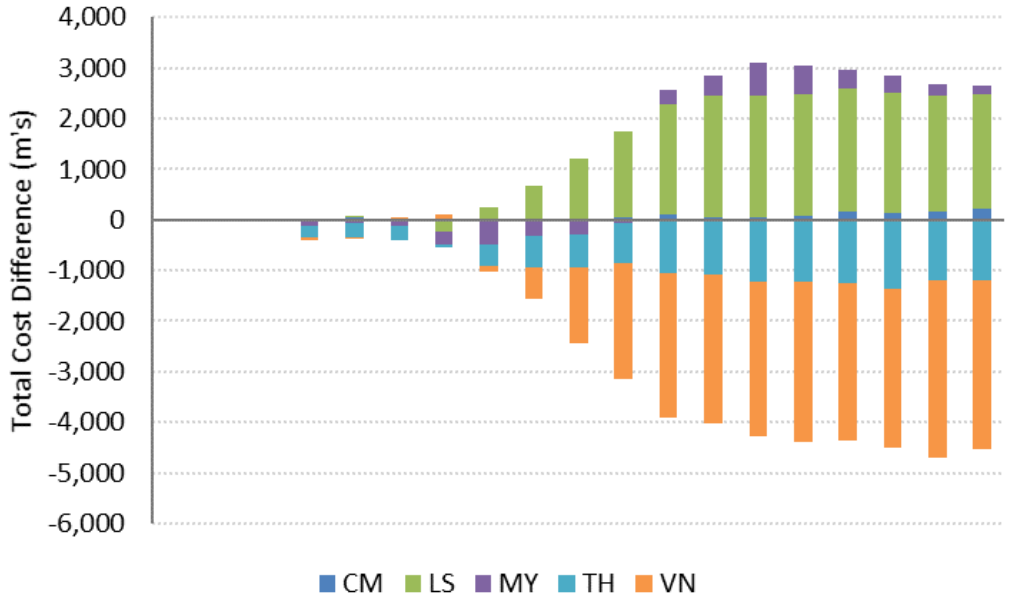


Figure 135 plots the cumulative investment cost across all of the business case links in the Integrated case, excluding national transmission augmentations which require a lot less capital in comparison. Total investment by 2035 reaches $3.4 billion with significant investment across several links connecting Laos north to Myanmar north due to significant benefits associated with the surplus capacity in Laos to Myanmar, followed by Thailand north to Myanmar central, and Laos north and south to Vietnam north and south respectively. These four links account for 70% of the total investment cost and highlights the flow paths and priority resulting in the highest cost savings purely from an economic cost perspective.

Figure 135 Cumulative Integrated Case Transmission Investment Cost

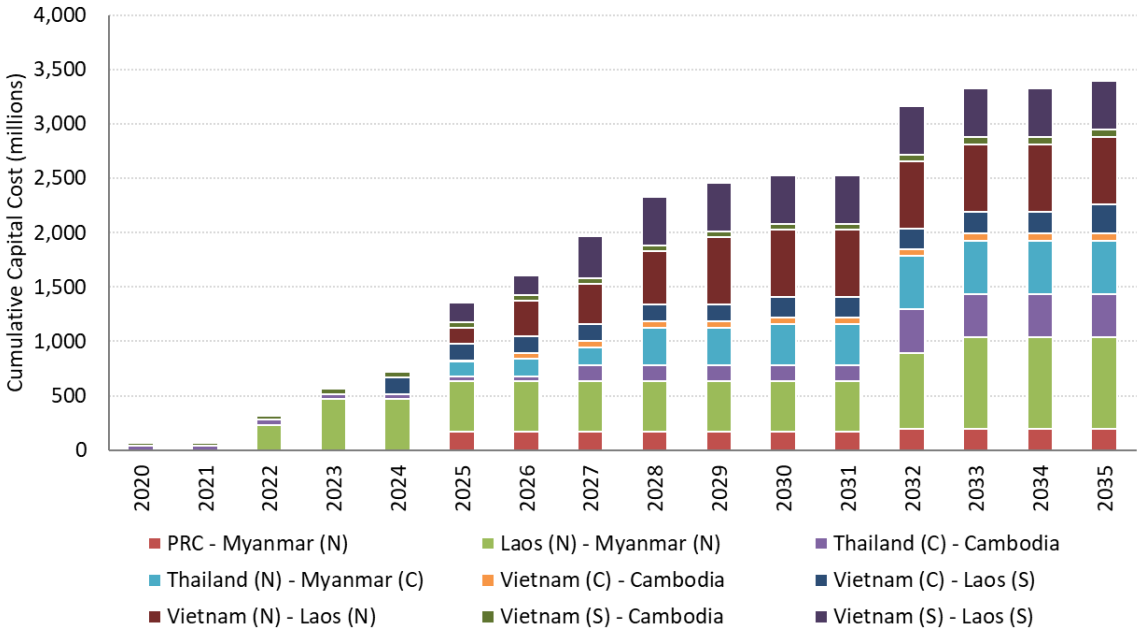
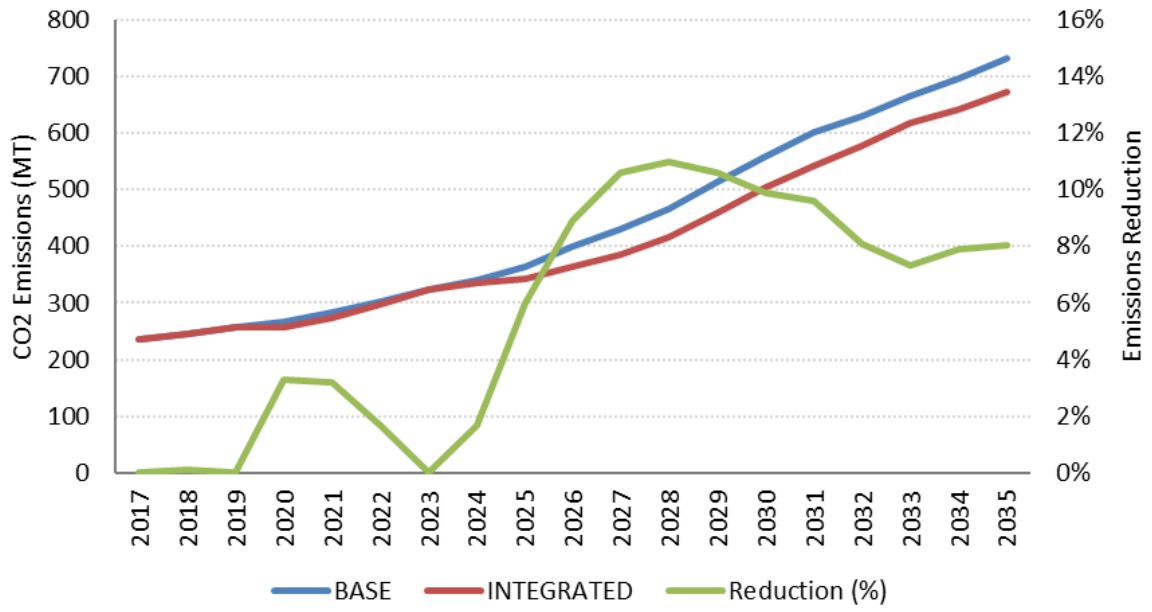


Figure 136 plots the emissions trajectory for the Base and Integrated Case. The slope of the emissions increases over time in both cases relating to the shape of the demand curve and higher coal generation

shares over time. However, the Integrated case with additional hydro capacity results in emissions reduction between 8-11% from 2025-2035 due to the displacement of mainly coal-fired generation.

Figure 136 Carbon Emissions (Base and Integrated Case)



8.6 System-to-System Interconnections and Synchronisation

8.6.1 Basis and Key Assumptions for Interconnection Strategy

The modelling of selected cross-border expansion projects and the Integrated case has enabled us to identify the benefits of each cross-border expansions in the GMS. Table 24 (presented earlier in the report) shows a proposed development strategy that is based on the principle of prioritising projects with the greatest economic benefits to the region. It is important to recognise that we did not consider low voltage / distribution network level connections and that, with the exception of cross-border links involving PRC, we have considered only AC (synchronous) interconnections of the transmission networks in the region.

In order to realise the identified benefits, an interconnection strategy is required that considers gradual steps towards implementing the projects in Table 3. In general, any such interconnection strategy would need to involve supporting investments in control schemes, building in N-1 redundancy, automatic control schemes and rules of power system dispatching. This highlights the importance of establishing a harmonised Grid Code for the region where suitable standards for connection and control would be defined. These issues have not been considered in the interconnection strategy – it has been based simply on matching a synchronisation programme to the prioritised investments. Further engineering studies would naturally need to be done.

The strategy is intended to provide guidance on a foreseeable synchronisation strategy to support the results of the integrated GMS case. In this discussion we do not discuss the lower voltage interconnections between Laos and Thailand, and between Laos and Vietnam. However, there may be some opportunities to revisit lower voltage connections as part of a wider strategy to synchronise grids in the region. A further comment on the foregoing is that we consider only the business cases that were analysed in this report; there may be other cross-border connections that warrant close attention such as between Northern Laos and Myanmar, PRC and Vietnam, and strengthening lower voltage connections between Laos and Thailand.

The proposed synchronisation strategy has been structured into four key phases, with full synchronisation suggested by 2031.

8.6.2 Stage 1: Period from 2022-24: Strengthening Cambodia, Laos and Vietnam and Northern Laos to Myanmar

The Integrated Case showed that the most immediate opportunities for cross-border trade are to expand the existing connection between Vietnam and Cambodia, and for southern Lao PDR to export power to central Viet Nam. In relation to enhancing system-to-system power trade:

- The expansion of an already synchronous connection between Vietnam and Cambodia is shown to be beneficial and could be done in a way to enhance power system security to Cambodia.
- Lao PDR south is suggested by the Integrated Case to be economically interconnected to Viet Nam. Interconnectivity between the south of Lao PDR's national grid and the rest of the country is very weak. Furthermore, the proposed exports from Lao PDR to Viet Nam in the south are planned to be done by connecting enclaves of hydro generators to Vietnam's power system, which is a first step towards synchronisation. A possible approach therefore would be to synchronise the enclaves and expand a subset of the southern power system of Lao PDR to synchronise with Viet Nam.
- Finally, the business case of northern Laos to Myanmar was shown to be economically viable in the shorter-term – in a similar way to the strategy for connection of southern Laos to Vietnam, formation of an isolated enclave of hydro assets in the north of Laos to export to Myanmar makes sense as an initial step.

This situation is illustrated conceptually in Figure 137 and Figure 138. The first diagram illustrates how southern Laos would be divided into a zone that is synchronised to Vietnam and a zone that remains synchronised to the rest of the Laos national system – the shaded area is what we will refer to as the "Eastern GMS". The second diagram illustrates Laos north being split into two separate isolated zones and exports to Myanmar – this is what we will refer to as the "Western GMS".

Based on the Integrated Case, the GMS does not have any other cross-border interconnections during this period, so we do not consider synchronisation outside of this initial stage.

Figure 137 Stage 1: Synchronisation Strategy for 2022-24 for Cambodia, Laos and Vietnam

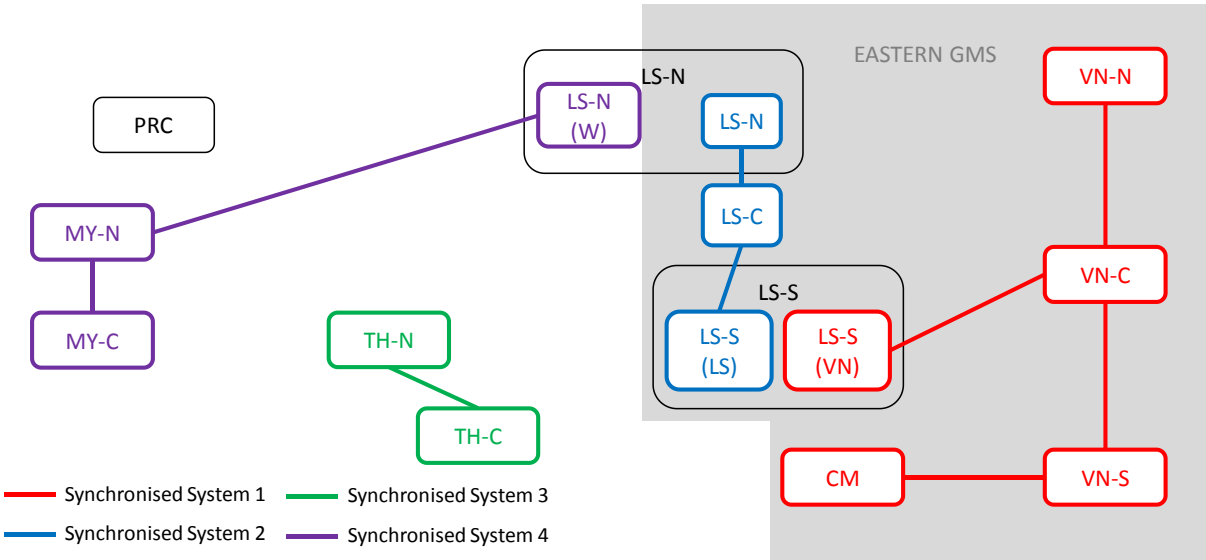
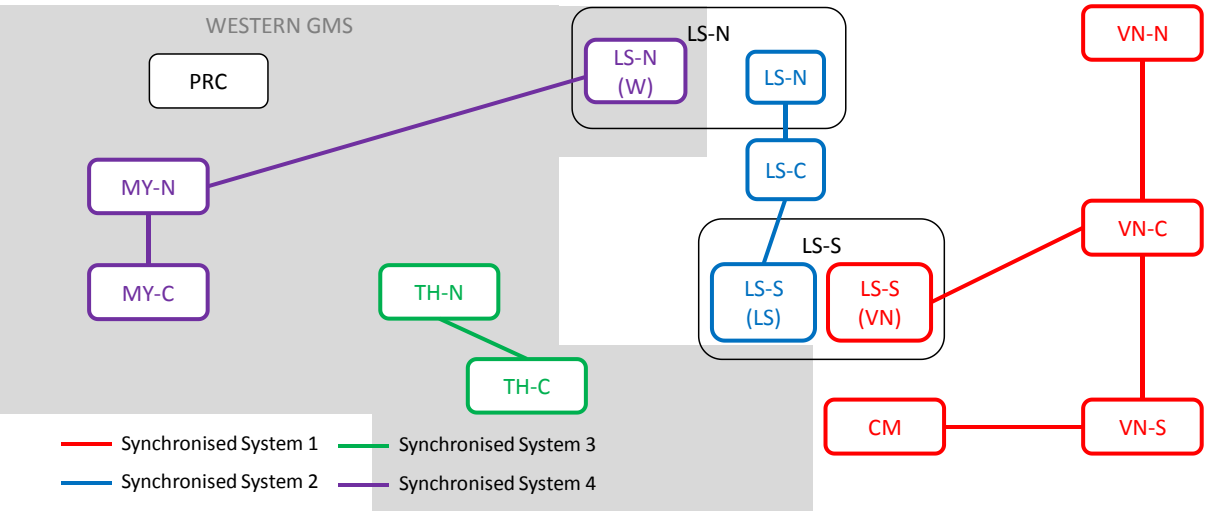


Figure 138 Stage 1: Synchronisation Strategy for 2022-24 for Laos (North) and Myanmar



8.6.3 Stage 2: Period from 2025-27: Eastern GMS (Cambodia, Laos and Vietnam) and Western GMS (Myanmar, PRC, Thailand)

During this period, there are six (6) expansions that were shown in the Integrated Case to be economically viable:

- Laos (North) to Vietnam (North);
- Cambodia to Vietnam (Central);
- Lao PDR (South) to Vietnam (South);
- Myanmar (Mandalay) to PRC;
- Thailand (central) to Cambodia (northwest); and
- Myanmar to Thailand.

From the perspective of a synchronisation strategy, it is useful to regard these connections as part of an “Eastern GMS” and a “Western GMS”. We define the Eastern GMS to consist of Laos, Vietnam, and eastern Cambodia power system and the Western GMS to consist of PRC, Myanmar, Thailand and the north-west of the Cambodia power system (around the Siem Reap load centre for example).

Figure 139 shows conceptual the situation for the period 2025-27, for the Eastern GMS, with key features being the following:

- Southern Laos network and Vietnamese network is strengthened and synchronised;
- Cambodian power system cross-border connections to Vietnam are strengthened; and
- Northern Laos split into two sub-regions with portion synchronised to Vietnamese north power system.

Figure 140 illustrates conceptually the situation for the period 2025-27, for the Western GMS highlighting the connections between PRC, Myanmar, Cambodia and Thailand. Key comments in relation to synchronisation of the involved power systems are:

- PRC connects to Myanmar via HVDC, so there are no significant issues with respect to staging synchronisation between grids;
- Split Cambodia into west and east sub-zones as first step in synchronisation to Thailand; and
- Similarly, split Myanmar central (Yangon) into west and east zones for synchronisation to Thailand.

Figure 139 Stage 2: Synchronisation Strategy for period 2022-24 for Eastern GMS

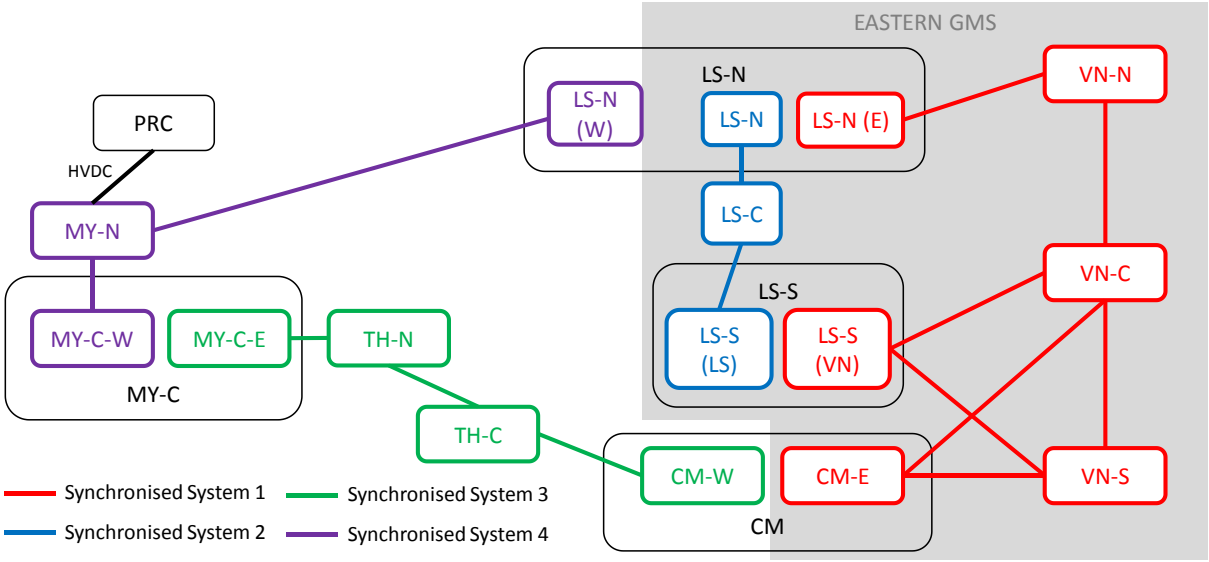
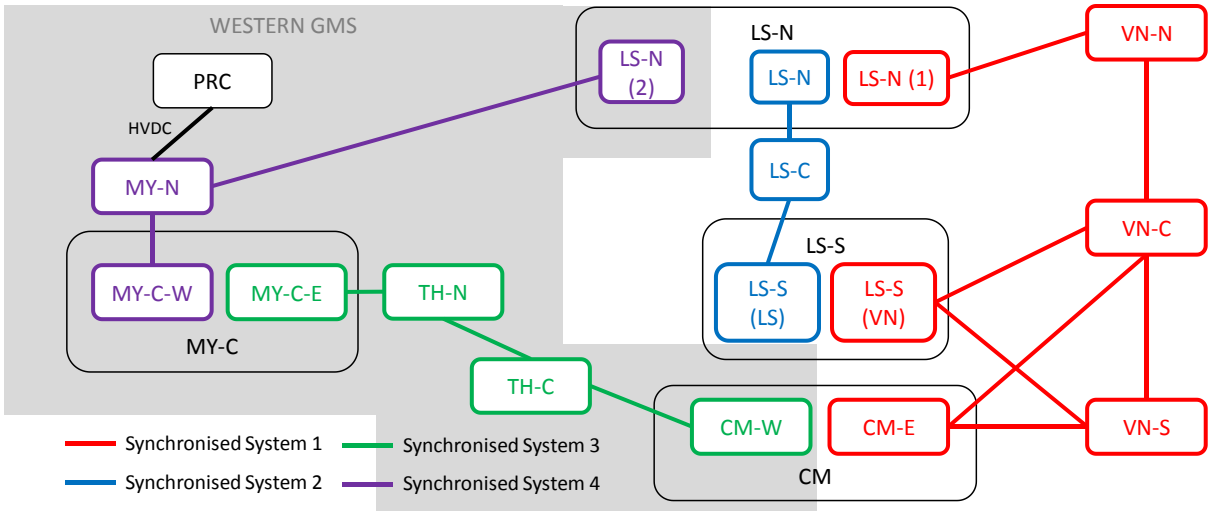


Figure 140 Stage 2: Synchronisation Strategy for period 2022-24 for Western GMS



8.6.4 Stage 3: Period from 2028-30: Eastern GMS Synchronisation and Western GMS Synchronisation

The cross-border connections from the Integrated Case for the period from 2028 to 2030 are essentially significant expansions of cross-border connections established in earlier phases, as follows:

- Further expansion of Myanmar to Thailand;
- Further expansion of Laos PDR (South) to Vietnam Central and South; and
- Further expansion of Laos PDR (North) to Vietnam (North).

These largely relate to upgrading existing connections that have been proposed for development during Stage 2. We therefore suggest that within this period that the western GMS region and the eastern GMS regions be internally synchronised:

- Figure 141 shows the consolidation of the eastern GMS and in particular synchronisation of Laos, Vietnam and Cambodia western into a single integrated sub-system; and

- Figure 142 shows the consolidation of the western GMS and in particular synchronisation of Myanmar, Thailand and western Cambodian power systems as a single integrated sub-system that has a HVDC connection to China in the north.

This way there are two separate but largely synchronised grids. The main justification for this approach is that the Thailand and Vietnamese systems are relatively large; therefore, we are interconnected and synchronising the smaller systems of Myanmar, Cambodia and Laos to their larger neighbours initially, before considering interconnection of the western and eastern systems.

Figure 141 Stage 3: Period 2028-30 Synchronisation of Eastern GMS

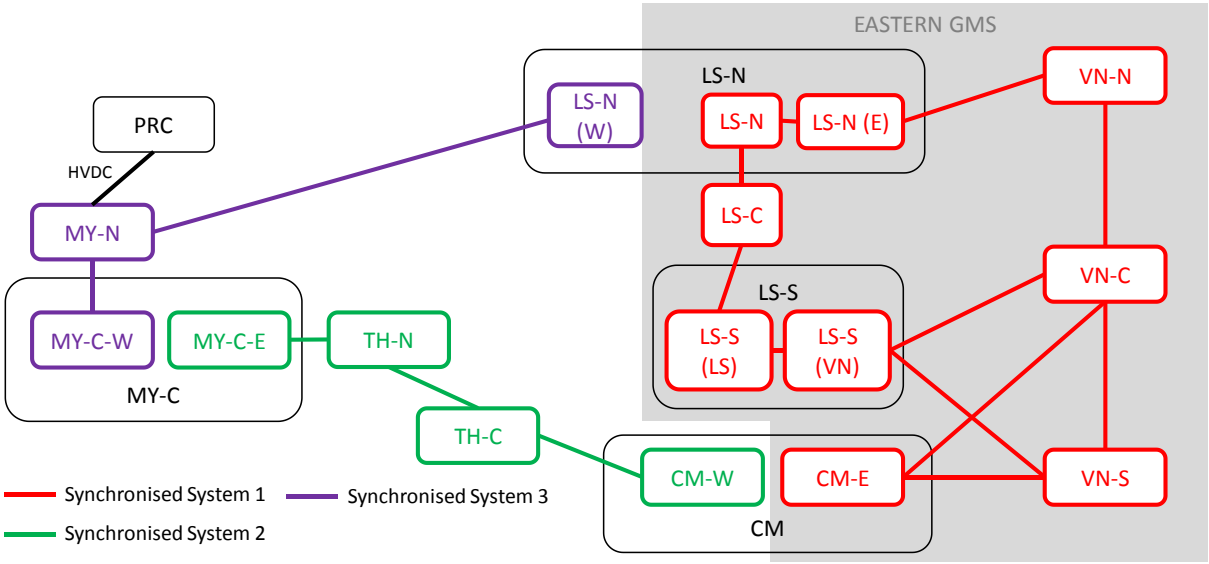
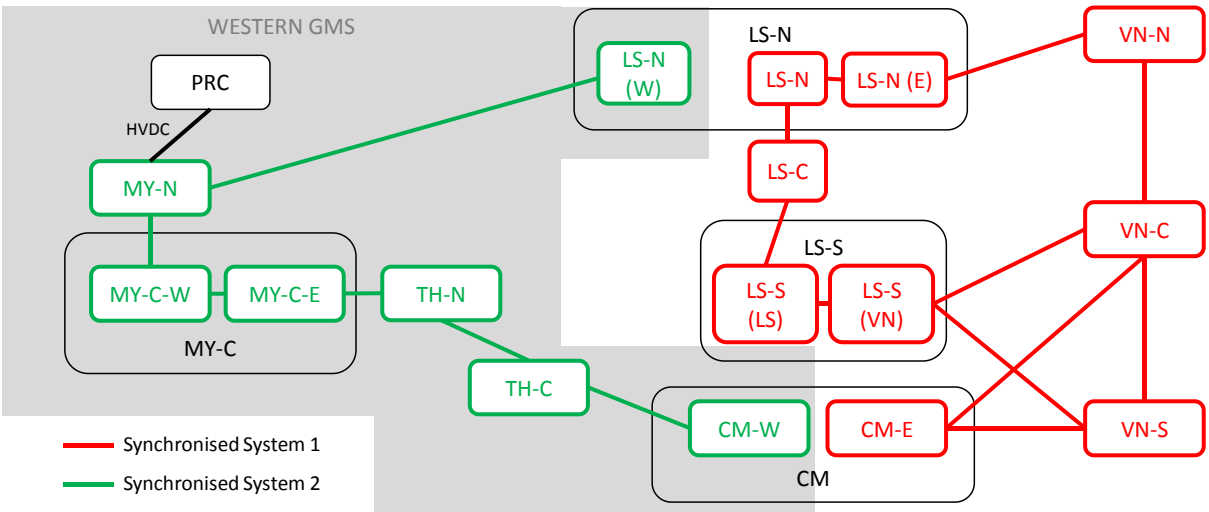


Figure 142 Stage 3: Period 2028-30 Synchronisation of Western GMS



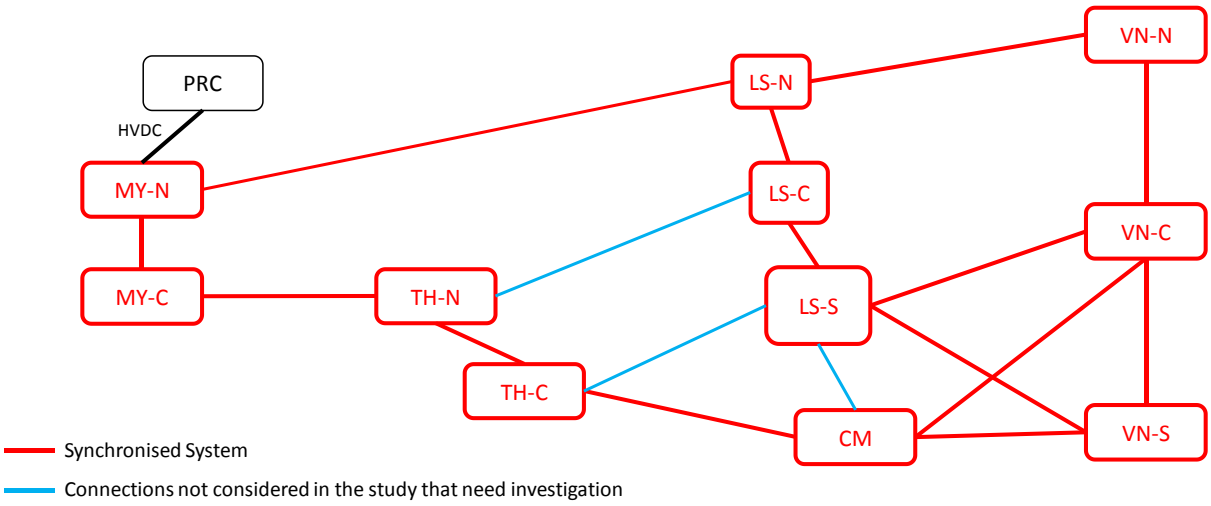
8.6.5 Stage 4: Period from 2031 and beyond: Full Synchronisation (Eastern GMS and Western GMS Synchronised)

Stage 4 is defined by the following cross-border interconnections:

- Lao PDR (South) to Vietnam (Central);
- Myanmar to Thailand (Norther);
- Thailand (Central) to Cambodia;
- Cambodia to Vietnam (South):
- Lao PDR (North) to Myanmar (North); and
- Myanmar (North) to PRC.

Figure 143 shows the overall integrated and synchronised regional power system based on the suggested strategy for synchronisation. Within this diagram, we have included a number of connections that we did not explicitly consider or study within this project. The role of these interconnections should be investigated and considered within a synchronisation strategy and to better balance power flows in the region.

Figure 143 Synchronisation Strategy for period 2028-30 for Cambodia, Laos and Vietnam



8.6.6 Roadmap for GMS Interconnection

In Figure 144, we provide a conceptual roadmap for regional integration and in Table 25, we provide an interconnection strategy. The conceptual roadmap is intended to illustrate the high priority cross-border connections over time, along with other important actions that are required. The table provides further details across four stages of regional integration beginning with the present state of the GMS and progressively moving towards a fully integrated and synchronised GMS by year 2031.

Figure 144 Conceptual Roadmap for Regional Integration

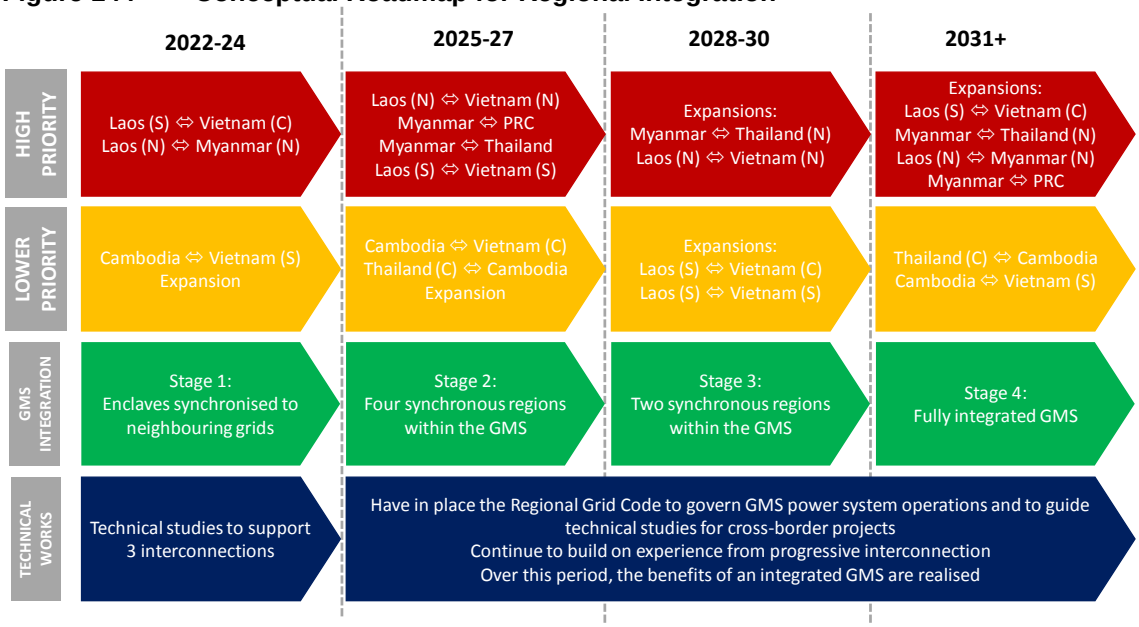


Table 25 Proposed Strategy for Integration of Synchronous Interconnections

Stage	Period	Preconditions	Key Actions	Purpose
1	2022-24	Technical feasibility studies for the proposed cross-border projects within this period.	Synchronisation of a portion of the southern Laos power system to Vietnam central and building upon the existing synchronous connection between Vietnam south and Cambodia and synchronising a portion of Las North grid to Myanmar.	Build on the limited number of existing synchronised interconnections and take initial steps towards interconnecting high priority cross-border interconnections with minimal implications for synchronised grid operations.
2	2025-27	Regional Grid Code in place to guide technical studies and identify supporting transmission network investments to enable synchronous interconnections to operate appropriately.	Form four synchronous interconnections within the region, with the synchronous interconnections being: (1) Vietnam and parts of Cambodia and Laos, (2) Laos and connections to Thailand, (3) Cambodia, Thailand and a portion of Myanmar's southern power system, and (4) Myanmar and PRC.	Build on the experience of stage 1 by expanding synchronous interconnections and subsequently managing power system operations under the Regional Grid Code. Continue to realise a significant fraction of the economic benefits of the high priority cross-border projects.
3	2028-30	Successful implementation of stage 2, and completion of technical studies to support further cross-border connections in the region.	Formation of eastern and western GMS synchronous interconnections through integration of Laos, Cambodia and Vietnam to form the eastern system, and integration / synchronisation of PRC, Myanmar, Thailand and Cambodia to form the western system.	Establish two significant synchronous regions within the GMS and have them operated under the Regional Grid Code. Most of the "low hanging fruit" benefits of the Integrated case are realised within this period.
4	2031 & beyond	Successful implementation of Stage 3, and completion of technical studies to support further cross-border connections in the region.	integration of western and eastern GMS synchronous interconnections to have a fully integrated and synchronised regional power system	Gain the full benefits of an integrated GMS.

8.7 Key Insights

The Integrated case combines the benefits of all the individually modelled business cases – jointly optimising generation and transmission. The Integrated case shows significant overall benefit to region ($3.5 billion NPV) as the result of swapping coal and gas capacity for hydro generation and gas for coal to a lesser extent and reducing urgency of developing thermal generation projects in some countries. Many of the benefits can be attributed to links from Laos to Vietnam, and Laos and PRC to Myanmar. The reserve sharing benefits also takes advantage of differing demand and hydro conditions across the GMS, and power surpluses are used more efficiently and directed to countries that have tighter supply and demand conditions.

In terms of regional transmission planning, most of the business cases have been shown to play a role in a regional transmission expansion plan. In particular, the priorities for the shorter term include Laos South to Vietnam Central, Northern Laos to Myanmar and increasing the interconnectivity between Vietnam and Cambodia as this is also a power system stability benefit. The longer-term should prioritise Laos North to Vietnam, PRC to Mandalay and to expand and build on the shorter-term cross-border links identified above.

National transmission planning needs to be coordinated with generation developments and regional transmission planning to realise the benefits modelled here. Grid strengthening of the Laos national power system from north to south is very important as evidenced by its location in the GMS, and hydro developments earmarked solely for exports. Similarly grid strengthening between North and Central Myanmar is very important if it wishes to become a net exporter of energy. Other observations and benefits include:

- Can support higher level of renewable energy integration;
- Hedge against dry seasons for hydro and/or extreme renewable energy conditions;
- Less imported coal in the near-term to medium-term;
- Less gas development in the longer-term;
- Reduction in emissions from the region;
- Will require significant country coordination of grid to grid planning and operation to realise the benefits of the integrated case; and
- A suitable synchronisation strategy can be formulated that follows the Integrated Case, which targets to have full synchronisation by 2031 in the GMS, based on the following four stages:
    - Stage 1 (2022-24) – involves synchronisation of a portion of the southern Laos power system to Vietnam central and building upon the existing synchronous connection between Vietnam south and Cambodia and synchronising a portion of Laos North to Myanmar;
    - Stage 2 (2025-27) – involves essentially forming four synchronous interconnections within the region, with the synchronous interconnections being as follows: (1) Vietnam and parts of Cambodia and Laos, (2) Laos and low voltage connections to Thailand, (3) Cambodia, Thailand and a portion of Myanmar's southern power system, and (4) Myanmar and PRC;
    - Stage 3 (2028-30) – formation of eastern and western GMS integrated (synchronised) systems by integration / synchronisation Laos, Cambodia and Vietnam to form the eastern system, and integration / synchronisation of PRC, Myanmar, Thailand and Cambodia to form the western system; and
    - Stage 4 (2031 and beyond) – integration of western and eastern GMS synchronous interconnections to have a fully integrated and synchronised regional power system.

This study has examined basic scenarios of supply and demand for PDPs of each country as we understand them to be at moment. We recognise that this is a moving target as countries update their plans. This study did not carry out detailed sensitivity analysis for materially different technology mixes (e.g. higher RE scenarios) which we would expect to further highlight the importance for cross-border trading, nor did it cover different energy efficiency scenarios or emissions limit scenarios.

9 Conclusions

GMS integration will benefit all countries within the region in the form of avoiding additional generation investments, deferring the need for national transmission upgrades, and avoiding higher power generation costs. There are clear diversification benefits that in a number of countries provide relief from under-investment in generation. Other identified benefits include being able to deploy higher levels of renewable energy in the region and better utilisation of hydro resources as a consequence of diversification in hydrological conditions and diversification in demand profiles of the inter-connected countries.

The modelling carried out in this study also shows that there are significant benefits from greater integration of Laos with its neighbouring countries. In the near-term, Laos could play a role in terms of providing additional power supplies to Myanmar and Vietnam with immediate short-term cost reductions, and over the longer-term for Thailand. Most of the benefits associated with the Integrated Case are the result of alleviation of Myanmar's short to medium term tightness in supply, use of surplus power from PRC, and use of hydro resources in Laos for exports to Vietnam and Myanmar. These benefits arise from only a limited number of interconnections that were studied, specifically the Myanmar to PRC and Laos, and Laos to Vietnam business cases.

Modelling of the individual business cases all resulted in positive net present values (up to $1.6 billion) arising from a deferral or avoidance of generation investment, and highly significant reductions in power generation costs. However, the results show a subset of the individual business cases to have much higher positive benefits relating to hydro displacing coal and gas generation. The benefits for the Integrated Case is simply a combination of all of the underlying Business case links which can be attributed to a small number of high NPV projects corresponding to the Business cases connecting hydro or low-cost exporting zones in Laos and PRC to the higher cost systems of Myanmar, Thailand and Vietnam. The magnitude of these benefits can be used as a way of prioritising the business cases.

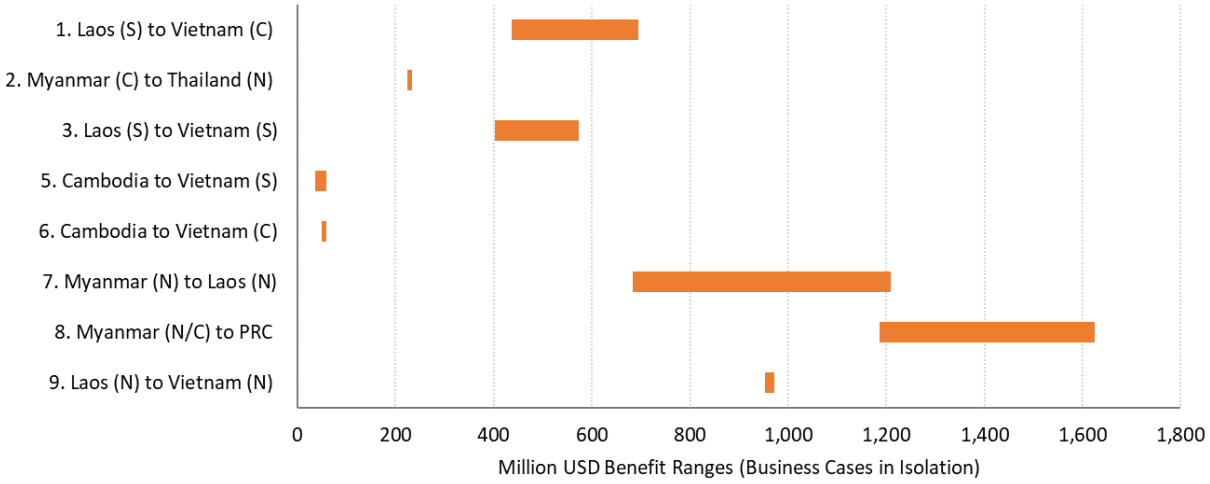
Figure 145 plots the NPV ranges for the individually modelled Business Cases and Figure 146 plots the highest NPV ranges per business case along with the NPV result from the Integrated Case. The larger the bar in these charts the higher the benefits flowing from the business case - higher project benefits are clearly associated with business cases involving Laos and Myanmar.

Figure 148 plots the total costs and benefits by country whereby significant developments in Lao PDR drive a lot of the generation cost reductions in Vietnam and Thailand. The cost of national grid transmission augmentations would relieve the total investment required to augment the Myanmar and Vietnam grids, but increase the importance of the Laos network in connecting the region. The net benefit is approximately $440m by 2035

Figure 147 compares the total transmission investment cost, excluding national transmission augmentations, across the individual business case links and the Integrated case cost[30]. The Integrated case is based on developing the optimal business case link capacities incrementally over time compared to the individual cases which were assumed to be in place at their full sizing at 2020 – the cost of the Integrated case is much smaller than the sum of the individual business case link investment costs, supporting the notion that prioritisation will be key in maximising the benefit across the GMS.

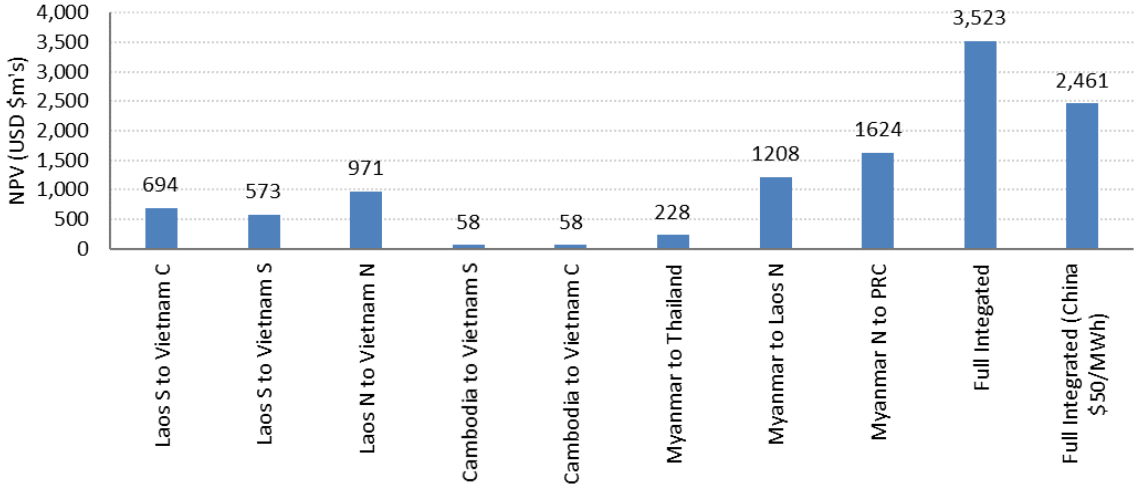
[30] Present value is based on a discount rate of 10% pa and valued at 2020.

Figure 145 Business Case NPV Ranges



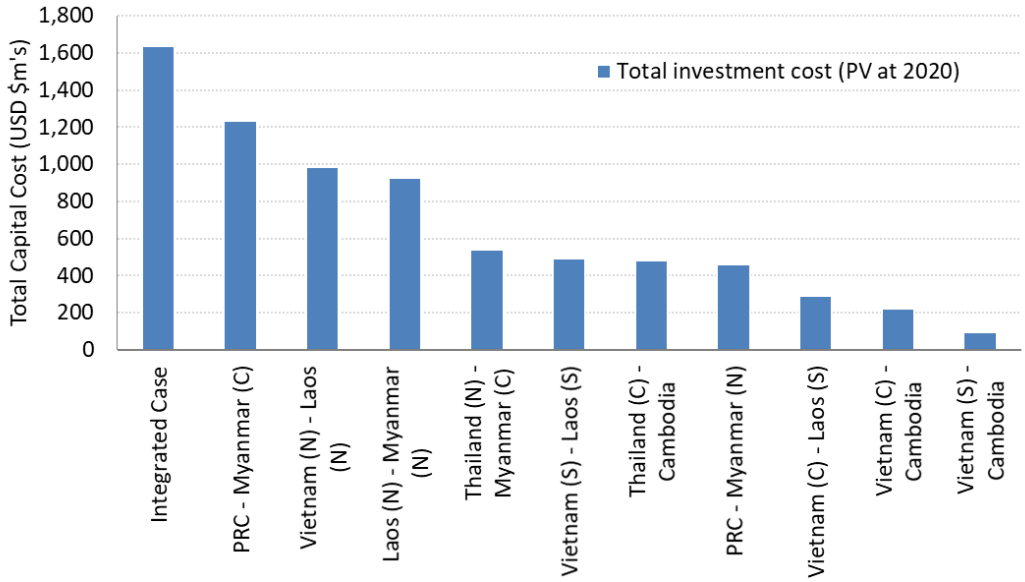
Case 4 not shown as it was not modelled separately

Figure 146 Optimal Business Case NPVs with Integrated Case



Individual business case links were based on sizes with the highest NPV

Figure 147 Total Transmission Investment Cost (Ordered)



The Integrated modelling highlighted several themes consistent throughout the individual business cases. These are summarised below:

- All countries benefit either from additional generation investment and national transmission upgrades, or are the recipient of imported power flows reducing power generation costs;
- There is better generation resource utilisation (particularly hydro resources) through the potential for diversification of generation supply and demand profiles across the connected countries;
- Diversification and additional supply options allow for immediate relief from generation supply under-investment, and higher levels of renewable energy integration than in the Base case;
- Lao PDR plays a very vital role in integrating the GMS, and in effect would become counterparty to all of the GMS countries;
- The integration of the GMS would relieve the total investment required to augment the Myanmar and Vietnam grids, but increase the importance of the Laos network in connecting the region. The net benefit is approximately $440m by 2035 (Figure 149);
- There are lower emissions than that of the Base case by approximately 7% over the period from 2020 to 2035 with a reduction in coal fired generation across the GMS (Figure 151). By 2035, the Integrated case results in 670 million tons of carbon dioxide equivalent emissions, down from 730 million tons in the Base case. On a standalone basis individual business cases reduce carbon emissions by up to 2.7% over the period from 2020 to 2035. Most of the emissions reductions in the Integrated case arise from Laos hydro displacing thermal generation located in Vietnam, benefits of which have not been quantified in addition to the reduction in generation costs;
- An integrated GMS allows for greater potential for further cross-border trading opportunities which will benefit and open up power planning options;
- Coordination is required in relation to grid-to-grid operations between country networks and also in delivering national transmission grid to support cross-border trading;
- The bulk benefits associated with the Integrated case (and associated business case links 1, 3, 7, 8, 9) relate to Myanmar's short to medium term supply requirements as well as surplus power from PRC, and the significant hydro resources in Laos for potential export into Vietnam and Myanmar that have systems with higher generation costs. These are associated with a smaller subset of all of the individual Business cases modelled; and
- A suitable synchronisation strategy can be formulated that follows the Integrated Case, which targets to have full synchronisation by 2031 in the GMS, based on the following four stages:

- Stage 1 (2022-24) – involves synchronisation of a portion of the southern Laos power system to Vietnam central and building upon the existing synchronous connection between Vietnam south and Cambodia and synchronising a portion of Laos North to Myanmar;
- Stage 2 (2025-27) – involves essentially forming four synchronous interconnections within the region, with the synchronous interconnections being as follows: (1) Vietnam and parts of Cambodia and Laos, (2) Laos and low voltage connections to Thailand, (3) Cambodia, Thailand and a portion of Myanmar's southern power system, and (4) Myanmar and PRC;
- Stage 3 (2028-30) – formation of eastern and western GMS integrated (synchronised) systems by integration / synchronisation Laos, Cambodia and Vietnam to form the eastern system, and integration / synchronisation of PRC, Myanmar, Thailand and Cambodia to form the western system; and
- Stage 4 (2031 and beyond) – integration of western and eastern GMS synchronous interconnections to have a fully integrated and synchronised regional power system.

Figure 148 Total Generation Cost Difference by Country

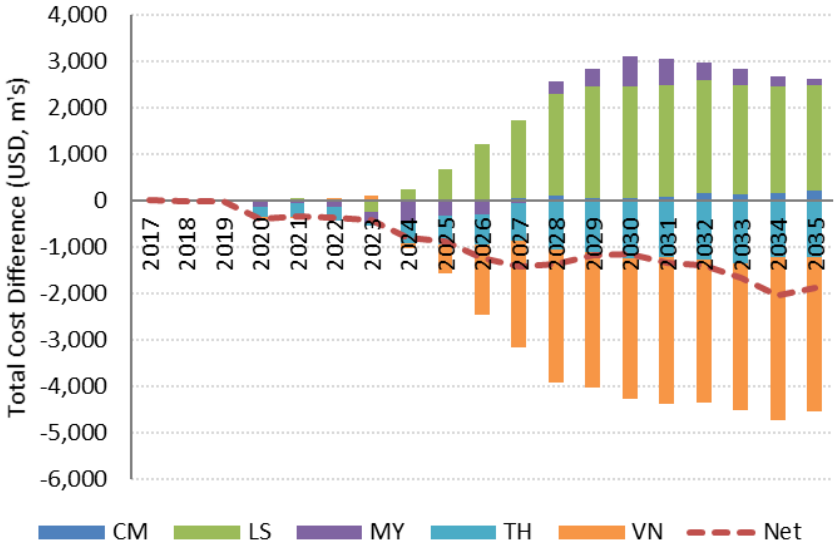


Figure 149 National Transmission Augmentation Cost (Accumulated)

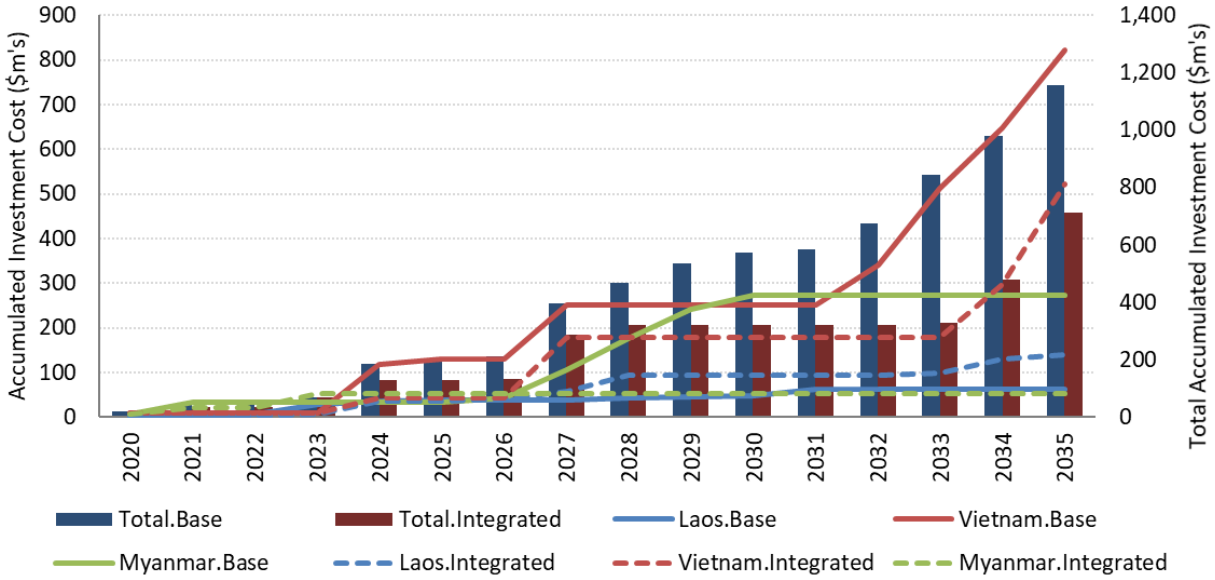


Figure 150 Carbon Emissions (Base and Integrated Case)

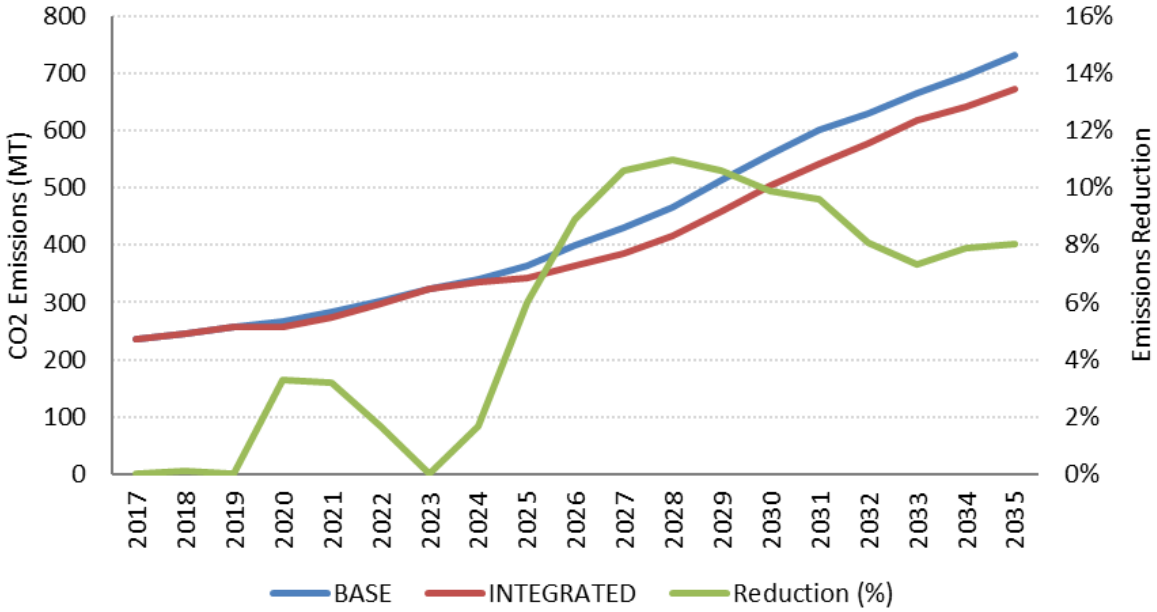
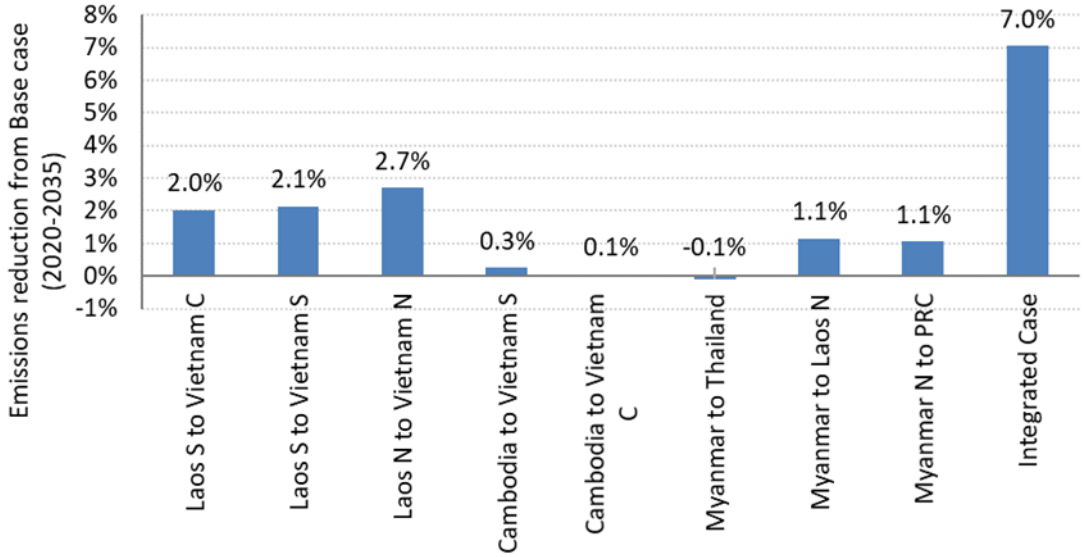


Figure 151 Carbon Emissions Reduction (Optimal Business Cases and Integrated Case against Base Case)



10 Next Steps

This study has demonstrated the benefits of greater integration of the GMS region and in particular, has identified the cross-border interconnections that will lead to the greatest benefits in the region. Based on these results we have formulated a 10-year roadmap that has prioritised the investments in cross-border connections based on those that deliver the greatest benefits to the region. The roadmap has identified a high level strategy for interconnection as well as identifying some important preconditions that need to be implemented as part of progressing the GMS towards a fully interconnected region.

In order to support the conceptual roadmap and facilitate the progression of the GMS towards a more tightly integrated power system, there are a number of important next steps that need to be taken. These include the following:

- More detailed technical studies need to be carried out to support the individual business cases. These need to identify additional investments that may be required in order to ensure power system operations will be reasonable;
- The economic viability of HVDC interconnection in the region needs consideration as an alternative to the AC interconnections that we have studied;
- A Regional Grid Code needs to be agreed and established, and the standards within subsequently used to guide, among other areas: (1) the technical studies for interconnection to ensure that they comply to the Regional Grid Code standards, and (2) operation of synchronised regions such that this is carried out in accordance with the rules defined in the Regional Grid Code). The work being carried out by the RPTCC Working Group on Performance Standards and Grid Codes that has been going on a parallel workstream under the current project has laid the foundations for this, however the adoption of the regional Code by each of the GMS countries and the agreement of a minimum set of requirements for interconnection will be key facilitating steps;
- Planning frameworks within the member countries need to be adjusted to incorporate cross-border transmission projects;
- A rigorous approach needs to be taken to the development and implementation of regional transmission wheeling charges, to ensure that the development costs of increased interconnection can be recovered from those public and private sector generators, consumers and power utilities who are benefitting from the opportunity for enhanced regional trading and to give a clear path for the remuneration of major transmission investments;
- A country-by-country implementation is needed of specific policies and regulatory reforms that will ensure open access to the national power networks and underpin the transparency with which the regional power systems are planned and operated;
- Further consideration should be given by the RPTCC and possible successor or subsidiary groups to the trading rules and balancing arrangements that should be implemented in parallel with the technical expansion of the power systems, to ensure that a sound basis for power trading is created.

Many of these steps build on work that is already being undertaken by the RPTCC members and other organisations within the GMS countries with support from international agencies. Work on other projects, as well as earlier work under this assignment, has demonstrated that the GMS member countries are at different stages both at policy level and in terms of practical implementation regarding issues such as:

- Power sector unbundling and ensuring the independence of the transmission function and the guarantee of third-party access to facilitate increased power trading;
- Defining the roles and responsibilities of the government ministries and other agencies responsible for power sector regulation;
- Creating the regulations and licences that will be needed to enable a combination of incumbent power utilities and new private sector developers of transmission infrastructure to work together in an integrated way;
- Identifying capacity building needs in the areas that are required to enhance the technical, project management and financial/economic capabilities of the power sector stakeholders. Significant planning challenges will be presented by the level of transmission system

investment that is required regionally, requiring strong system study skills and a commitment to progressing investment in the transmission systems. In addition, the operational requirements of increased synchronous interconnection across the region will require detailed study and preparatory work.

- In order to implement capacity building effectively, partnerships between GMS national planning institutions, power utilities and regulatory bodies and their equivalents in other regions (e.g. Europe, the Nordic countries, Southern Africa, ASEAN) could be considered through twinning arrangements that would give the GMS bodies access to a wide pool of experience.
- Addressing the challenges posed particularly in Lao PDR by the existence of IPPs that are exporting power across borders over dedicated interconnectors constructed on a BOT basis, the utilisation of which is defined under the terms of PPAs, but which will need to form part of the synchronised regional network.

In order to progress towards the vision of an interconnected regional transmission system and regional synchronisation that can lead to effective power trading and the levels of benefits demonstrated in the business case analysis, achieving the highest level of regional cooperation is essential. We recognise the importance of the continued role of the RPTCC and the potential evolution of this body into the RPCC in future as being critical to the future evolution of the GMS power sector.

A Appendix A: Detailed Modelling Results

Table 26 Net Present Value of Benefits across all Business Cases (million, real 2016)

Business Case	Size (MW)	Capex	Generation	Internal Transmission	Transmission	Net
Viet Nam C to Laos S (BC1)	500	71	543	-46	-107	461
	1000	-151	1,006	-80	-137	637
	2000	-811	1,755	-77	-176	691
Viet Nam S to Laos S (BC3)	500	63	592	-30	-180	446
	1000	-229	1,070	-64	-231	547
	2000	-957	1,857	-66	-296	538
Viet Nam N to Laos N (BC9)	1500	-454	1,586	41	-278	895
	2500	-775	2,157	40	-423	999
	3500	-1,147	2,661	23	-592	944
Viet Nam C to Cambodia (BC6)	200	616	-339	-4	-52	221
	400	762	-438	-3	-103	219
	800	1,004	-601	1	-133	272
Viet Nam S to Cambodia (BC5)	200	621	-342	-2	-45	232
	400	688	-385	-2	-43	257
	600	749	-437	-1	-58	254
Thailand N to Myanmar C BC2)	500	311	124	-10	-197	228
Laos N to Myanmar N (BC7)	500	287	480	0	-84	683
	1000	225	903	12	-108	1,032
	2000	-294	1,641	0	-139	1,208
China to Myanmar C (BC8)	1000	895	883	-14	-577	1,187
China to Myanmar N (BC8)	1000	886	939	15	-216	1,624
Integrated (China @ $0/MWh, BC10)	Various	-640	4989	73	-899	3,523
Integrated (China @ $50/MWh, BC10)	Various	-640	3927	73	-899	2,461

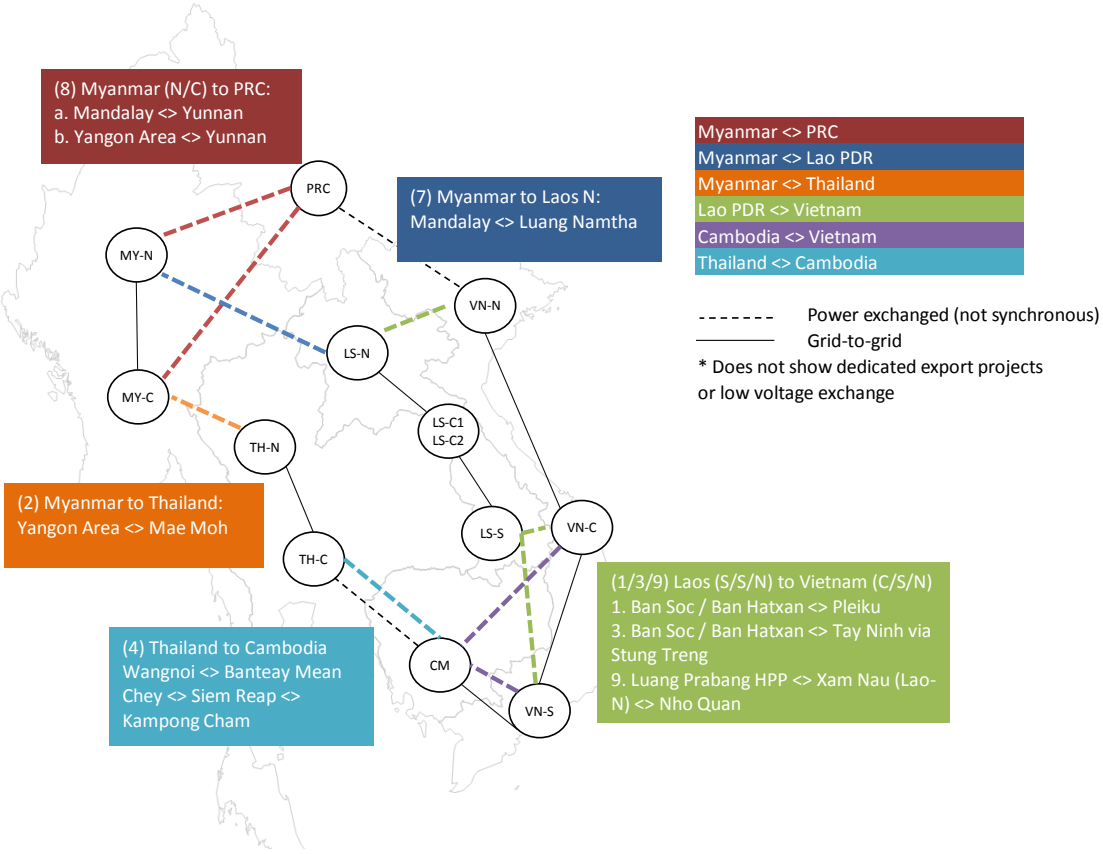
B Appendix B: GMS Modelling Methodology

B.1 Network Topology

The GMS was modelled using the regional representation shown in Figure 152. This allows for high-level economic cost-benefit analysis and understanding of the general patterns in power flows, considering differences between the power systems across the GMS countries.

The business cases were modelled one at a time, with the business case (transmission project) assumed to be in operation from the year 2020. Any intra-country transmission lines were allowed in the model to be augmented on a least cost basis. This enables us to understand how national power systems may need to be expanded in support of cross-border power trade. The interconnectors that were allowed to be expanded as needed are highlighted in purple in Figure 152.

Figure 152 Network Topology*



** Lao PDR is modelled as four regions. The central region is split into Central 1 (C1) and Central 2 (C2) regions but has been represented as one node here.*

B.2 Key Assumptions

The Base Case assumes the GMS countries continue to develop projects as per their power development plans (generally standalone with limited connectivity with neighbouring countries). Generation projects coming online prior to 2022 are assumed to be committed and new entry is allowed (least-cost basis) from 2022 onwards. Demand projections based on medium case demand forecasts from the power development plans.

The Business Cases (all except the Integrated Case) model the cross-border links (grid to grid) coming online from 2020. Generator new entry and intra-country link augmentations are allowed on a least cost basis. All other assumptions are held constant.

Table 27 below outlines the high-level assumptions used in determining dispatch and least-cost new entry for the Base Case and business cases and Table 28 present the generic plant assumptions for each of the fuel and technology types. All thermal new entrants assume a 10% weighted average cost of capital.

Table 27 Key Assumptions

Assumption	Description
Grid level	High voltage and some medium voltage connections that we regard to be important.
New entrant basis	On a least-cost basis with a long-term energy reserve margin of at least 15% at the country level.
Generation	Existing generation with generation planned over the period to 2021 assumed to be committed. New entrants brought in on a least-cost basis is consistent with the technologies and timings as per each country's power development plans. See Table 29 below.
Demand	Projected electricity demand based on medium demand forecasts as per the development plans for each GMS country.
Hydro profiles	Hydro generators are modelled using monthly energy constraints profiled against historical generation. Lao PDR with its flexible hydro storage and minimal electricity demand relative to hydro potential was modelled with an annual energy constraint.
Renewable energy	Renewable energy developments were fixed across the Base and Business Cases and has been set in accordance with business as usual renewable energy development plans of each of the GMS countries.
Fuel cost	Fuel costs are uniform across the GMS and assumed to remain constant throughout the modelling horizon.
Capital costs	Capital costs are uniform across the GMS and assumed to remain constant throughout the modelling horizon. Weighted average cost of capital assumed to be 10% for all conventional thermal plant.

Table 28 Plant Assumptions (All Countries, 2017-2035)

Fuel and Technology	Capital Cost ($/kW)	Fuel Cost ($/GJ)	Auxiliary Use (%)	Technical Life (Years)	Efficiency (%)	Maintenance (%)	Forced Outage (%)
Hydro	2,150	0	0.0	40		0	0
Wind (Onshore)	1,450	0	0.0	25		0	0
Coal (Supercritical)	1,750	3.00	7.5	25	45	11	10
Gas (CCGT)	950	7.50	3.0	25	60	8	8
Diesel	450	13	3.0	30	35	0	3
Fuel Oil	450	9	0.0	25	35	0	3

Table 29 New Entrant Capacity Constraints

Assumption	New Entry (Thermal and Hydro)		
Myanmar	Non-committed coal plants from 2022, mostly in the Central region	Gas allowed from early stage but dependent on economics versus coal	Coal capacity constrained from early 2030
Thailand	Coal and gas allowed from 2020 mostly in Central region	No hydro resources available for development	
Viet Nam	Coal and gas allowed from 2020 across all regions.	No domestic hydro resource allowed to enter.	Central region has very limited coal and gas new entry, north has limited gas new entry.
Laos	No gas across regions	C1 region can build up to 1000 MW of coal	11 GW of hydro (total) allowed from 2022 across all regions
Cambodia	3000 MW of hydro allowed from 2020	2500 MW of coal allowed from 2025	

Table 30 shows a summary of indicative cost estimates for HVAC and HVDC systems in the context of both GMS and non-GMS countries based on the information obtained. Ballpark estimates for the cost of the Business Case transmission (and intra-country transmission) projects are simply determined by multiplying the length of the line in kilometres by the estimated cost-per-kilometre. The indicative transmission costs have been estimated from a number of reports and studies, both internationally (North America, Europe and Australia) and in the context of the GMS. An additional 10% for fixed operating and maintenance costs is applied.

Table 30 Indicative Transmission Cost Estimates (Real 2016 USD)

Type	Rating (MW)	Cost per km (USD million / km)		Cost per MW per km (USD/MW/km)		Average cost (USD/MW/km)
		GMS	Non-GMS	GMS	Non-GMS	
HVAC	Up to 500 MW	0.6	0.73	1,700	2,020	1,860
	500 – 1,000 MW	0.9	0.86	1,090	1,130	1,110
	1,000 – 2,000 MW	1.13	1.14	700	810	760
	2,000 – 3,000 MW	1.8	1.9	640	710	670
HVDC	from 500 MW	0.68	1.2	460	670	560

B.3 Integrated GMS Case Methodology

The Integrated Case methodology follows that of the Base Case and individual Business Case studies with the following differences:

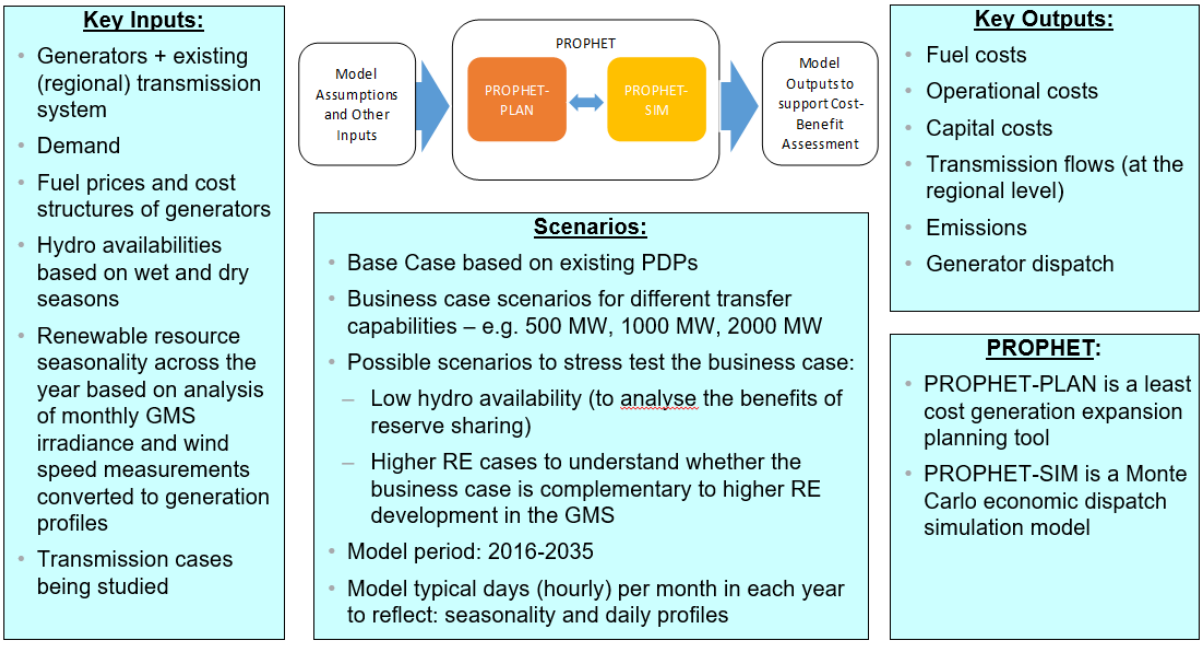
- All candidate cross-border transmission projects are available as options that the model could develop and let it decide which business case projects (regional transmission projects) to build with the earliest commissioning date set for each BC link;
- Allow all national transmission links to be upgraded as required to support regional trade;
- All cross-border transmission projects are modelled as continuous i.e. no lumpy investment – this is to understand the “optimal” sizes

- Compare Base case to Integrated Case with benefits (and costs) over period from 2017-35 mainly defined by:
  - Differences in generation capacity build ⇔ deferred / avoided capacity or possibly capacity that needs to be developed earlier (not so common);
  - Differences in generation costs ⇔ fuel cost savings;
  - Differences in national transmission expansions ⇔ deferred / avoided transmission upgrades or possibly transmission upgrades that need to come earlier (quite common); and
  - Cost of cross-border transmission projects.

B.4 Modelling Platform

The modelling of the GMS was done in PROPHET as shown in Figure 153 below. The PROPHET modelling is done in the Planning module. The Planning module is designed to determine new entrant capacity on a region basis and provides a long-term guide for system planning. The long-term generation and transmission expansion plans are based on least-cost and/or other intertemporal constraints applicable to the modelling problem.

Figure 153 Modelling Process and Platform



C Appendix C: Base Case Results

C.1 Capacity Outlook

This section describes the Base Case. The Base Case assumes each country continues to develop its own power system as per its power development plan, generally based on little to no cross-border trading. Capacity developments for Viet Nam, Cambodia and Lao PDR are shown in Figure 156 to Figure 159. The main features of the Base Case are:

- **Myanmar:** Myanmar has tight supply & demand in the short term as committed hydro and coal projects are delayed. Significant coal projects developed to meeting medium-term demand and gas generation over the longer-term.
- **Thailand:** Offshore gas projects backfilled by LNG with some retirements – supply augmented by export projects from Lao PDR – based on PDP2015 + AEDP. Imported coal is developed from 2025.
- **Viet Nam:** LNG is used to replace declining offshore gas reserves around the year 2025. Coal is developed in the South and North regions to meet growing demand. The generation mix is based on latest PDP (March 2016) and Gas Master Plan.
- **Lao PDR:** Modelled outlook is consistent with its plans to develop numerous hydro export-oriented projects for Thailand and Viet Nam. Additional hydro projects are developed for domestic demand to service a growing industrial sector.
- **Cambodia:** Committed coal and hydro developments are developed in the short-term with additional hydro in the north developed around 2025 before thermal projects and grid augmentations in the south.
- **GMS:** The main trend across the GMS shows hydro and gas developed in the shorter to medium term followed by coal developments from about 2025.

Figure 154 Myanmar Capacity Development (Base Case)

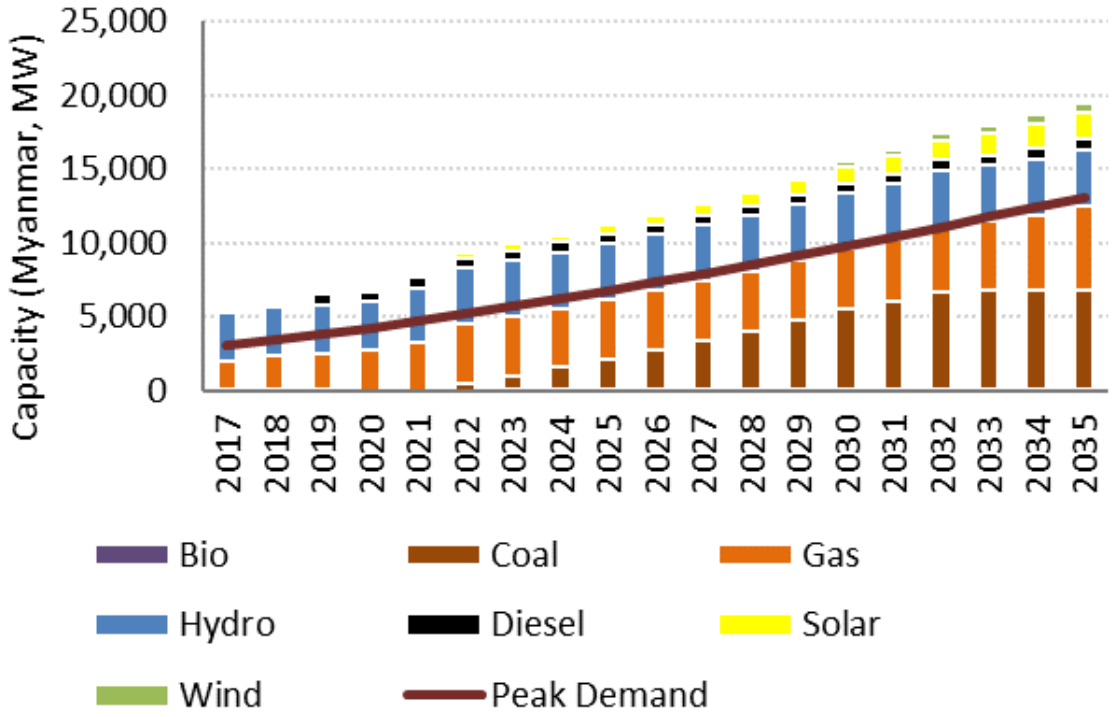


Figure 155 Thailand Capacity Development (Base Case)

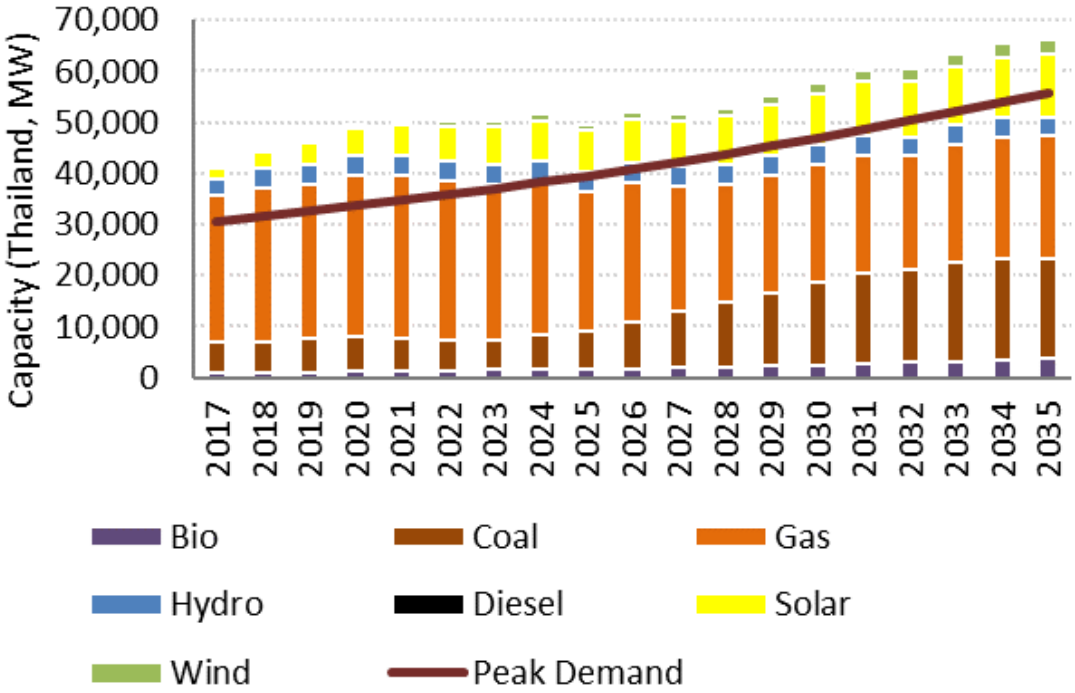


Figure 156 Viet Nam Capacity Development (Base Case)

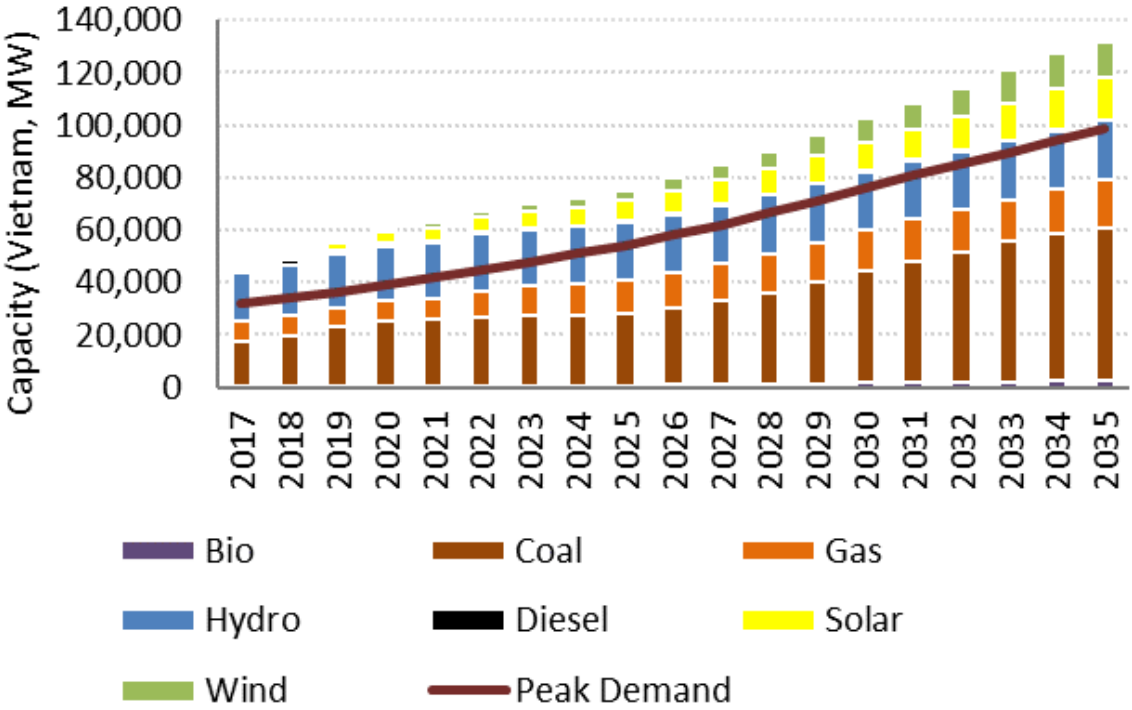


Figure 157 Lao PDR Capacity Development (Base Case)

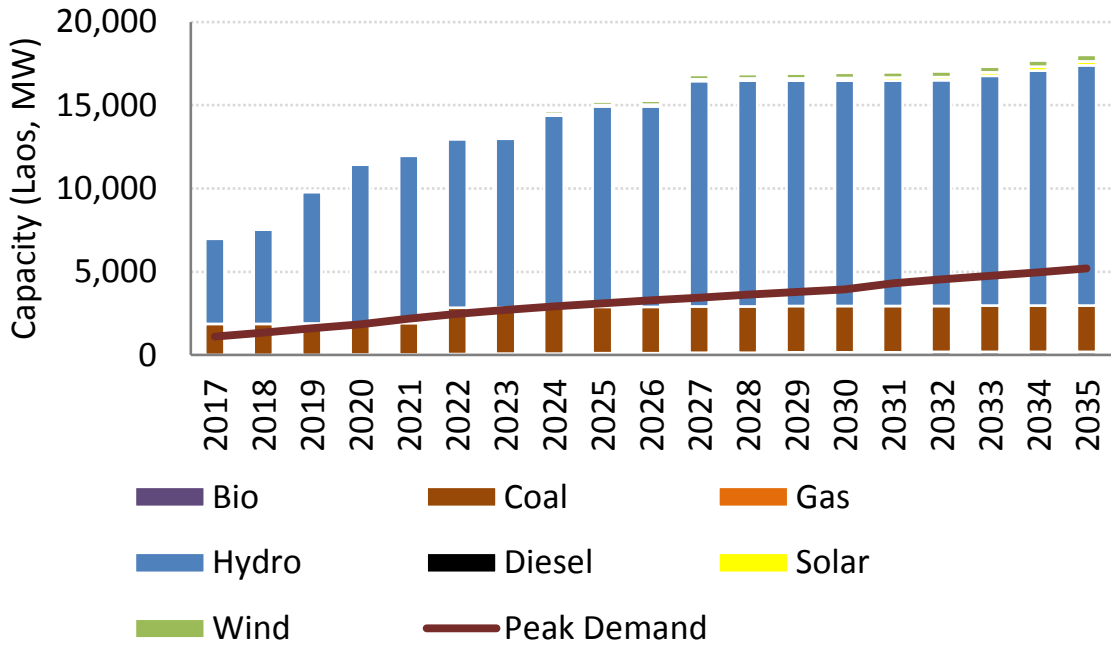


Figure 158 Cambodia Capacity Development (Base Case)

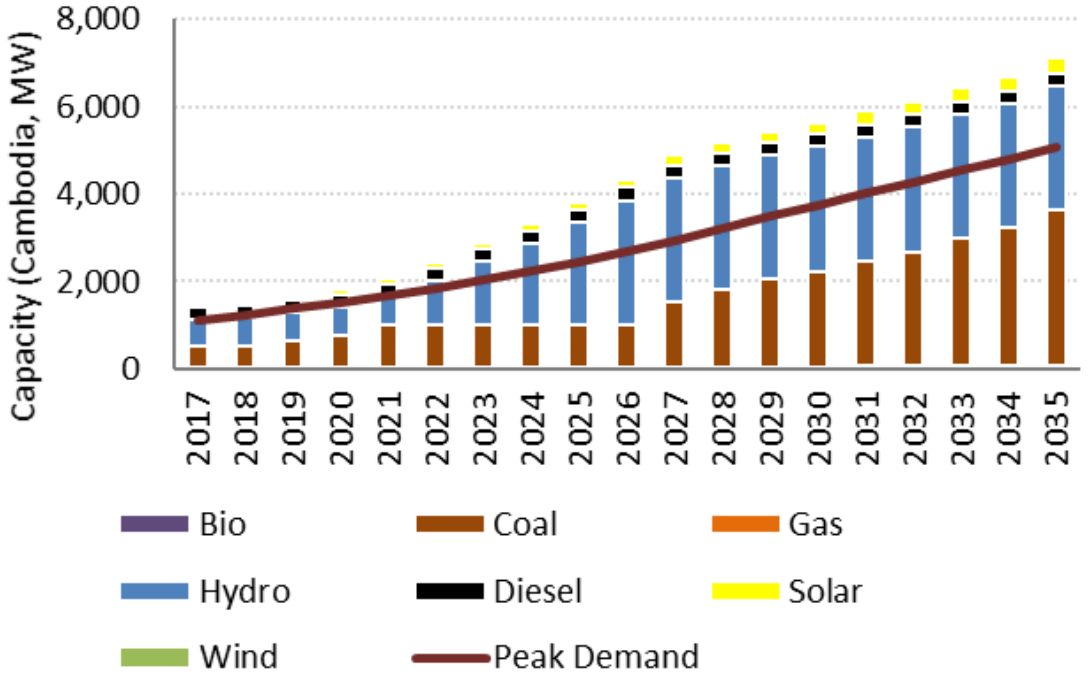
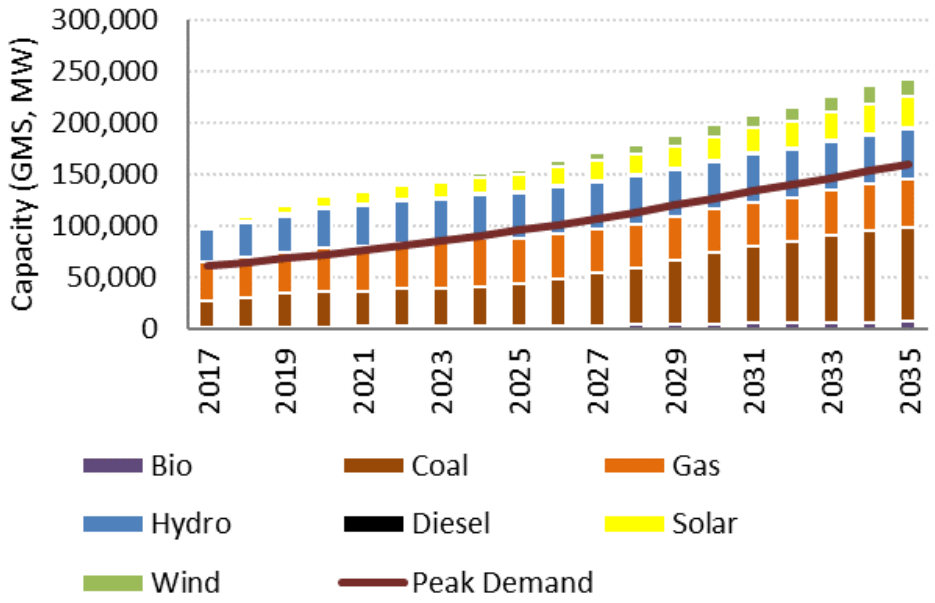


Figure 159 GMS Capacity Development (Base Case)



C.2 Net Exports

The GMS in the Base Case has limited cross-border exchange of power under current National Power Development plans. The main cross-border power exchanges are from Lao PDR to Viet Nam and Thailand. Cross-border power exchange is plotted in Figure 160 and shows an average exchange of 4,000 MW by 2020 and 6,000 MW by 2027. Cambodia is a net importer to 2025 after which it tends to become self-sufficient as a result of coal generation developments. There are no further cross-border trade opportunities in Base Case.

Figure 160 GMS Net Exports