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Ricardo Energy & Environment

World Bank: GMS Power Market Development

Presentation to RPTCC-24 on Task 1
Prepared by: Intelligent Energy Systems

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Task 1: Defining Business Cases for Greater Power Market Integration in the GMS

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TOPICS

1. Task 1 Scope and Today's Focus
2. Summary of Findings from Business Cases (Recap)
3. Methodology for Integrated GMS Modelling
4. Integrated GMS Modelling Results
5. Conclusions and Insights

Appendices:

A. Business Case Summary
B. Business as Usual Outlooks (Detailed)
C. Modelling Methodology & General Assumptions

1. Task 1 Scope and Today's Focus

Task 1 Objectives: Assessment of Business Cases to Support GMS Power Market Integration

- Objective to assess a number of **business cases** that would enhance cross-border trade in the GMS
- Each business case is a **cross-border** transmission project that represents a **system-to-system** connection
- End-goal is to rank & prioritise the business cases based on:
  - Potential to accelerate GMS electricity trade
  - Those that make the most commercial & economic sense
  - Those that appear to be "do-able"
  - Those that might appear to offer some other benefits to the region (enhance reliability or stability for example)
- **The focus of this presentation is to present the findings of a Fully Integrated case**

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Study Stages

Integrated GMS Modelling

RPTCC-21	RPTCC-22	RPTCC-23	RPTCC-24
3 Business Cases to show Methodology (Laos, Vietnam, Thailand & Myanmar)	5 Cases Cambodia, Laos and Viet Nam Focus	3 Cases Myanmar Focus (PRC, Laos & Thailand)	Integrated GMS Modelling (Gen + TX)
Siem Reap	Chengdu	Vientiane	Nay Pyi Taw

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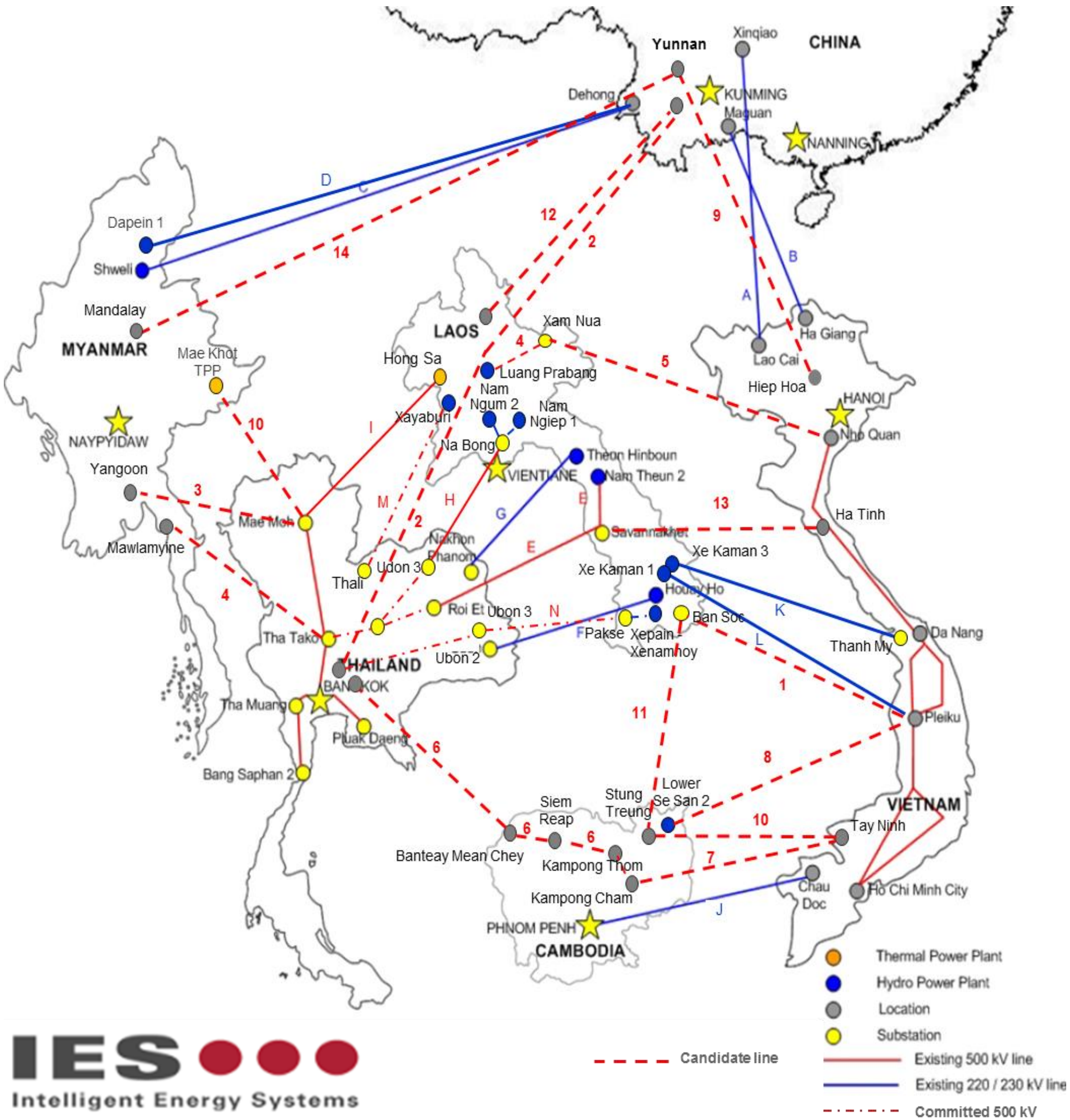
Background: Candidate Cross-Border (CB) Projects were based on Previous Studies



- Compiled candidate CB projects based on studies conducted by ADB, APERC, IEA, others + our own understanding
- Since these studies outlooks for all countries have changed
- We have filtered the CB projects down to a short list of 10
- We have also consulted on what other cases may worth considering and made some judgements about what to study

* ADB RIF: ADB Regional Investment Framework Implementation Plan
* APERC: Asia Pacific Energy Research Center

Business Case (Transmission Project) Assessment Framework – Filter the List

Economic	• Evaluation of costs and benefits • Avoided fuel costs and deferred investment • What country / countries benefit?
Technical	• Reserve sharing • Improved use of existing resources (G & T) • Implications for national grids (synchronization, operations, congestion & stability)
Commercial	• Compatibility with multi-lateral trade • Existing regulatory arrangements pose minimal barriers
Environmental	• Avoided emissions and other externalities • Better use of existing infrastructure • Well-matched to Renewable Energy (RE) potential

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Cross-Border Interconnection Projects Previously Studied and Presented

BC No.	Region (From)	Region (To)	Connection Points (From – To)	Covered?	Length (km)
1	Lao PDR (South)	Viet Nam (Central)	Ban Soc / Ban Hatxan ⇔ Pleiku	RPTCC-22	190
2	Myanmar	Thailand (North)	Yangoon area ⇔ Mae Moh	RPTCC-23	350
3	Lao PDR (South)	Viet Nam (South)	Ban Soc / Ban Hatxan ⇔ Tay Ninh via Stung Treng	RPTCC-22	320
4	Thailand (Central)	Cambodia	Wangnoi ⇔Banteay Mean Chey ⇔ Siem Reap ⇔ Kampong Cham	In Integrated GMS only	
5	Cambodia	Viet Nam (South)	Kampong Cham ⇔ Tay Ninh	RPTCC-22	100
6	Cambodia	Viet Nam (Central)	Lower Se San 2 HPP ⇔ Pleiku	RPTCC-22	230
7	Lao PDR (North)	Myanmar (North)	Conceptual link (specific connection points not determined)	RPTCC-23	600
8a	Myanmar	PRC	Mandalay ⇔ Yunnan	RPTCC-23	350
8b	Myanmar	PRC	Yangon ⇔ Yunnan	RPTCC-23	1031
9	Lao PDR (North)	Viet Nam (North)	Luang Prabang HPP ⇔ Xam Nau (Lao-N) ⇔ Nho Quan	RPTCC-22	400

Laos ⇔ Vietnam

Cambodia ⇔ Vietnam

Myanmar Focus

Previous work focused on examining each cross-border project in isolation with benefits evaluated against a business as usual outlook for the GMS with limited cross-border trade

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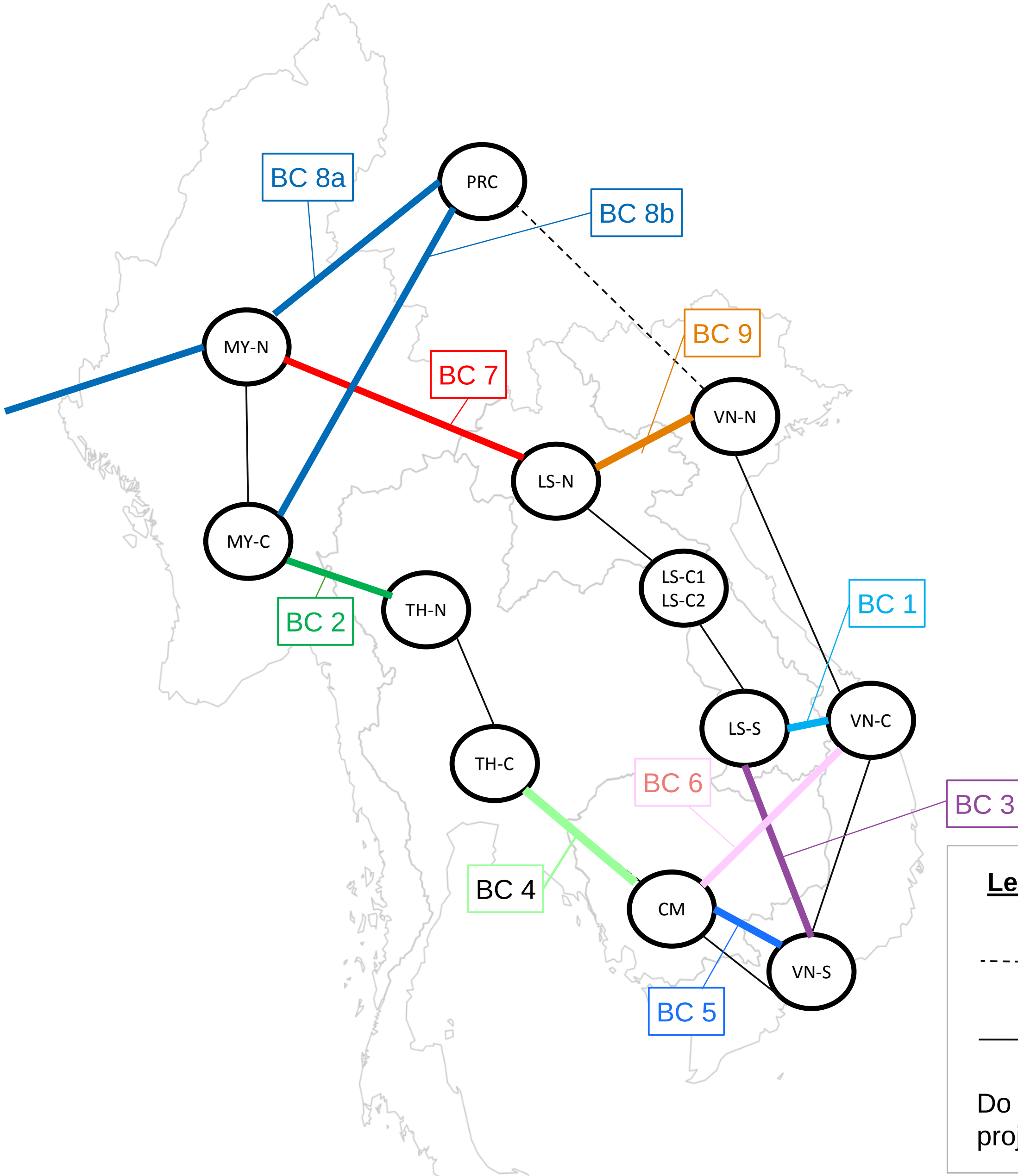
10 GMS Business Cases: 1, 2, 3, 4, 5, 6, 7, 8a/b & 9



Legend:

- - - - - - - - Power exchanged (not synchronous)

———— Grid-to-grid

Do not show dedicated export projects or low voltage exchange

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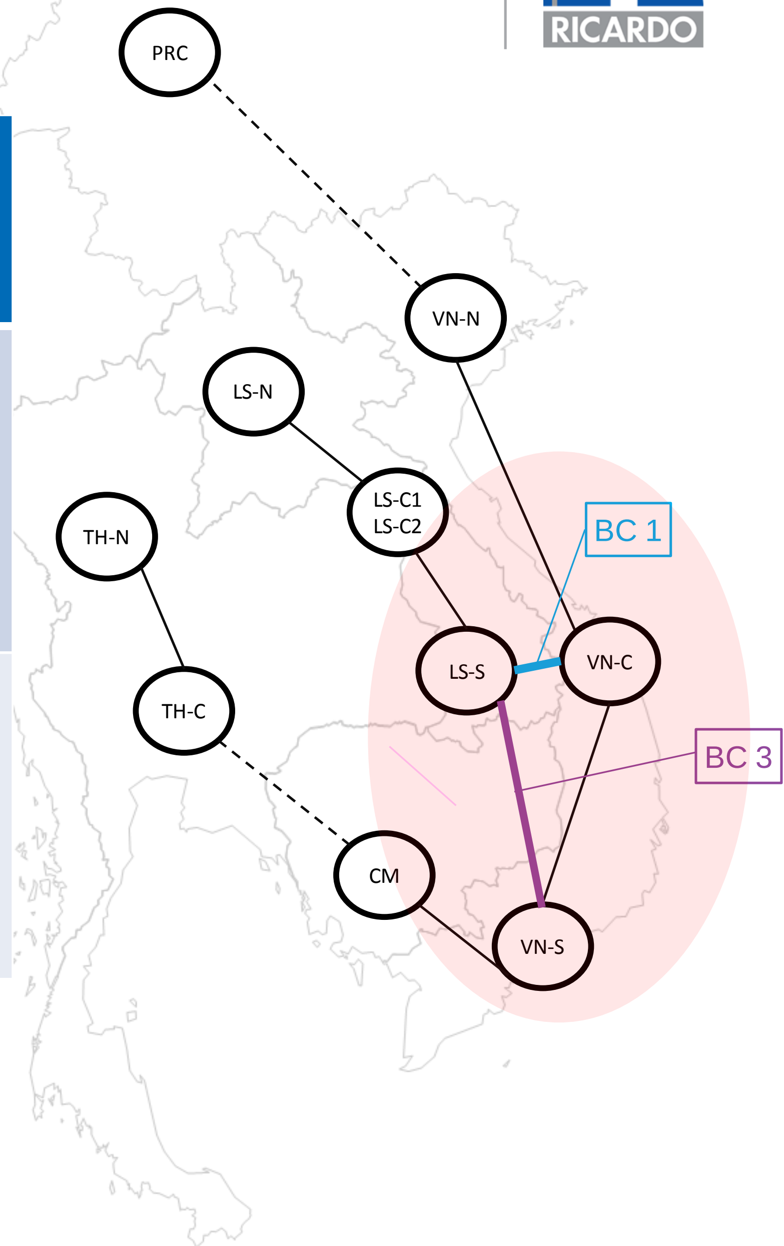
2. Summary of Main Findings for Previous Business Cases

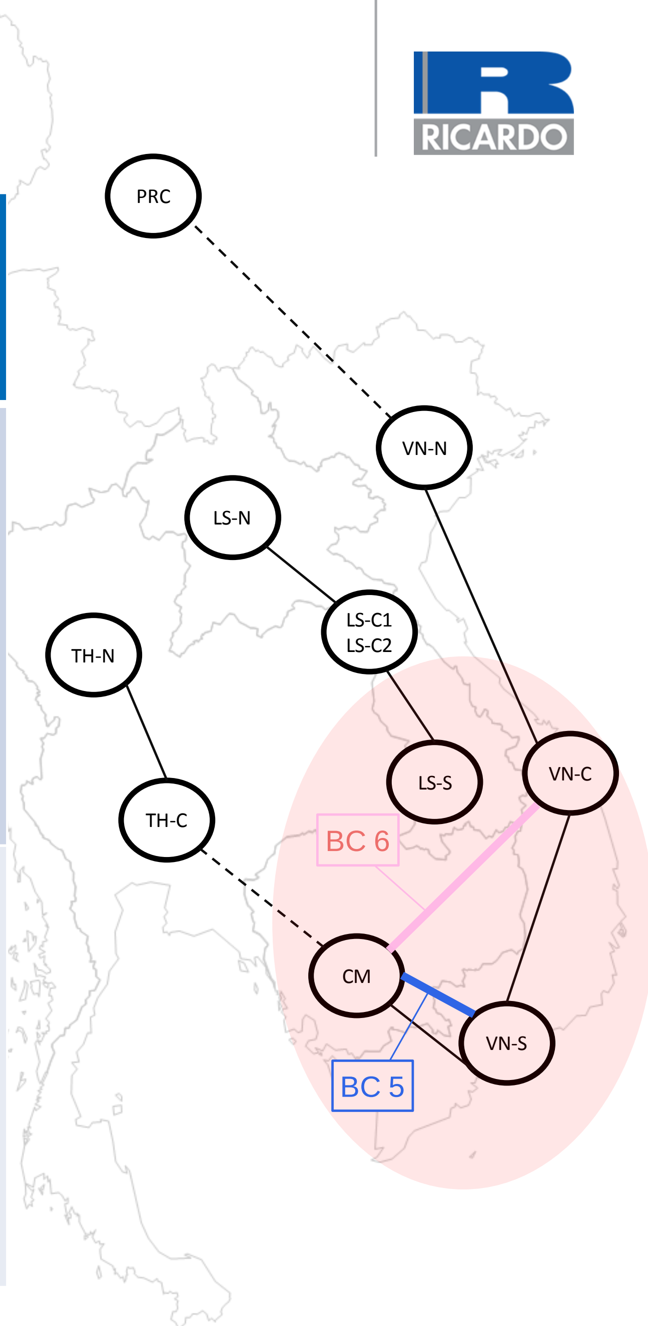
Summary: Southern Laos ⬄ Vietnam

#	Name & 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 Vietnam	Laos grid strengthening becomes critical to full utilization of hydro storages	Existing network infrastructure in Vietnam & 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 Vietnam	Laos grid strengthening becomes critical to full utilization of hydro storages	BC# 1 appears more feasible than BC# 3 and they result in similar benefits



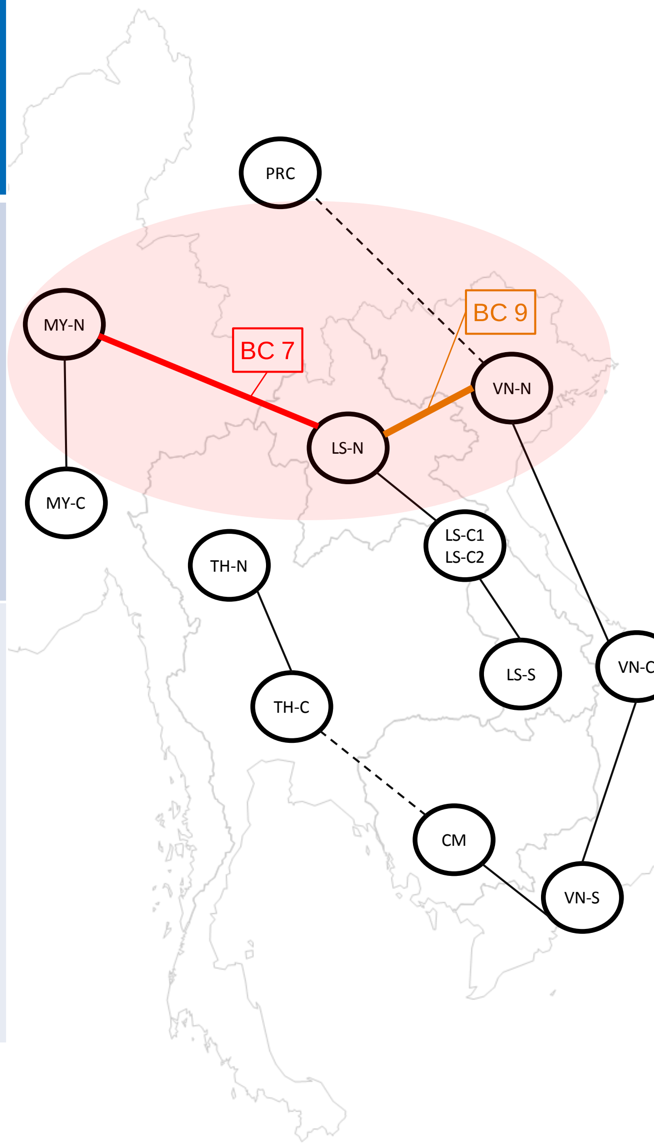
Summary: Cambodia ⇔ Vietnam

#	Name & Sizes	NPV Range ($m 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
5	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
6	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)



Summary: Northern Laos ⇔ Myanmar / Vietnam

#	Name & Sizes	NPV Range ($m 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
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
9	Lao (N) ⇔ VN (N) Luang Prabang HPP ⇔ Xam Nau (Lao-N) ⇔ Nho Quan (400 km) Sizes: 1500, 2500, 3500 MW	953 - 971	Hydro generation and capacity in Laos substitute for coal and also augments hydro supply in Vietnam North	Requires less grid strengthening that BC1 and BC3 because hydro generation in north of Laos is evacuated directly to north of Vietnam	Generally considered a longer-term option for Vietnam (prioritized lower than Laos imports in the central region) More hydro developed in Laos with higher link size



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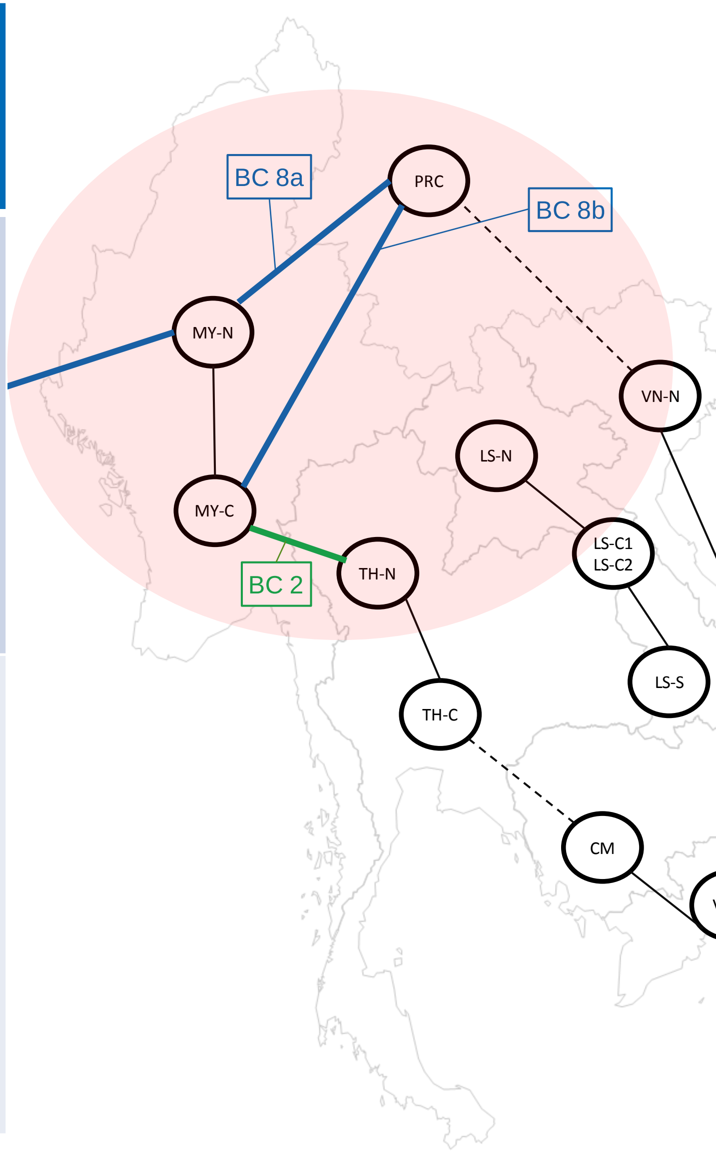
Summary: Myanmar ⇔ Thailand / PRC

#	Name & Sizes	NPV Range ($m 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
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.
8	Myanmar (N/C) ⇔ PRC Mandalay ⇔ Yunnan (350 km) Yangon ⇔ Yunnan (800 km) Sizes: 1000 MW	1,187-1,624	PRC generation and capacity in substitute for coal and gas in Myanmar Central and North, respectively	Requires transmission upgrades between Mandalay and Yangon to be coordinated with the development and to be commissioned successively by 2020-22	Opportunity to export surplus power into Myanmar with opportunity to sell power to Bangladesh



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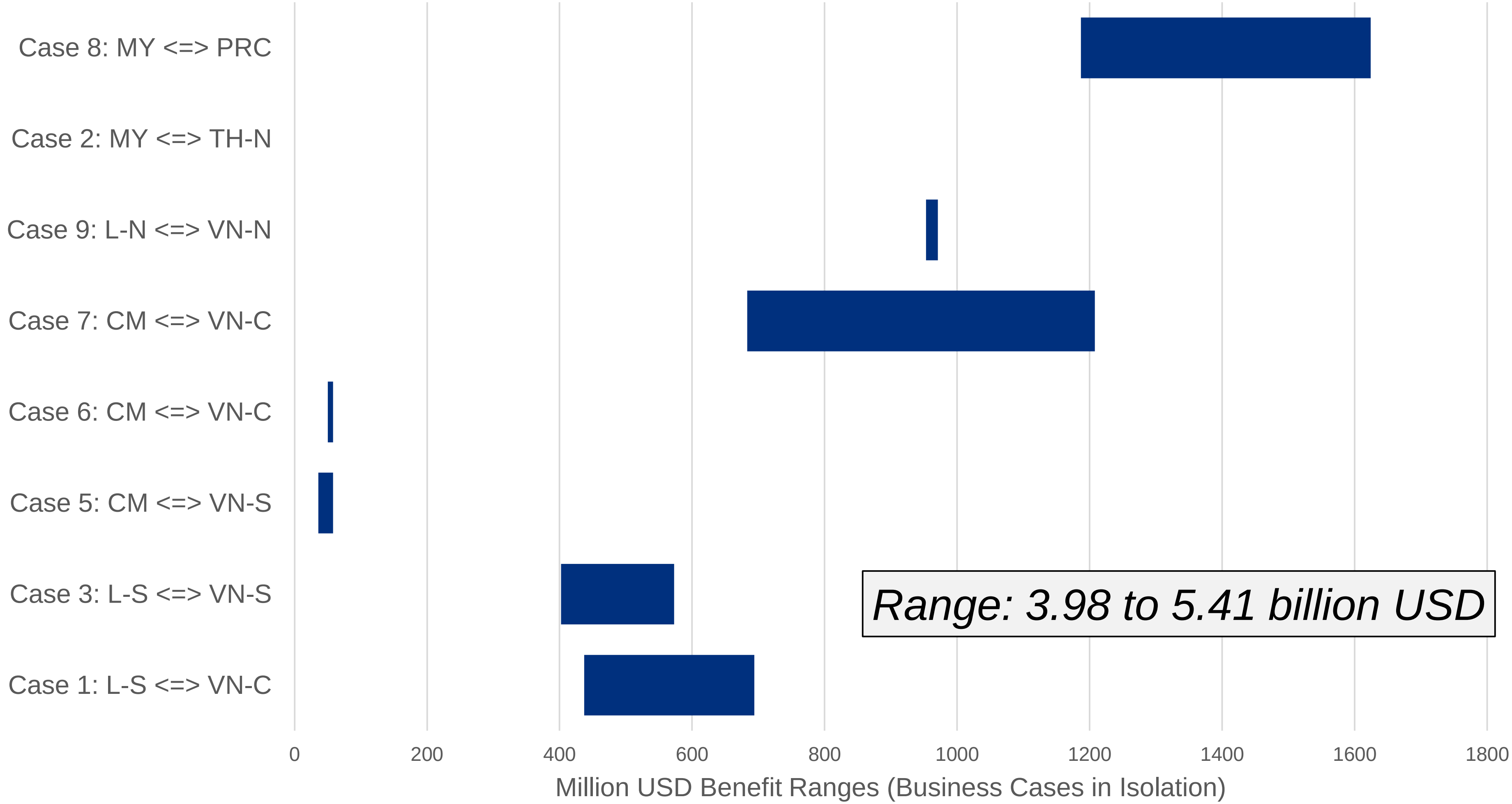
Summary of the Benefits for Business Cases Developed in Isolation



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3. Methodology

Approach: Different Models

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Long-Term Least Cost Generation & Transmission Planning (T & G co-optimised based on a regional model)

Approach for this work is this step only

Dispatch Simulations (Security Constrained Economic Dispatch with Transmission Network + DC Power Flow)

Note that transmission expansion includes: national system reinforcements as well as the cross-border projects themselves

Detailed Technical / Power Engineering Models / Assessments (Voltage Management + Stability Issues)

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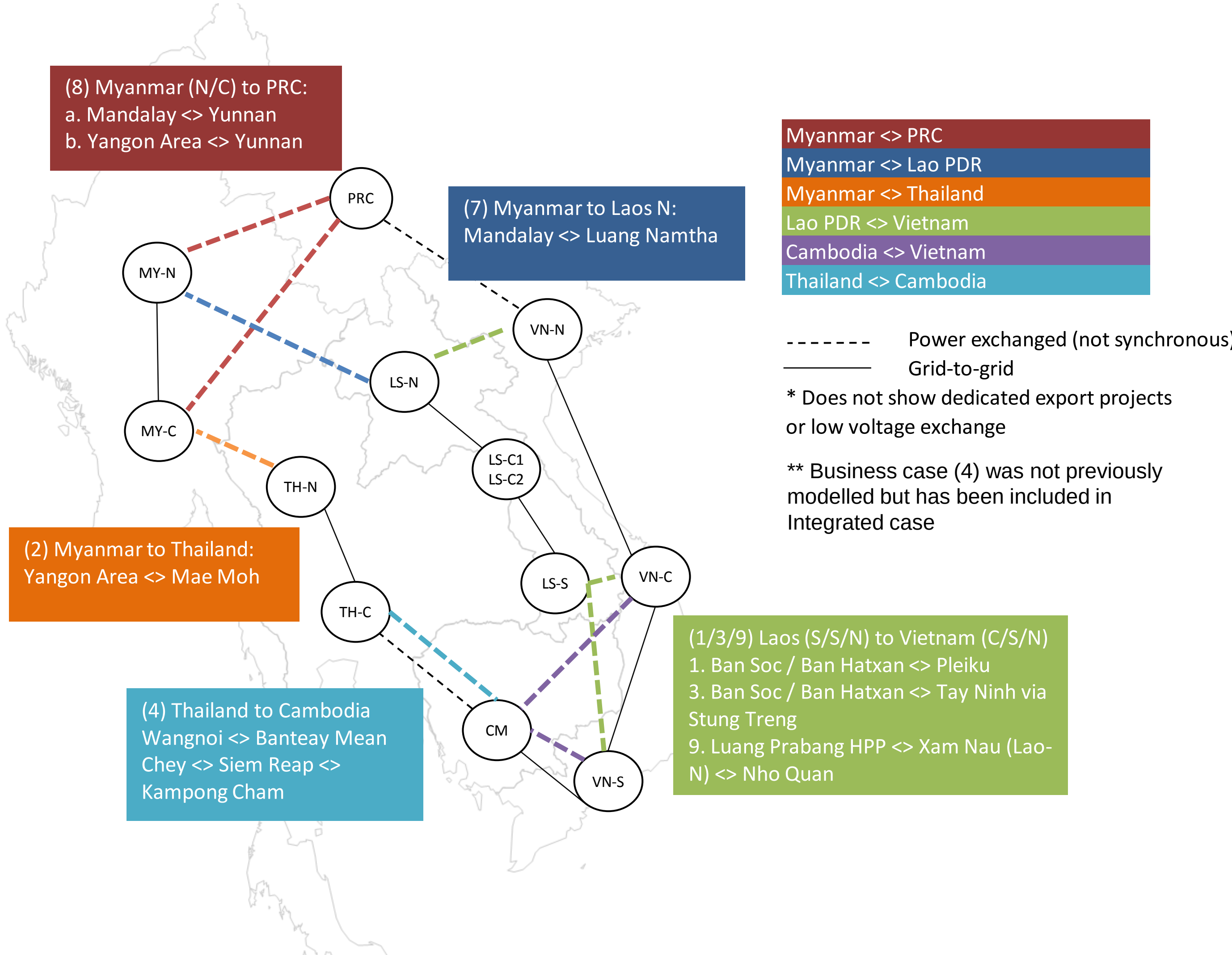
GMS Integrated Case (Incorporating all Business Cases)

Objectives of integrated case were:

- Develop an overall Integrated Generation + Transmission plan
- Identify combinations of business cases that may make sense to develop jointly
- Leveraging the insights from the study of the cross-border projects one by one



Cross-Border Interconnection Projects: Allowed Timings of Cross-Border Transmission Upgrades

BC No.	Region (From)	Region (To)	Connection Points (From – To)	Earliest Year
1	Lao PDR (South)	Viet Nam (Central)	Ban Soc / Ban Hatxan ⬄ Pleiku	2022
2	Myanmar	Thailand (North)	Yangoon 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 ⬄ Vietnam

Cambodia ⬄ Vietnam

Myanmar Focus

Previous analysis assumed projects in place in 2020 to enable comparisons on a like for like basis

Methodology

- **Base Case**:
  - No cross-border transmission project in place
  - A business as usual outlook based on current PDPs 2017-35
- **Integrated GMS Case**:
  - Put all **candidate** cross-border transmission projects as options that the model could develop and let it decide which business case projects (**regional transmission projects**) to build
  - Allow **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)
  - Cost of cross-border transmission projects

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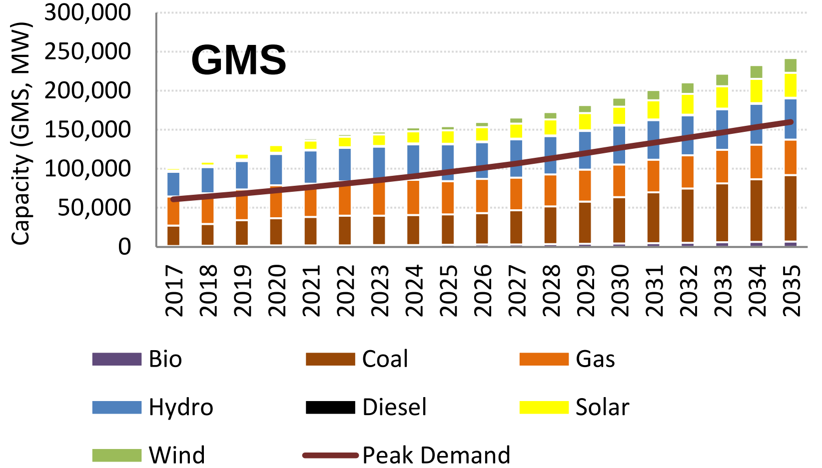
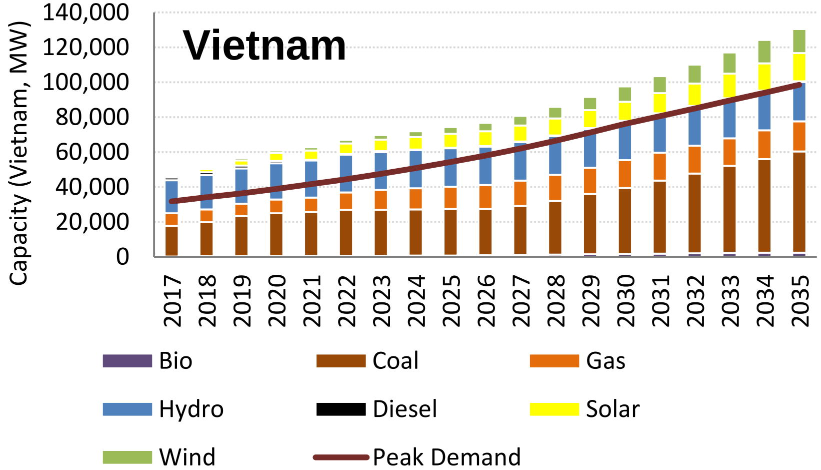
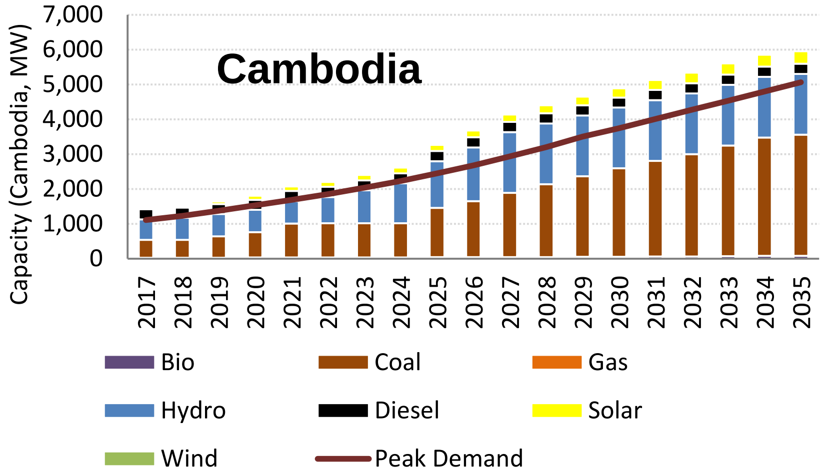
Base Case: Capacity Expansion (GMS/Vietnam/Cambodia)







GMS: GMS has limited power exchange under existing national power development plans and no further cross-border trade opportunities in base case. Coal and gas generation the main fuel type to meet increasing demand.

Viet Nam: LNG "backfills" declining offshore gas reserves. Coal developments in South & North regions to demand. Generation mix based on latest PDP (March 2016) and Gas Roadmap.

Cambodia: Committed coal & hydro developments in short-term with additional hydro in the north developed before thermal projects in the south.

Determined as least cost expansion beyond committed generation projects

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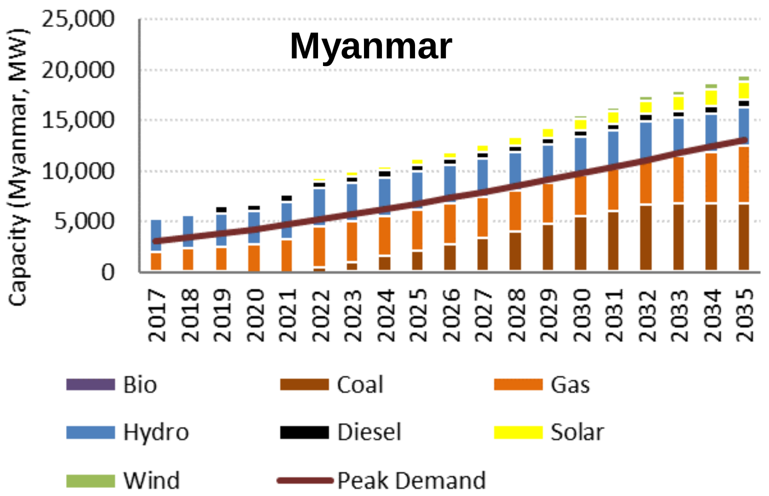
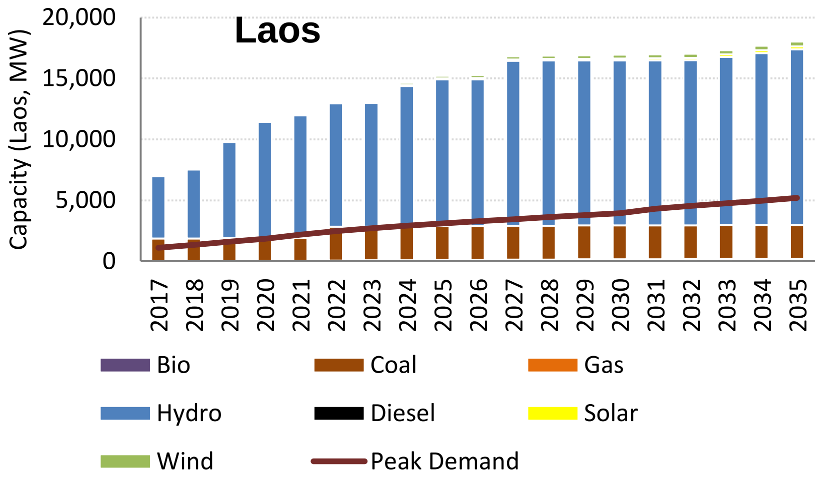
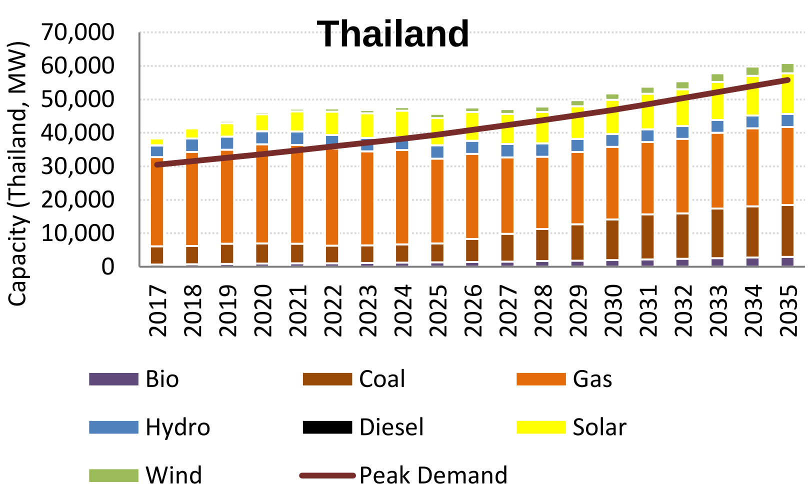
Base Case: Capacity Expansion (Myanmar/Thailand/Laos)







Myanmar: Tight supply & demand in the short term as committed projects delayed. Coal and LNG assumed from 2023/2025 based on least cost expansion.

Thailand: Offshore gas projects backfilled by LNG with some retirements – supply augmented by export projects from Lao PDR – based on PDP2015 + AEDP.

Lao PDR: numerous hydro export oriented projects developed for Thailand & Viet Nam. Others developed for domestic demand including growing industrial sector growth. Some coal developments assumed to be committed.

4. Integrated GMS Case Results

Results

- **Consider results in terms of the implications for:**
  1. Regional transmission expansion
  2. National transmission expansion
  3. Generation expansion
  4. Overall economic benefit

- **Note**: we have considered only the business cases that we have study one by one – there may be many other projects that could be considered

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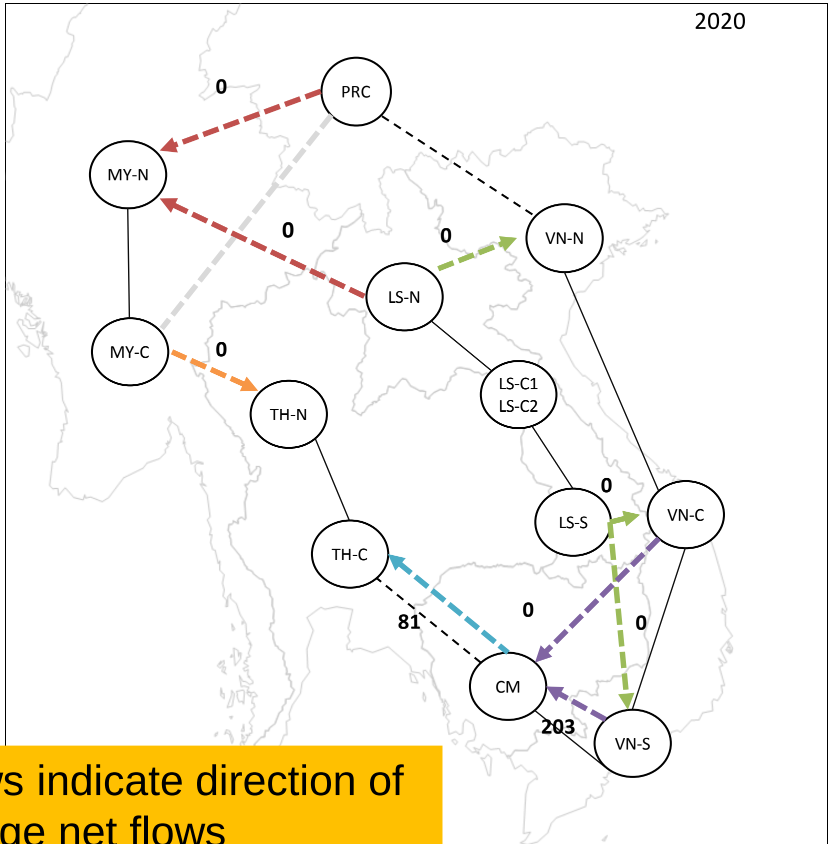
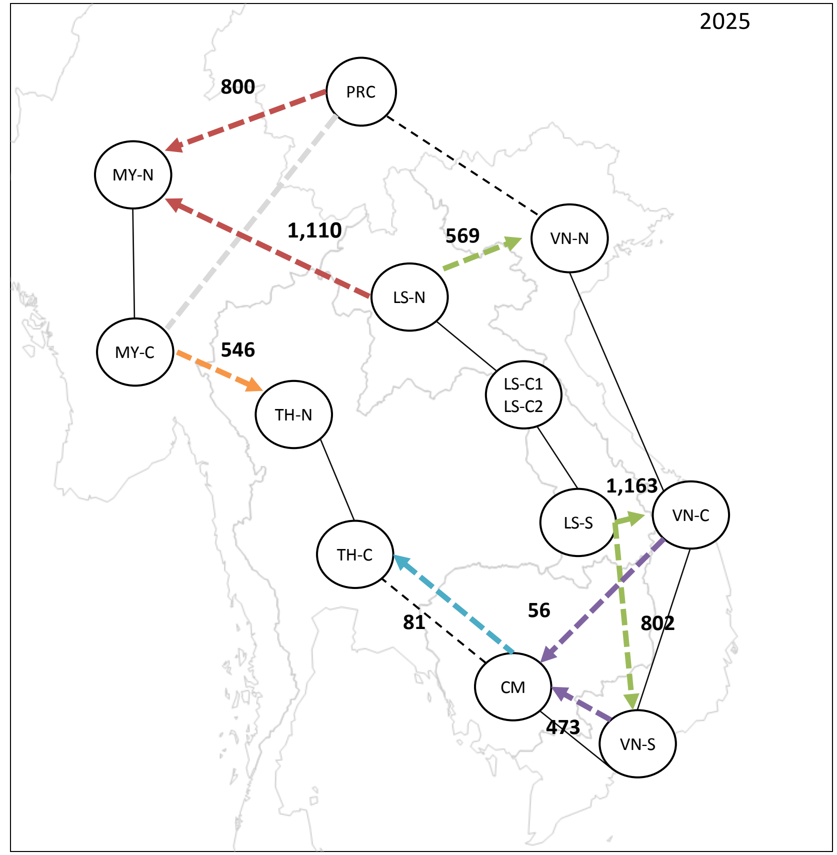
4.1. Implications for Regional Transmission Expansions

Business Case Link Transmission Upgrades (2020/25, MW capacity)

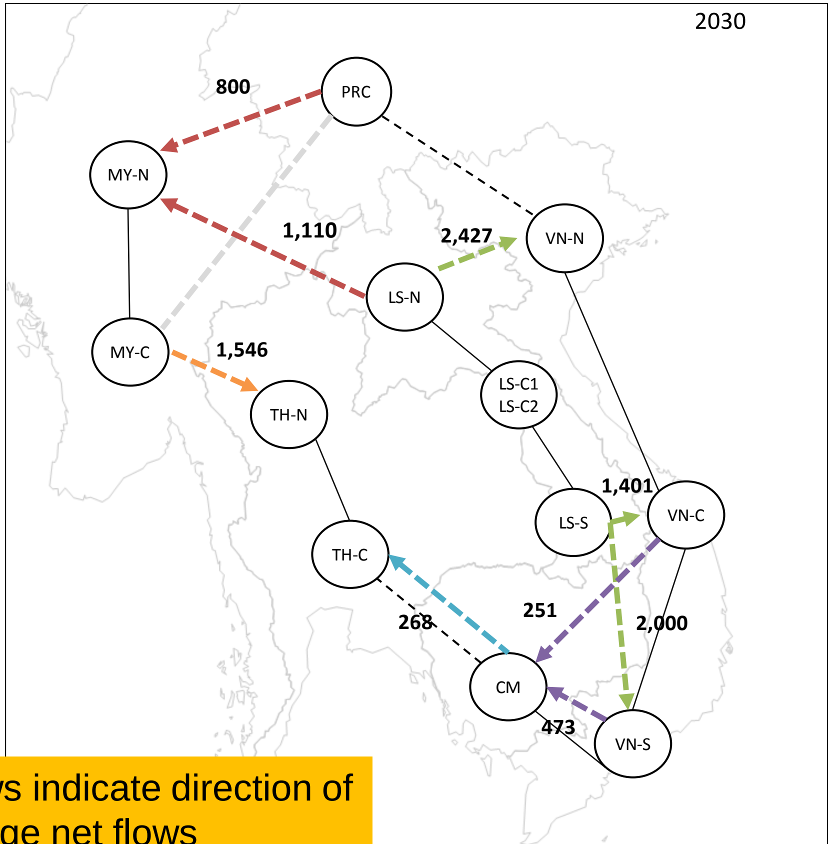


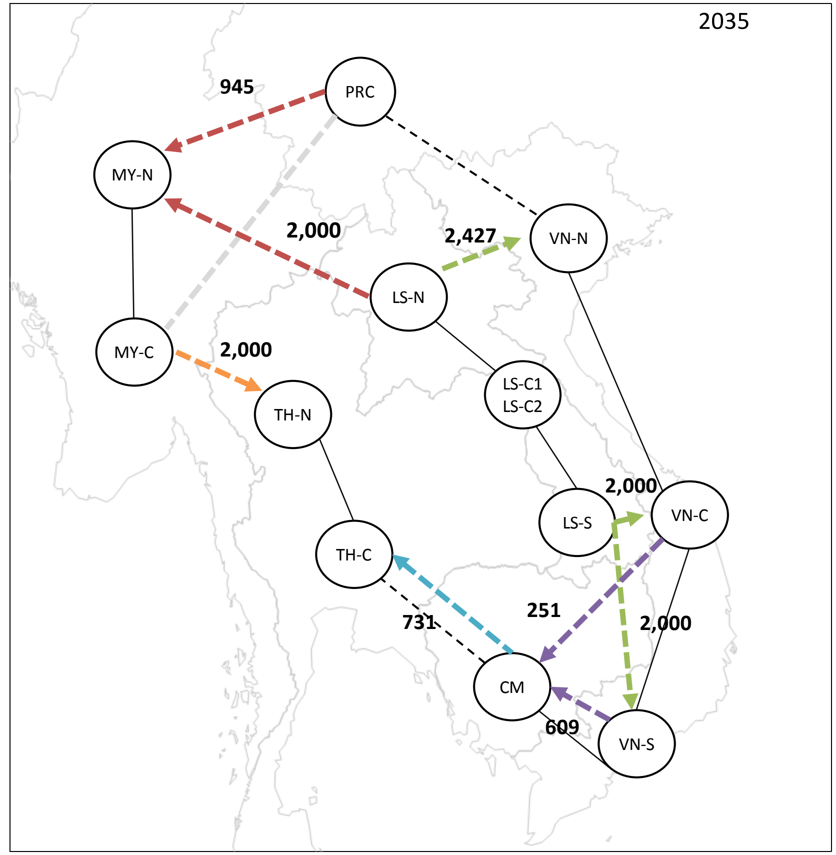


Arrows indicate direction of average net flows

- Most business case links are built from the first allowable year (flows in 2020 from existing connections)
- PRC to MY-C not needed with the other available options
- All GMS countries are connected suggesting the high importance of cross-border trading (least cost perspective)

Business Case Link Transmission Upgrades (2030/35, MW capacity)





Arrows indicate direction of average net flows

- By 2035 a lot of the Business Case links are augmented up to the maximum size option studied
- Vietnam has significant connections to Laos and Cambodia, and Myanmar to PRC and Thailand

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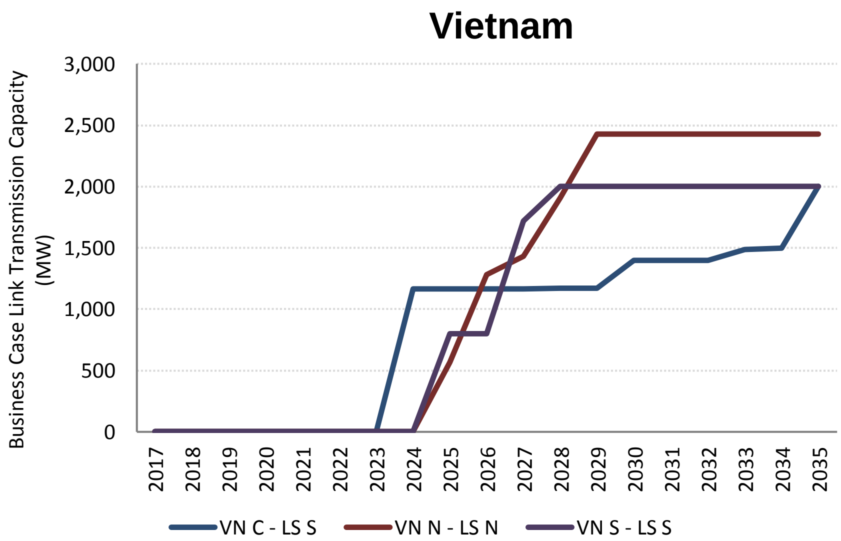
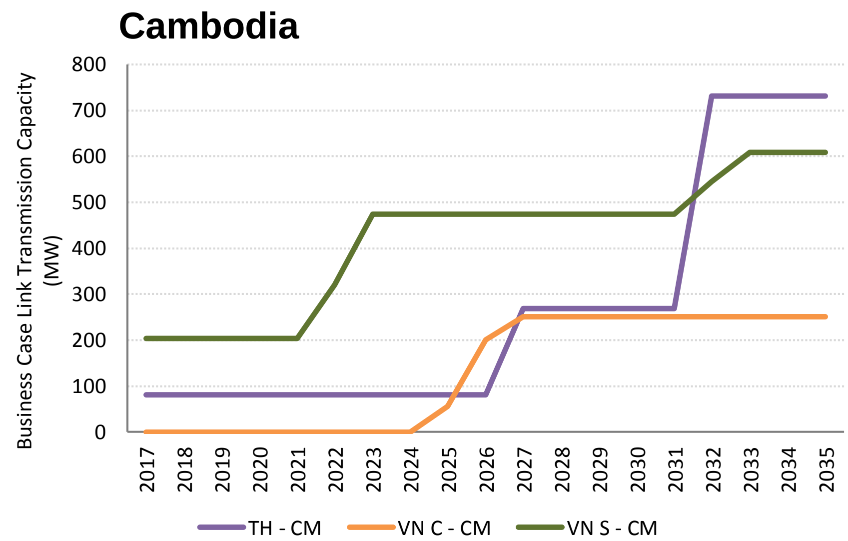
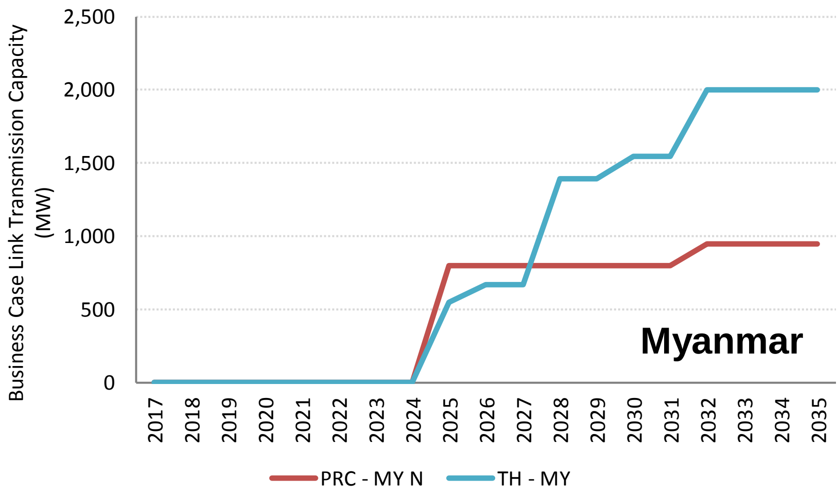
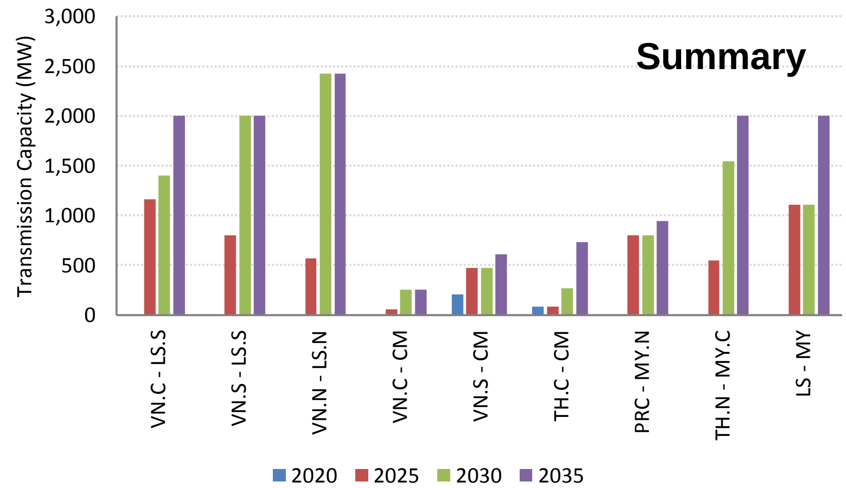
Regional Transmission: Expansions



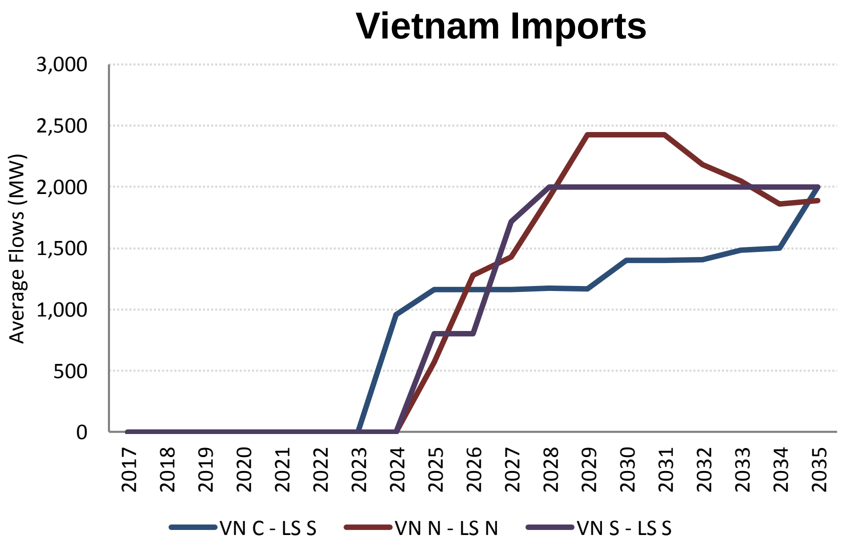


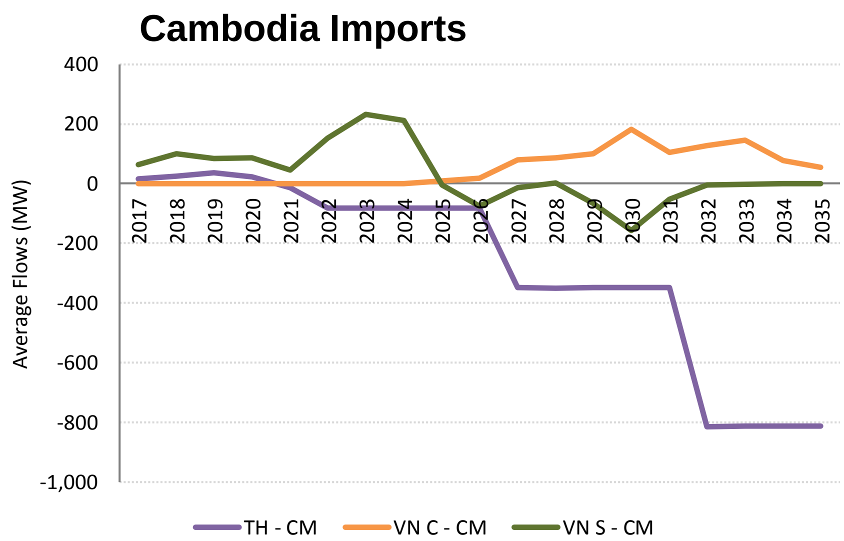


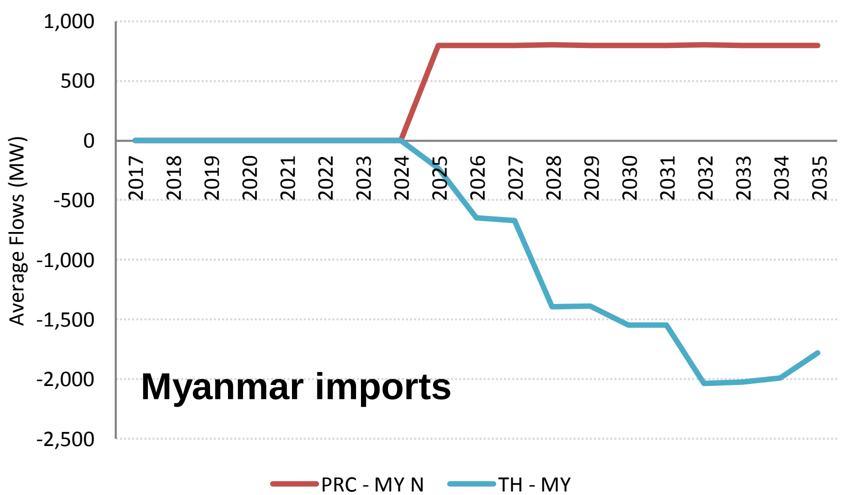


* Bi-directional capacities

Regional Transmission: Average Power Flows







- Vietnam is a net importer from Laos (hydro)
- Cambodia imports power from Vietnam to support its dry season power requirements, and exports into Thailand at other times
- Myanmar imports low cost surplus power from China and exports a significant amount to Thailand in the longer term

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Main Features of Regional Transmission Expansion

BC No.	Region (From)	Region (To)	Regional Transmission Expansion	Earliest Year
1	Lao PDR (South)	Viet Nam (Central)	• 1200 MW developed in 2022 • 1200 MW => 1500 MW by 2027 • 1500 MW => 2000 MW by 2035	2022
2	Myanmar	Thailand (North)	• 850 MW developed 2025-30 • 850 => 2000 MW by 2030	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 2028 • 300 MW => 700 MW in 2032	2025
5	Cambodia	Viet Nam (South)	• 200 MW => 500 MW in 2022 • 500 MW => 600 MW by 2033	2022
6	Cambodia	Viet Nam (Central)	• 200 MW by 2026/27	2025
7	Lao PDR (North)	Myanmar (North)	• 1000 MW in 2025 • 1000 MW => 2000 MW by 2035	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)	• 2500 MW in place by 2028	2025

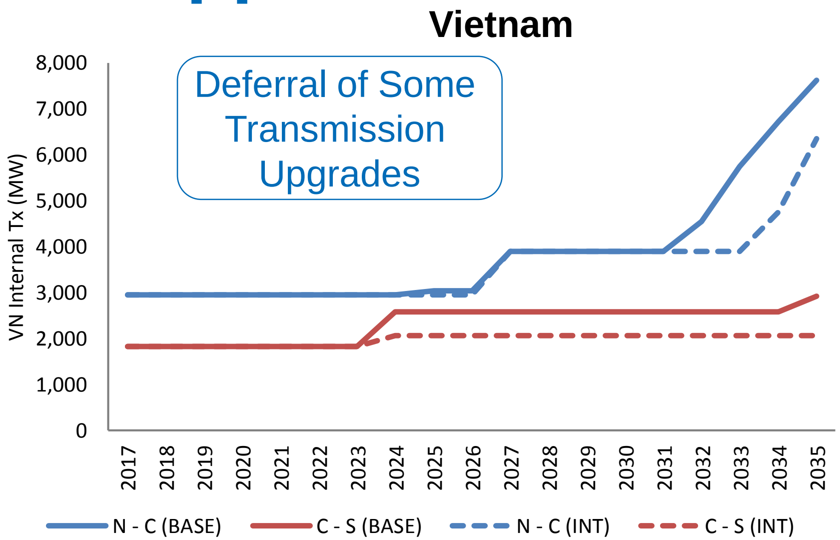
Laos ⬄ Vietnam

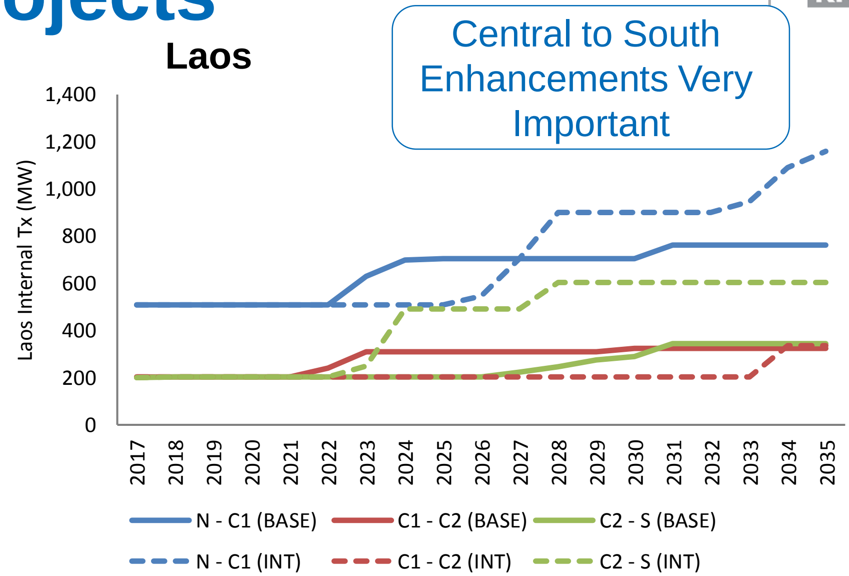
Cambodia ⬄ Vietnam

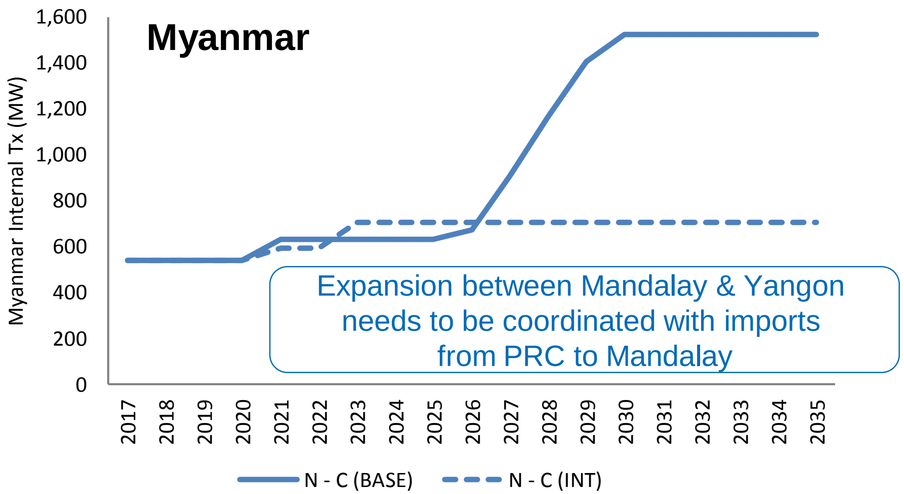
Myanmar Focus

4.2. Implications for National Transmission Expansions

National Transmission Augmentations Required to Support Cross-Border Projects

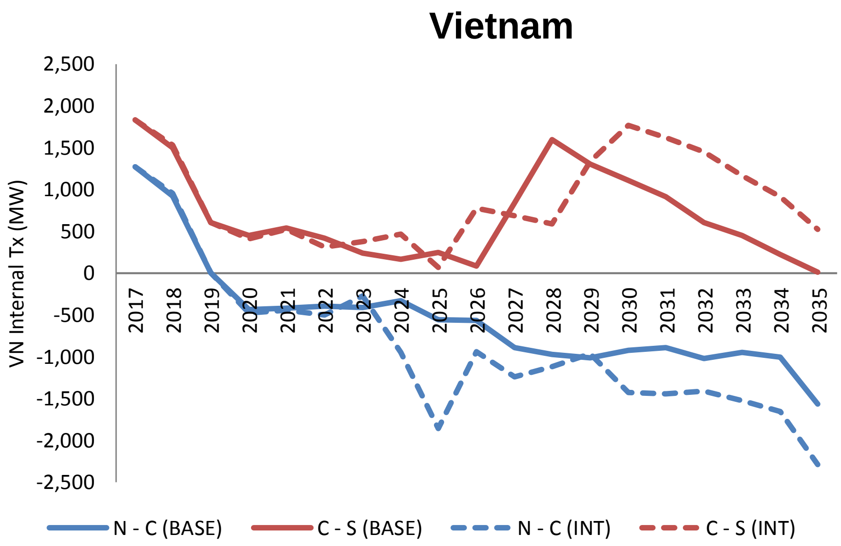


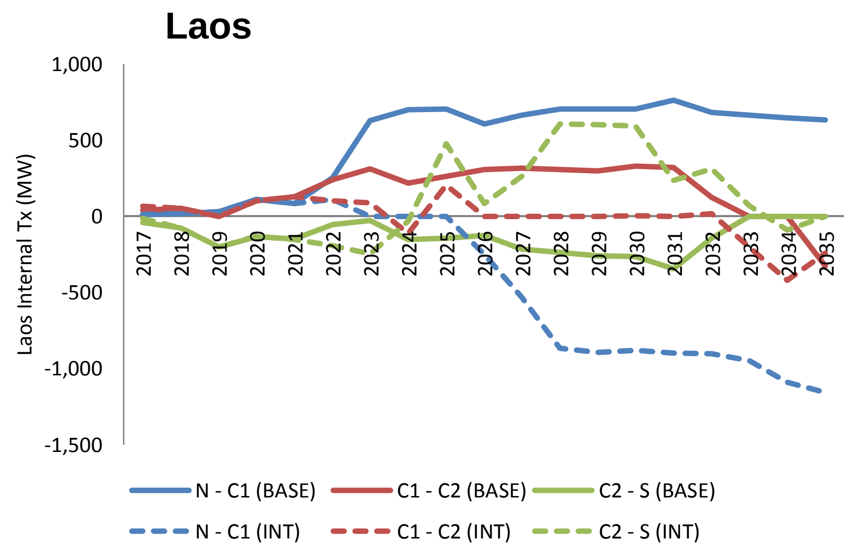


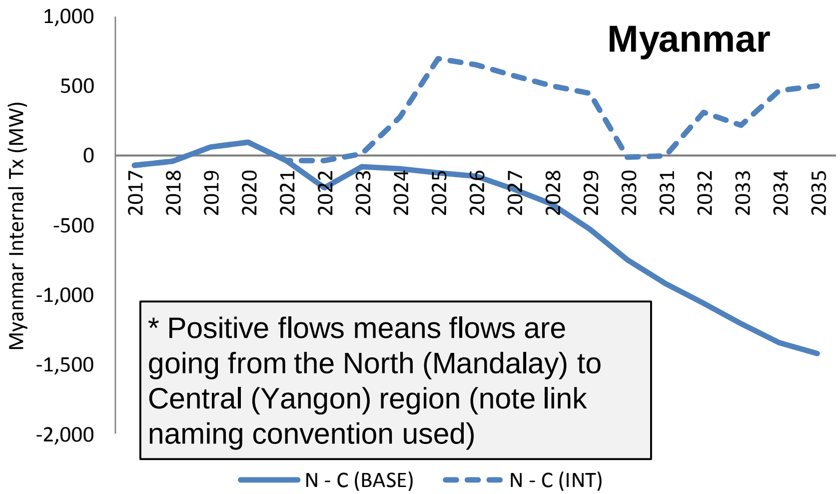


- Vietnam internal transmission augmentations are avoided or delayed with imports from Laos (North and South) into the respective Vietnam regions removing the need to wheel as much power within the country
- Lao PDR: there are slight timing differences to the links with the main change being to add significant transmission limits from C2-S to support power flows into Vietnam south
- Myanmar: requires earlier augmentation to N to C given the additional (surplus) power from PRC and supports the delay in committed plant in the C region. Long-term it also significantly reduces the need for the C region to export back to the North

Internal Link Average Net Flows (for Reference)



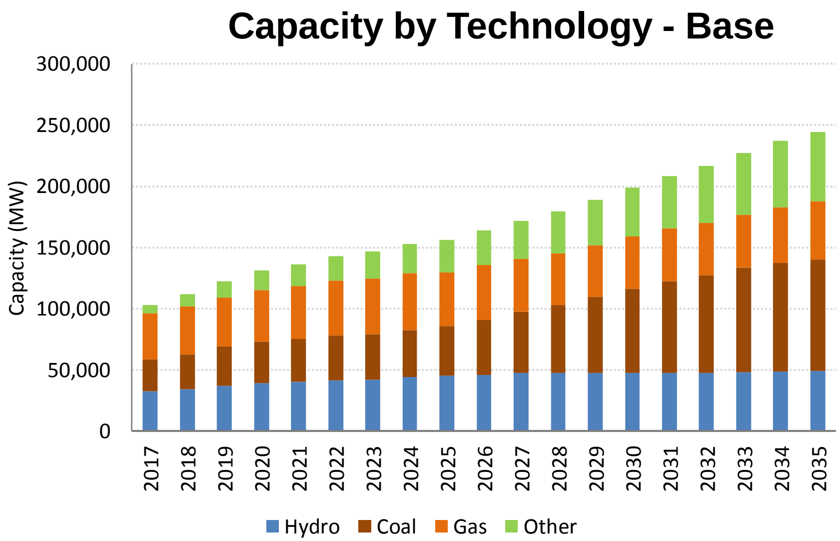


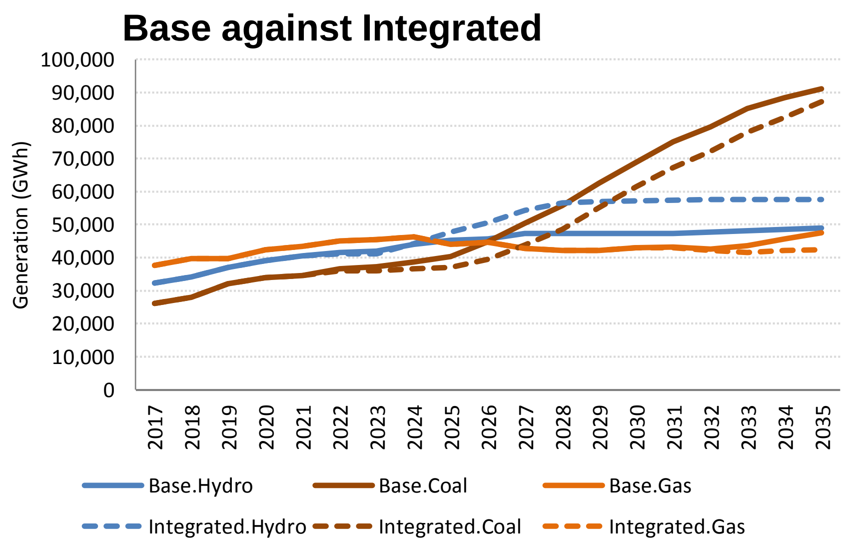


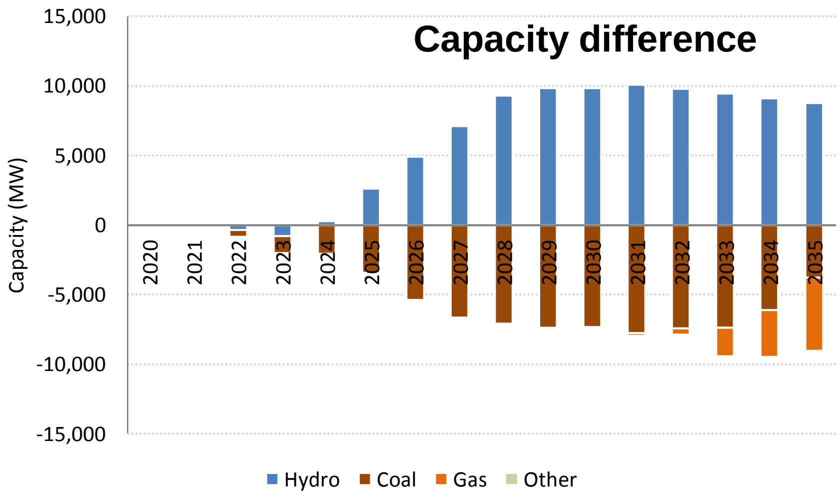
- **Vietnam**: the average net flows doesn't change significantly for the N-C link. The higher flows from C-S result from additional hydro generation from Laos
- **Laos internal flows change significantly** with N to C1 flows reversing with the Integrated case to support flows into Vietnam N, and C2 flows into S to export into Vietnam S
- **Myanmar**: over the long-term power tends to flow from Mandalay (north) to Yangon (central) more than in the base case, where power tends to flow in the opposite direction (power flowing from Yangon to Mandalay)

4.3. Implications for Generation Expansion

Capacity Outlook – GMS Wide







- Base case has little cross-border trading and the increasing demands across the GMS is predominantly met by coal and gas over the long-term (Vietnam, Thailand, Myanmar, Cambodia)
- The Integrated case has **up to 10 GW of additional hydro from Lao PDR**
- **Avoided coal capacity of 8 GW** and up to **5 GW of gas by 2035**

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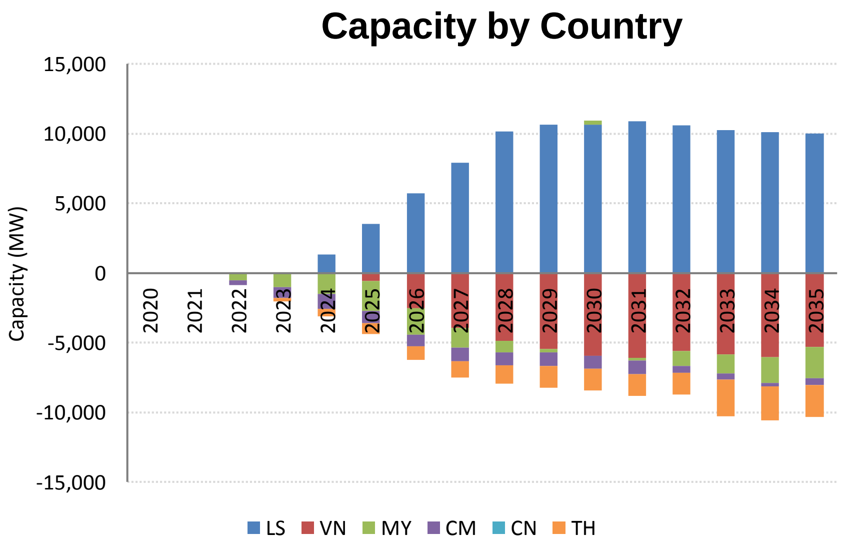
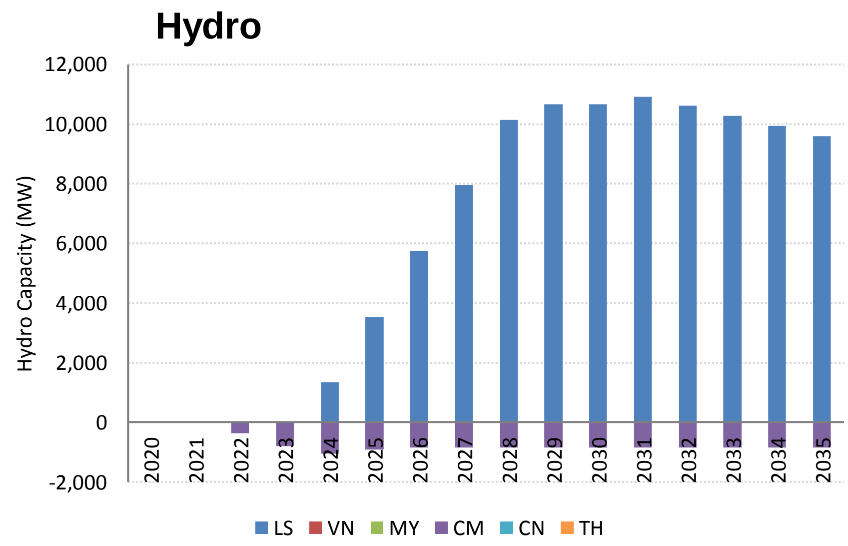
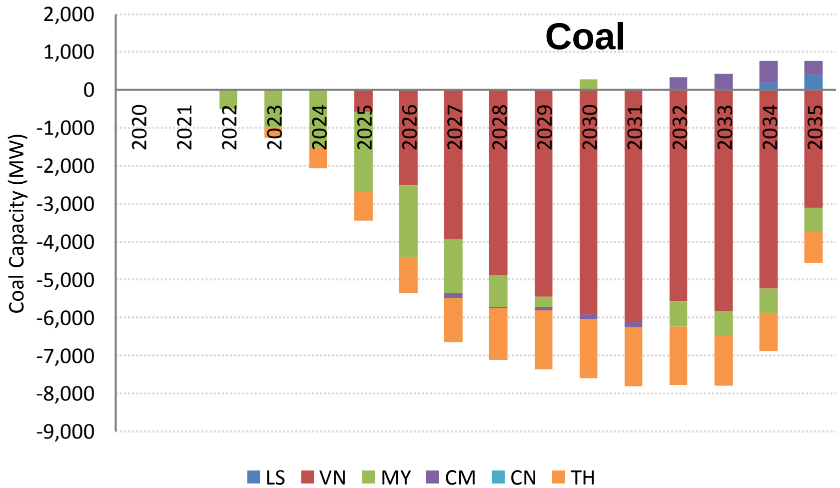
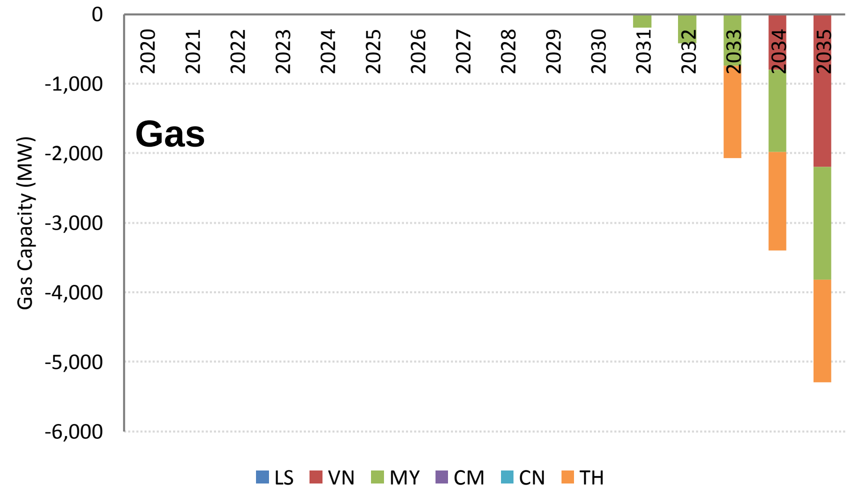
Capacity Outlook Differences: Country & Type









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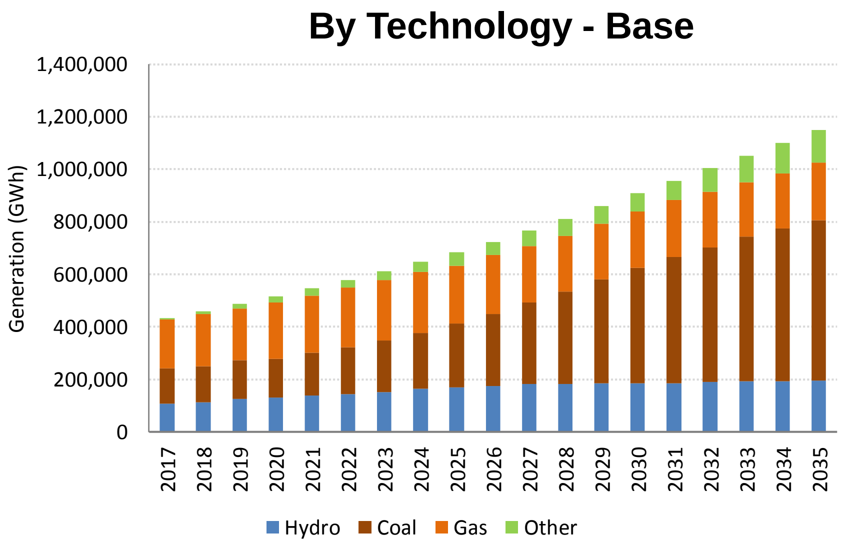
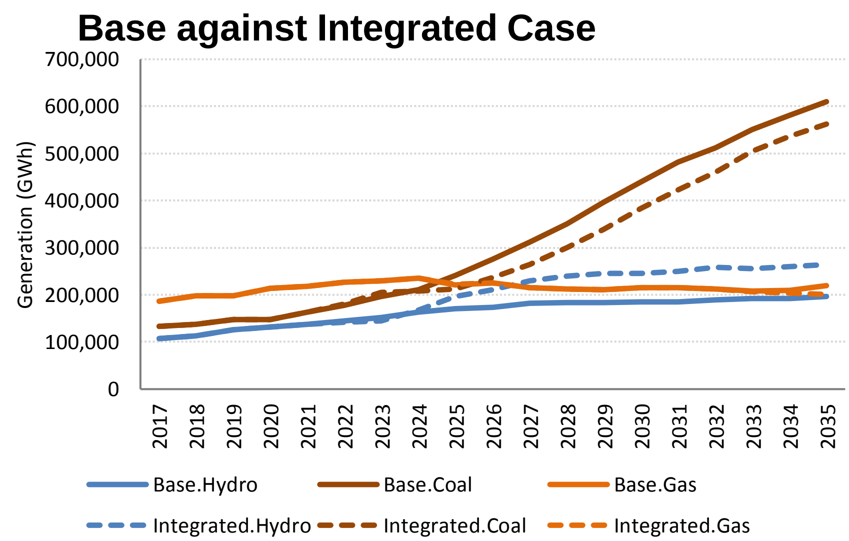
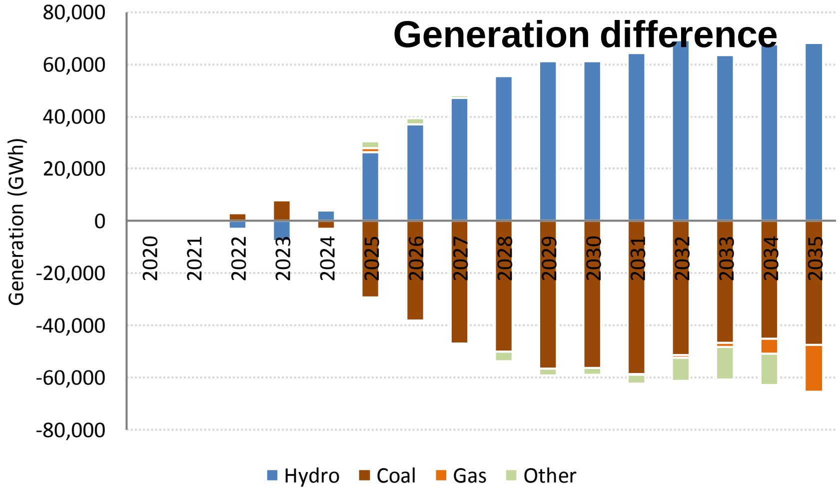
LS = Laos, VN = Vietnam, MY = Myanmar, CM = Cambodia, CN = China, TH = Thailand

Generation Outlook – GMS (for Reference)

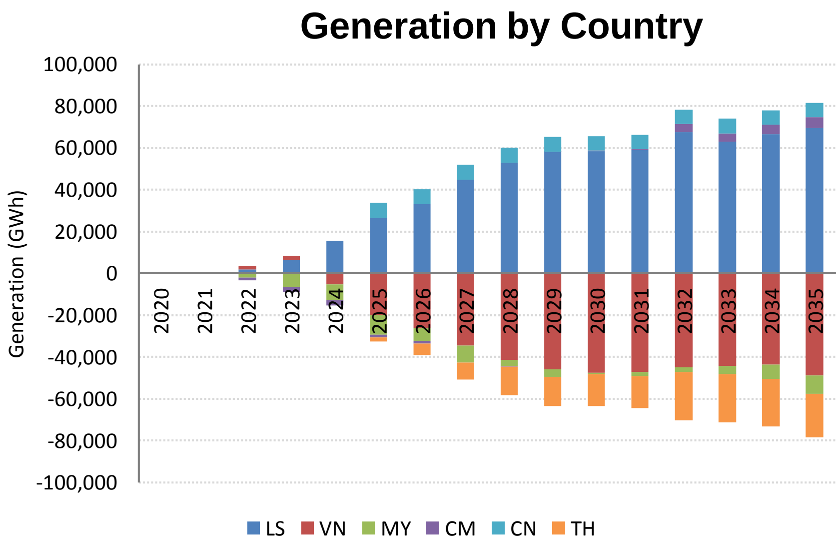


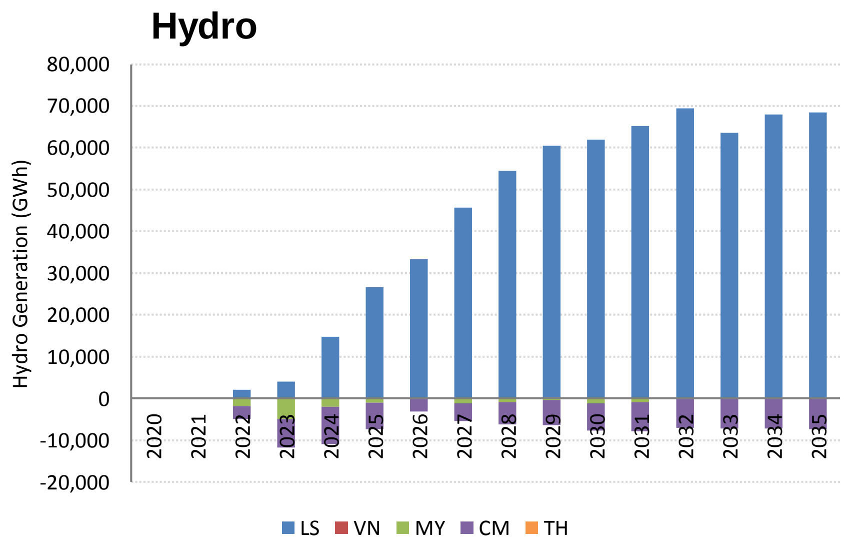


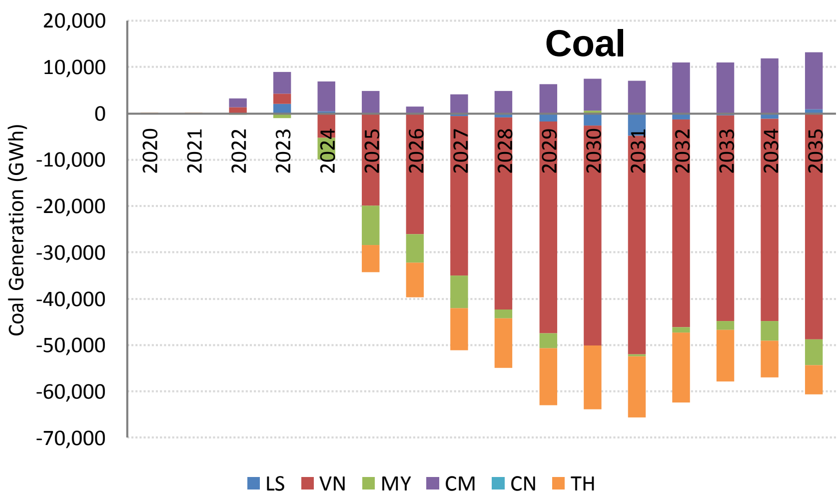


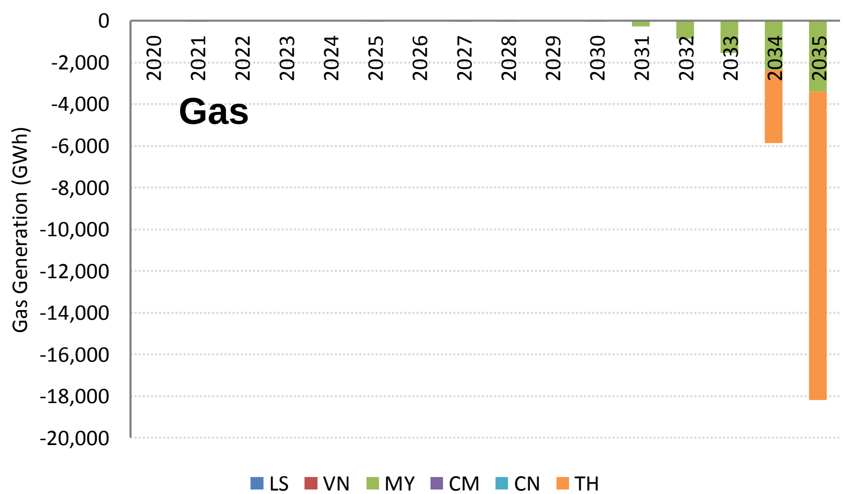
- Similar outlook to capacity charts
- Additional hydro capacity generates an additional 70 TWh displacing coal and gas over the long-term in Vietnam and Thailand
- Outlook for the GMS even with cross-border trading is dominated coal generation, however, hydro share increases over gas generation

Generation Outlook Differences: Country & Type (for Reference)



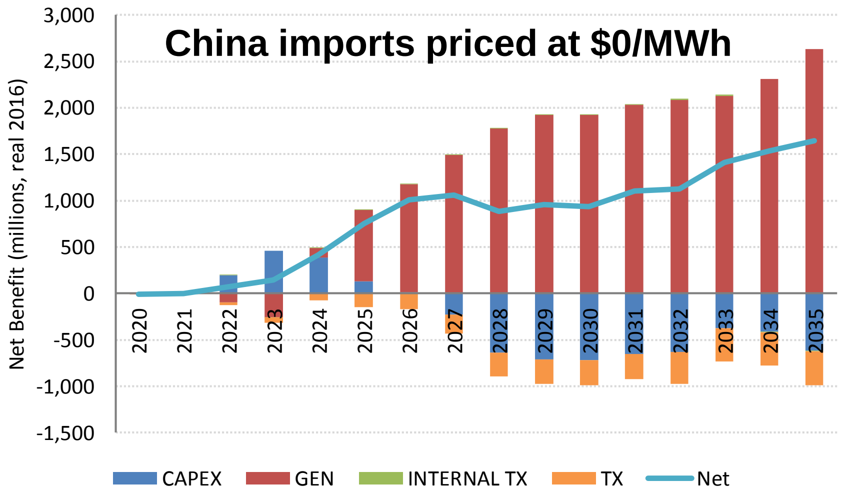


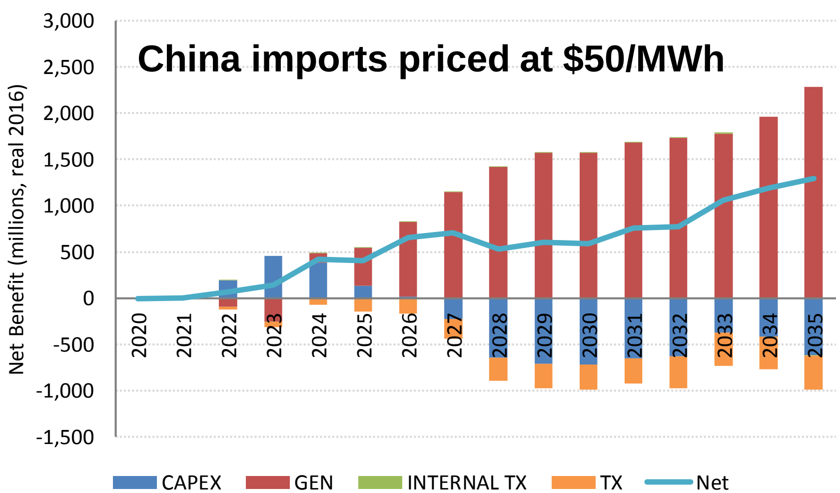




4.4. Economic Implications: NPV of Benefits less Costs

NPV of Avoided Costs less Transmission Capex





- The net benefits associated with the integrated case is significant and is entirely accounted for by generation cost benefits (hydro displacing coal and gas generation)
  - Note this portion of generation benefit includes imports from China which has been valued at $0/MWh
- Chart to the bottom shows the impact is valued at $50/MWh (approximate break-even level for the PRC to MY-N business case)
- There is an associated negative capex benefit (from additional capex spend)
- Negligible impact from internal transmission augmentations to support the Integrated case
- NPV at 2017 (real USD) is included in the table below for both cases
  - NPV for Integrated case assuming no cost to China imports is $3.5 bn
  - NPV assuming $50/MWh import cost from China results in $2.4 bn

$m's	Capex	Gen Opex	National Tx	Regional Tx	NPV
NPV	-640	4,989	13	-846	3,516
NPV (China)	-640	3,927	13	-846	2,453

Unit: Millions of USD

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5. Conclusions

Conclusion for Integrated Case (1)

- Integrated case combines the benefits of all the underlying business cases presented to date – jointly optimising Generation & Transmission

- The Integrated case shows significant overall benefit to region ($3.5 bn NPV) as the result of:
  - Swapping coal and gas capacity for hydro generation
  - (And gas for coal to a lesser extent)
  - Reduces urgency of developing thermal generation projects in some countries
  - Reserve sharing benefits taking advantage of different conditions in connected power systems
  - Power surpluses are used more efficiently to countries that have tighter supply and demand conditions

Conclusion for Integrated Case (2)

Regional transmission planning:

- Most of the business cases we have been studying have been shown to play a role in a regional transmission expansion plan

- Suggested priorities in the shorter term :
  - Laos South to Vietnam Central
  - Northern Laos to Myanmar
  - Increased the interconnectivity between Vietnam and Cambodia
    - (Not only an economic benefit but also a power system stability benefit…)

- Suggested priorities in the longer-term:
  - Laos North to Vietnam
  - PRC to Mandalay
  - Expand / build on the shorter-term cross-border identified above

Conclusion for Integrated Case (3)

National transmission planning :

- Grid strengthening of Laos national power system from north to south is very important
- Similarly grid strengthening between Norther and South of Myanmar is very important

- ⬄ Coordination between national and regional transmission planning is therefore very important to realising the benefits

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Conclusion for Integrated Case (4)

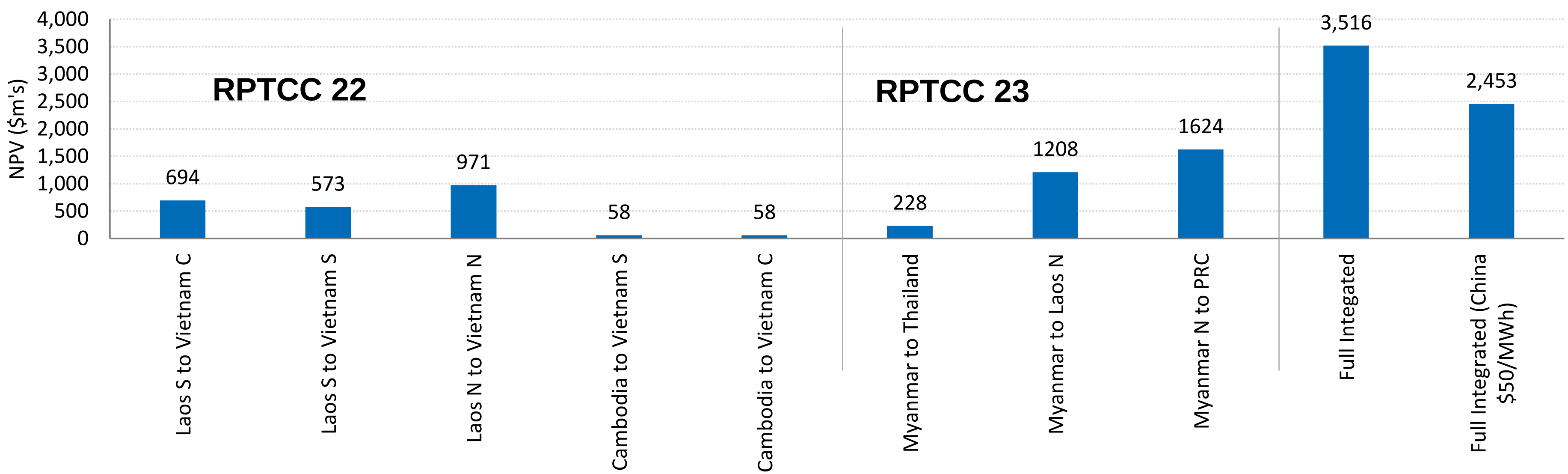
- Other observations / benefits:
  - Can support higher level of renewable energy integration
  - Hedge against dry seasons for hydro and/or extreme RE conditions
  - Lao PDR plays a significant role in facilitating cross-border trading across the GMS
  - Myanmar also plays a significant role in the longer-term as a net exporter
  - 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

- Note: have only studied basic scenarios of supply and demand for PDPs of each country as we understand them to be at moment
  - Recognise that this is a moving target though as countries update their plans
  - Have not carried out detailed sensitivity analysis for materially different technology mixes (e.g. higher RE scenarios)
  - Have not studied energy efficiency scenarios or emissions limit scenarios etc.

Integrated Case Summary

No.	Name and Sizes	NPV Range ($m, benefits from 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
10	Integrated Case, all links included except Myanmar N to Laos N Sizes: Continuous investment modelled	$3.5bn or $2.4bn (China imports valued at $50/MWh)	Significant avoided thermal (mainly coal) capacity, with hydro developments Avoided generation 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 2020

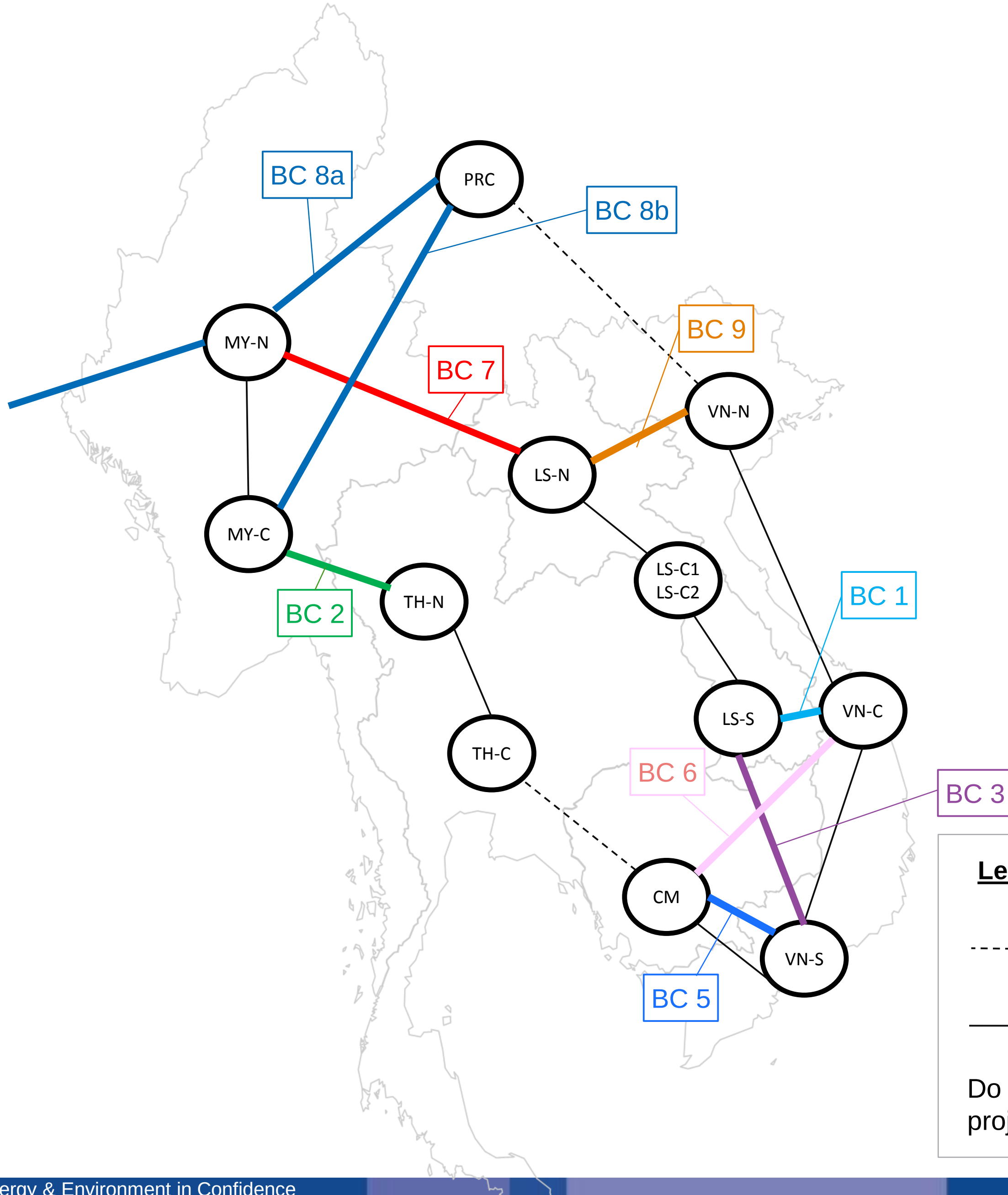


Next Steps (Task 1)

THANK YOU – QUESTIONS & ANSWERS

APPENDIX A: BUSINESS CASE SUMMARY

9 GMS Business Cases: 1, 2, 3, 5, 6, 7, 8a, 8b & 9



Legend:

- - - - - - - - Power exchanged (not synchronous)

———— Grid-to-grid

Do not show dedicated export projects or low voltage exchange

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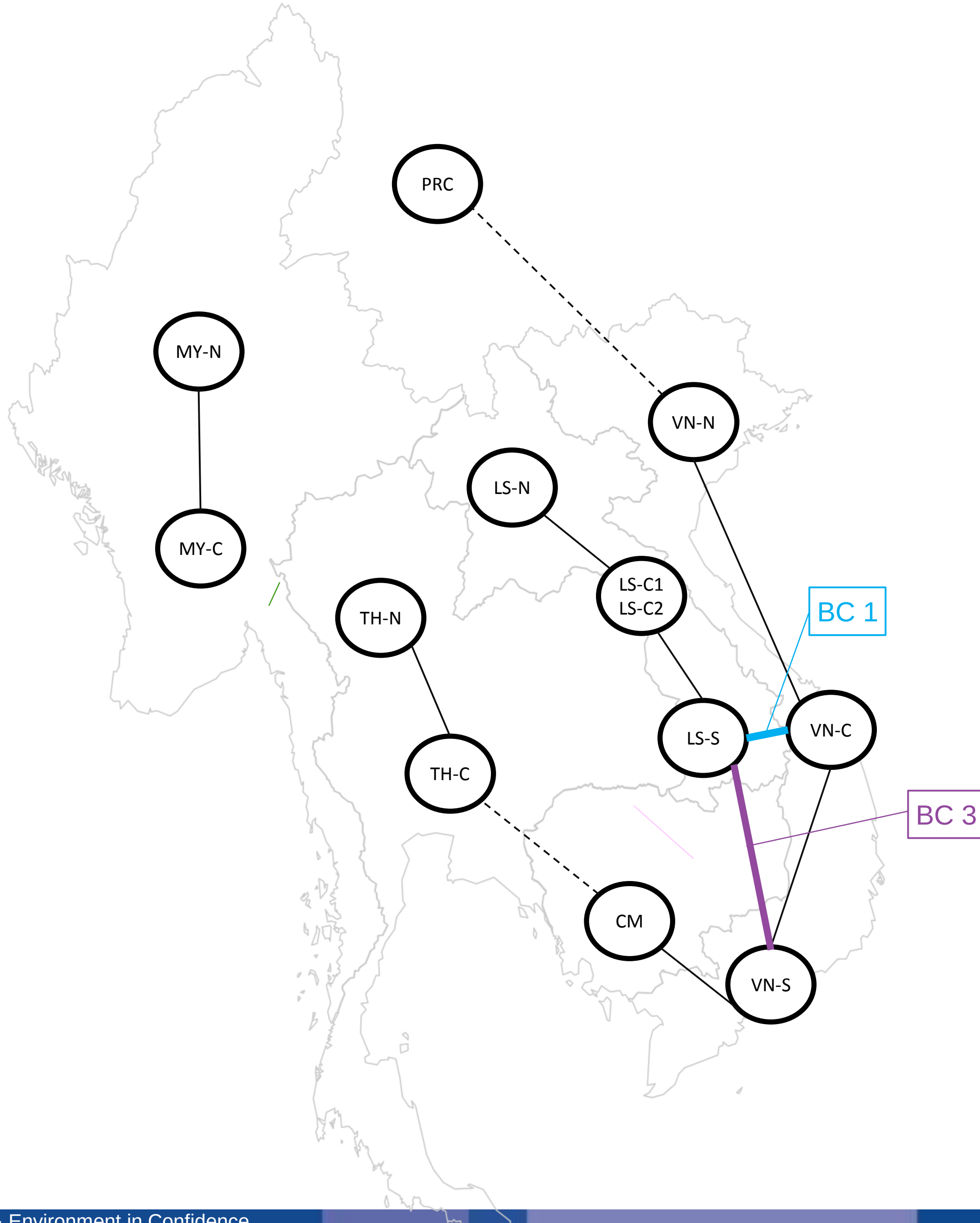
9 GMS Business Cases: 1 and 3



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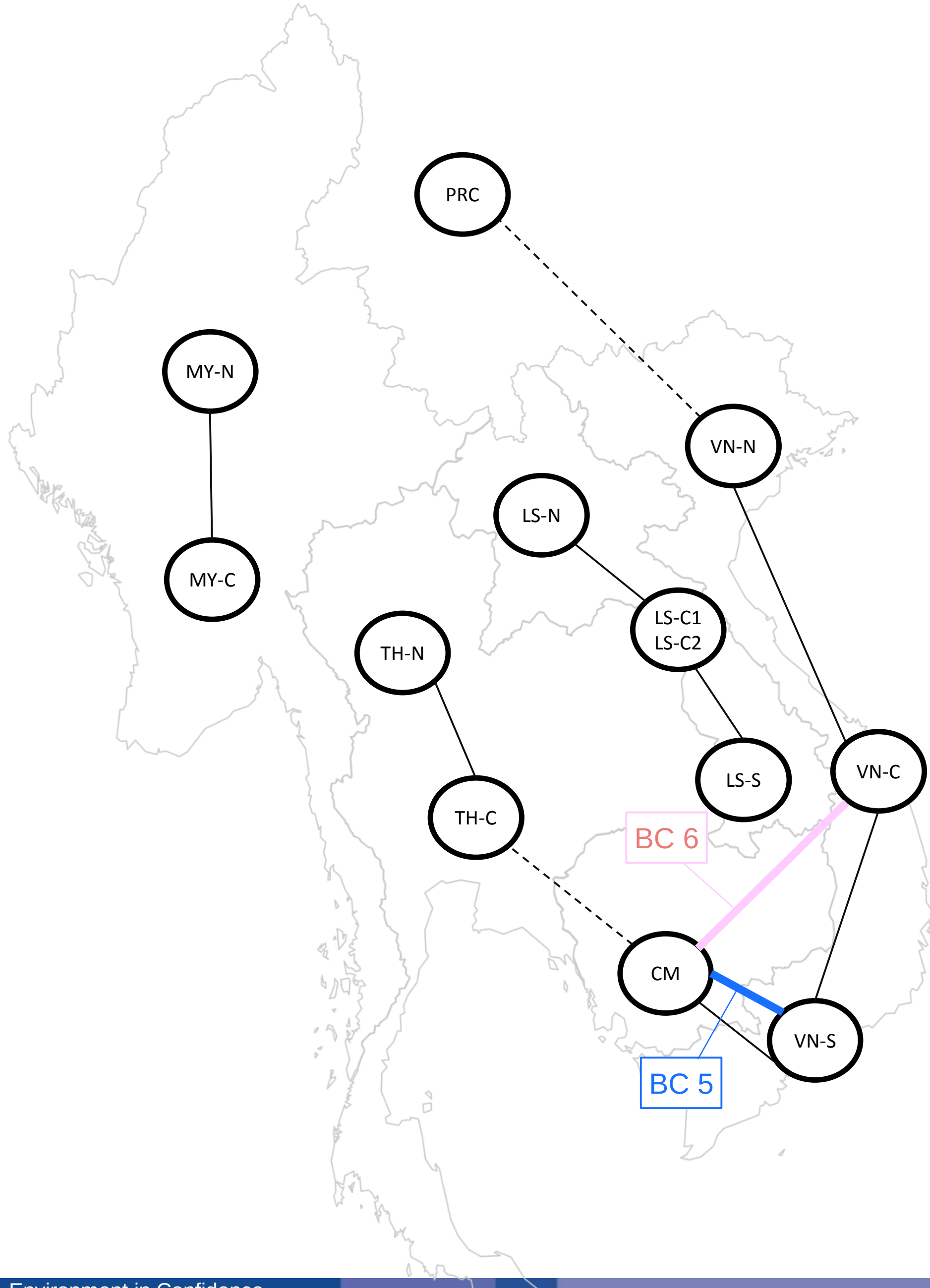
9 GMS Business Cases: 5 and 6



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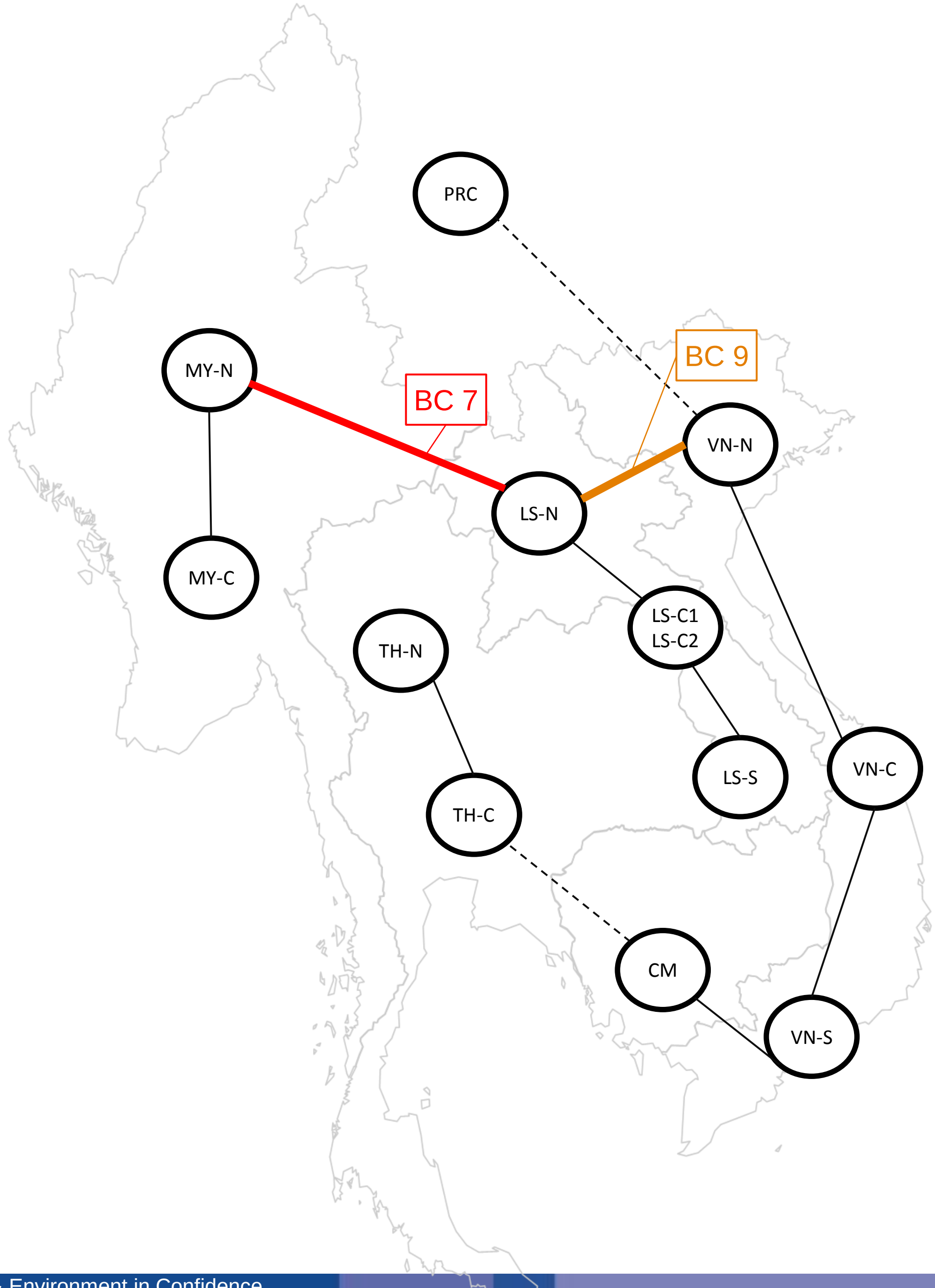
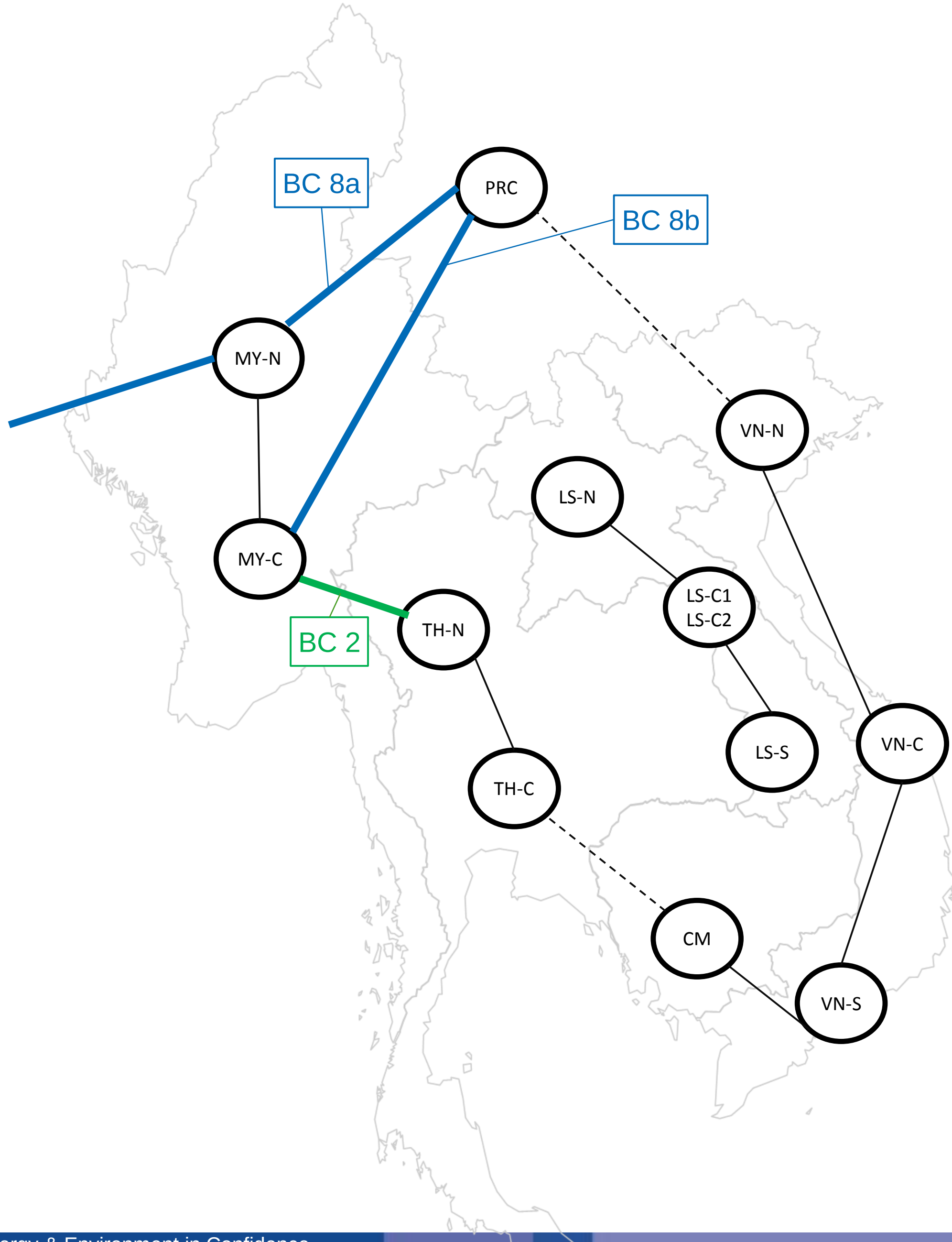
9 GMS Business Cases: 7 and 9



9 Business Cases: 2, 8a and 8b



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Summary of All Business Cases (1, RPTCC 22)

No.	Name & 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 Vietnam	Laos grid strengthening becomes critical to full utilization of hydro storages	Existing network infrastructure in Vietnam & 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 Vietnam	Laos grid strengthening becomes critical to full utilization of hydro storages	BC# 1 appears 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) Sizes: 1500, 2500, 3500 MW	953 - 971	Hydro generation and capacity in Laos substitute for coal and also augments hydro supply in Vietnam North	Requires less grid strengthening that BC1 and BC3 because hydro generation in north of Laos is evacuated directly to north of Vietnam	Generally considered a longer-term option for Vietnam (prioritized lower than Laos imports in the central region) More hydro developed in Laos with higher link size

Summary of All Business Cases (2, RPTCC 22)

No.	Name & Sizes	NPV Range ($m 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
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
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)

Summary of All Business Cases (3, RPTCC 23)

RICARDO

No.	Name and Sizes	NPV Range ($m, benefits from 2020-35)	Implications for Generation	Implications for National Transmission	Other Comments
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) Yangon ⇔ Yunnan (800 km) Sizes: 1000 MW	1,187-1,624	PRC generation and capacity in substitute for coal and gas in Myanmar Central and North, respectively	Requires transmission upgrades between Mandalay and Yangon to be coordinated with the development and to be commissioned successively by 2020-22	Opportunity to export surplus power into Myanmar with opportunity to sell power to Bangladesh

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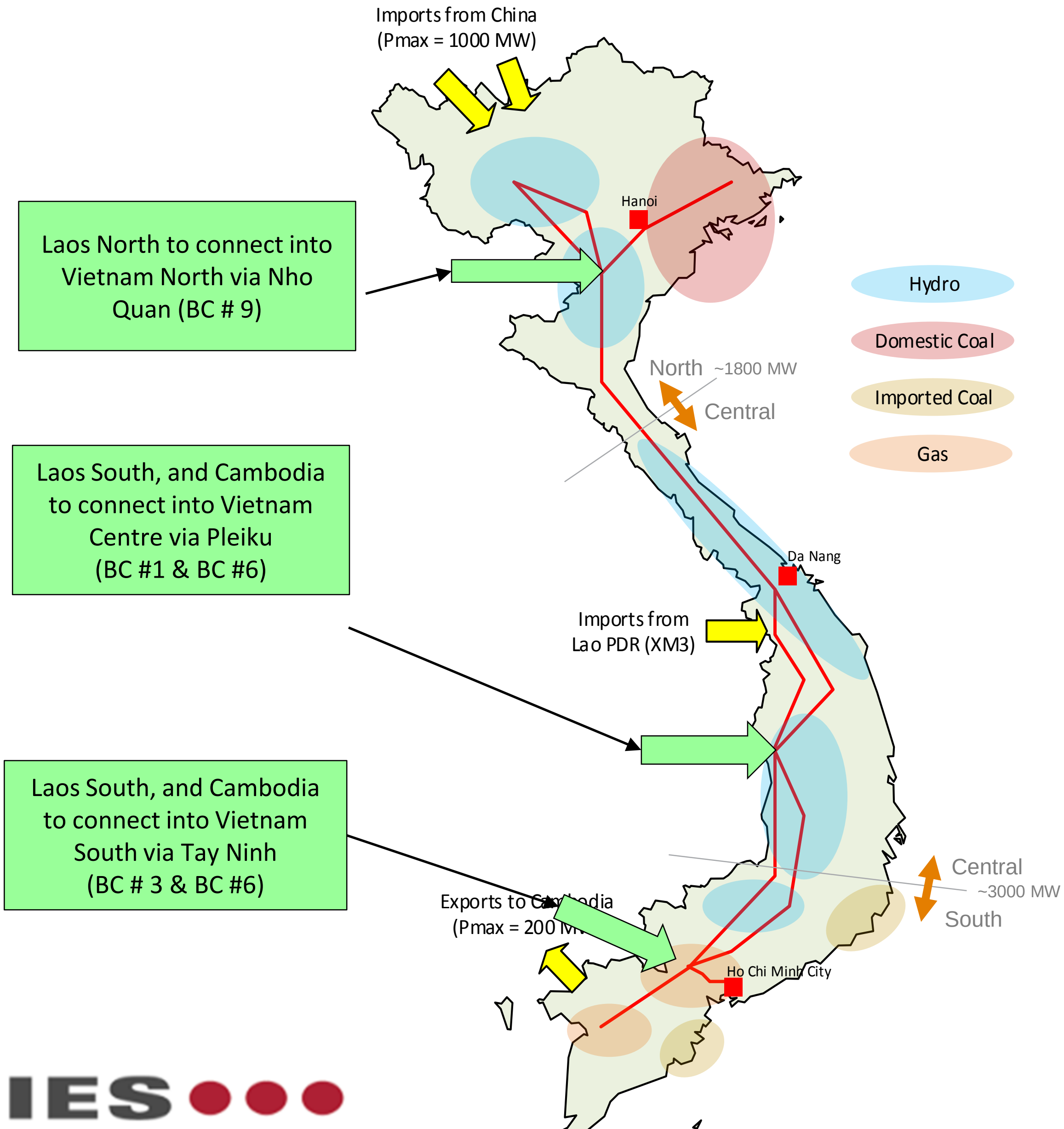
APPENDIX B: BUSINESS AS USUAL OUTLOOKS

Vietnam Power System



KEY FEATURES:

- North, central and south regions
- Large storage hydro-dominated system with more hydro in the central and north regions compared to the south
- Domestic coal resources in north, with newer imported coal projects in the south
- Gas and oil fired power stations in the south
- Gas delivered
- 500 kV backbone with limits between north, centre and south regions
- Power exchanges with neighbouring countries – each slightly different:
  - China – non synchronous exchange
  - Lao PDR – dedicated hydro projects export to Vietnam
  - Cambodia – synchronised to export power to Cambodia

RESOURCE DEVELOPMENT OPTIONS:

- Offshore gas fields (Ca Voi Xanh in central & Block B in south)
- LNG terminals (feature in Gas Master Plan)
- Imported coal (various locations)
- Pumped storage hydro
- Renewable energy: solar, wind, small hydro & biomass

- Non options at this time:
  - Further development of large hydro
  - Nuclear

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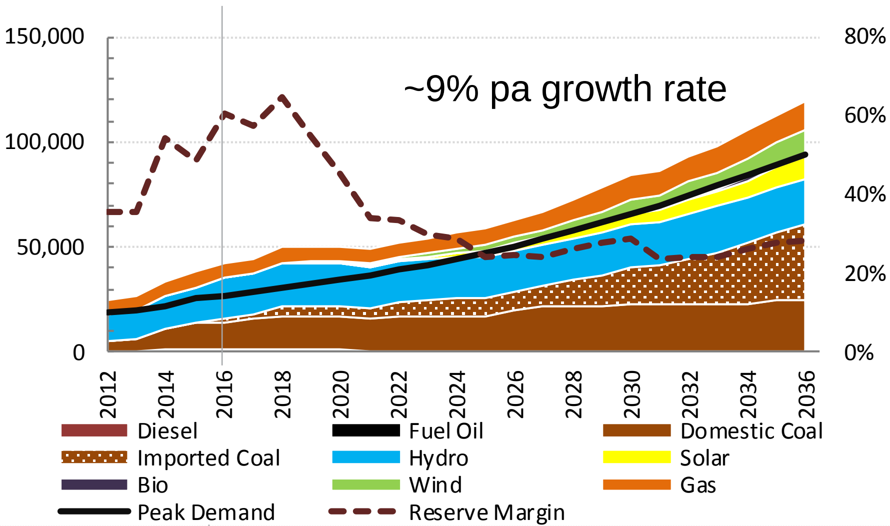
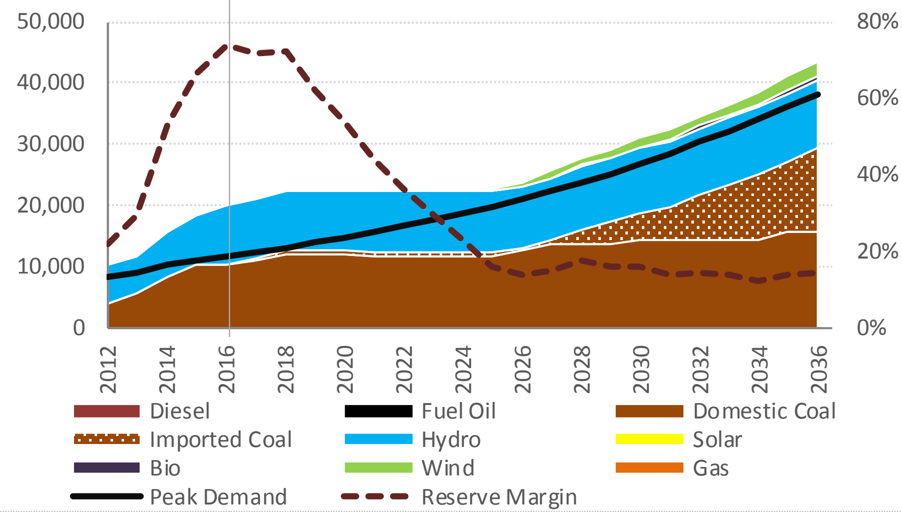
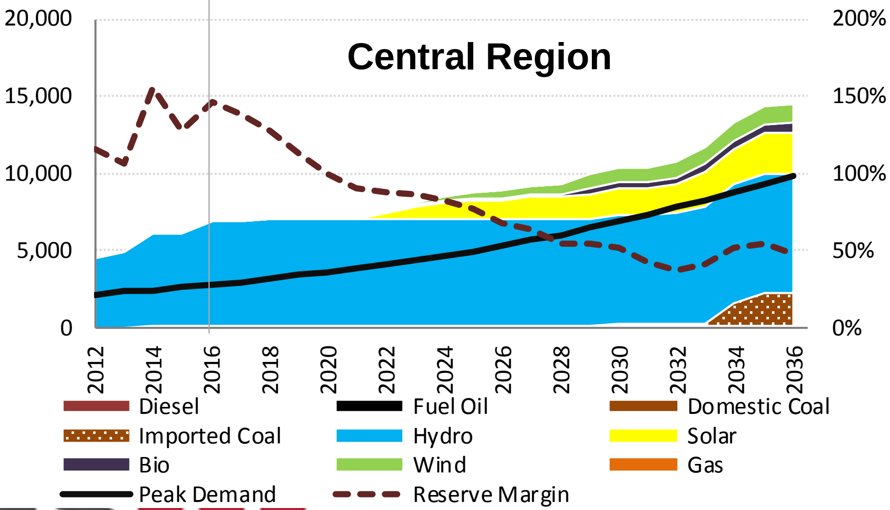
Vietnam Supply & Demand Outlook (MW)

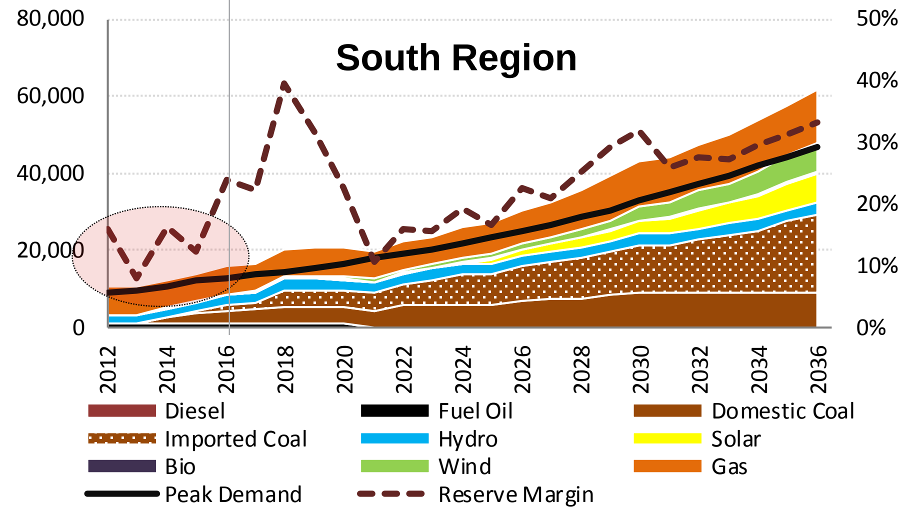
System



North Region







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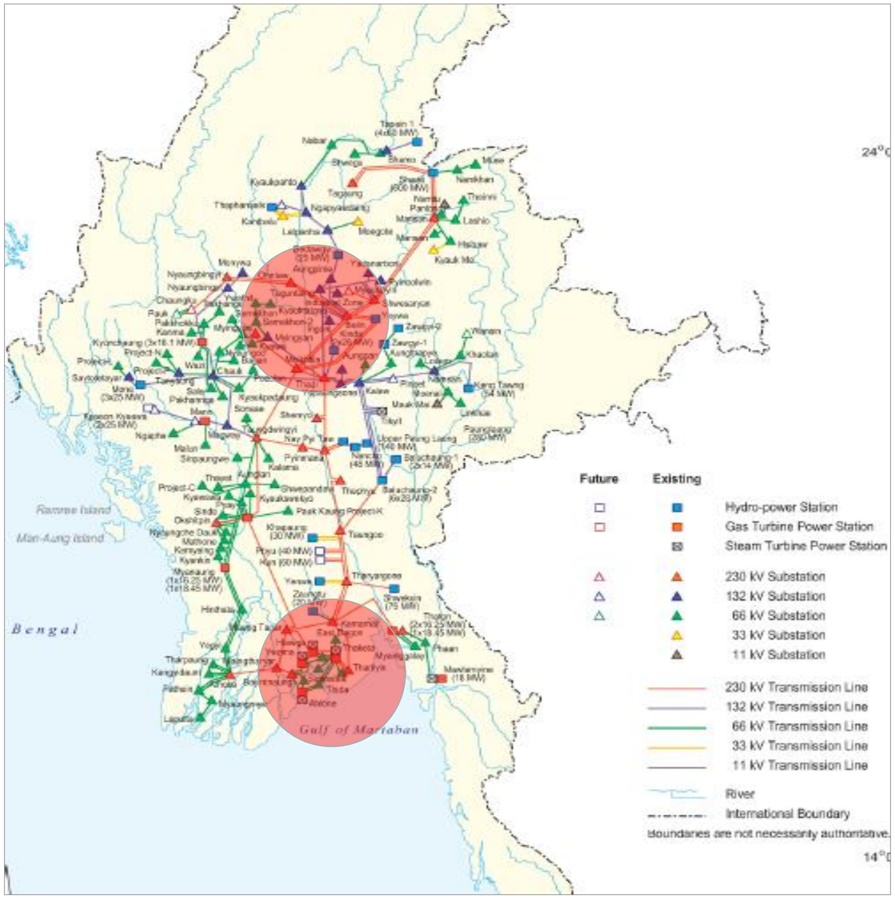
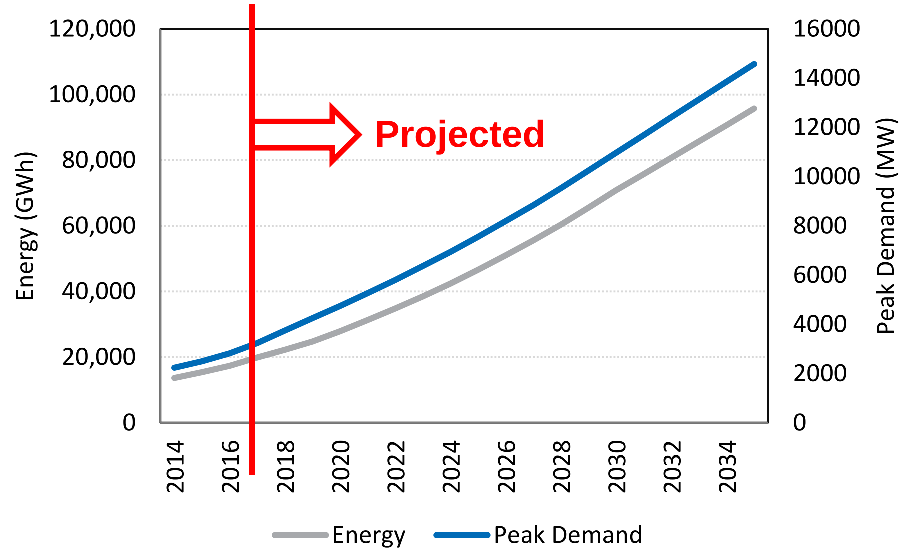
Myanmar Current Situation: Basic Statistics

Transmission Network + Demand Centres

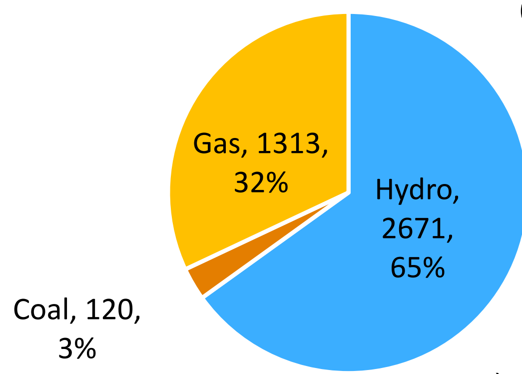


Demand Centre

System Wide Demand (Actual + Projected)



Capacity Mix 2016



⇒ **Hydro Dominated Power System**

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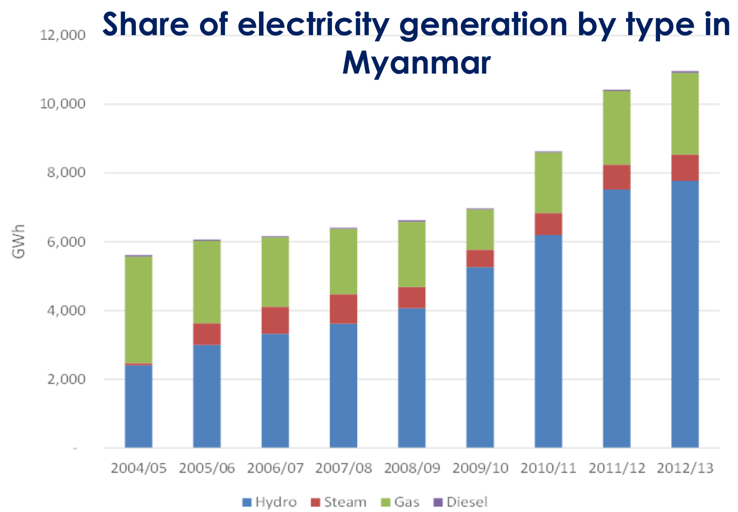
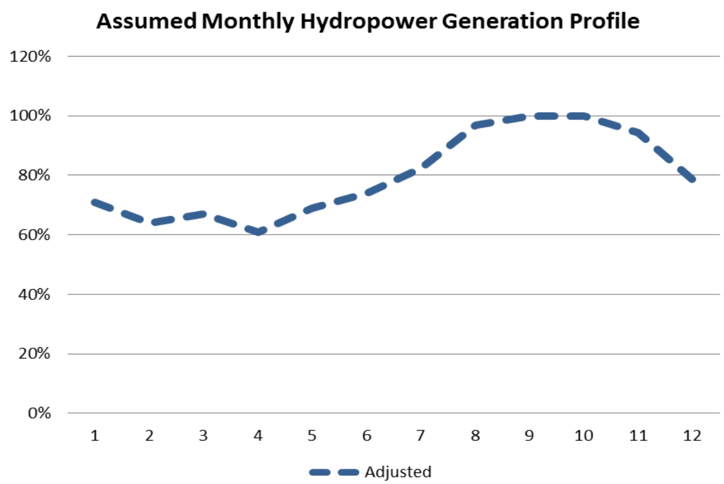
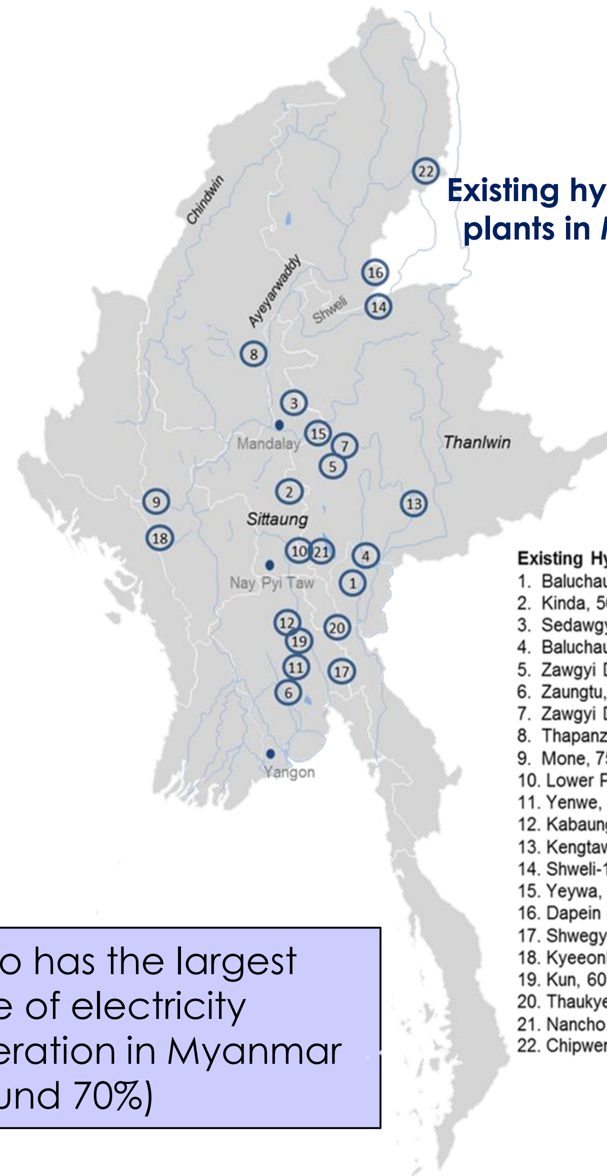
Myanmar Current Situation: Hydro Resource







Existing hydro power plants in Myanmar

Existing Hydropower Plants

1. Baluchaung-2, 168 MW
2. Kinda, 56 MW
3. Sedawgyi, 25 MW
4. Baluchaung-1, 28 MW
5. Zawgyi Dam, 18 MW
6. Zaungtu, 20 MW
7. Zawgyi Dam 2, 12 MW
8. Thapanzeik, 30 MW
9. Mone, 75 MW
10. Lower Paung Laung, 280 MW
11. Yenwe, 25 MW
12. Kabaung, 30 MW
13. Kengtawng, 54 MW
14. Shweli-1, 600 MW
15. Yeywa, 790 MW
16. Dapein – 1, 240 MW
17. Shwegyin, 75 MW
18. KyeeonKyeewa, 74 MW
19. Kun, 60 MW
20. Thaukyegat-II, 120 MW
21. Nancho, 40 MW
22. Chipwenge, 99 MW

Hydro has the largest share of electricity generation in Myanmar (around 70%)

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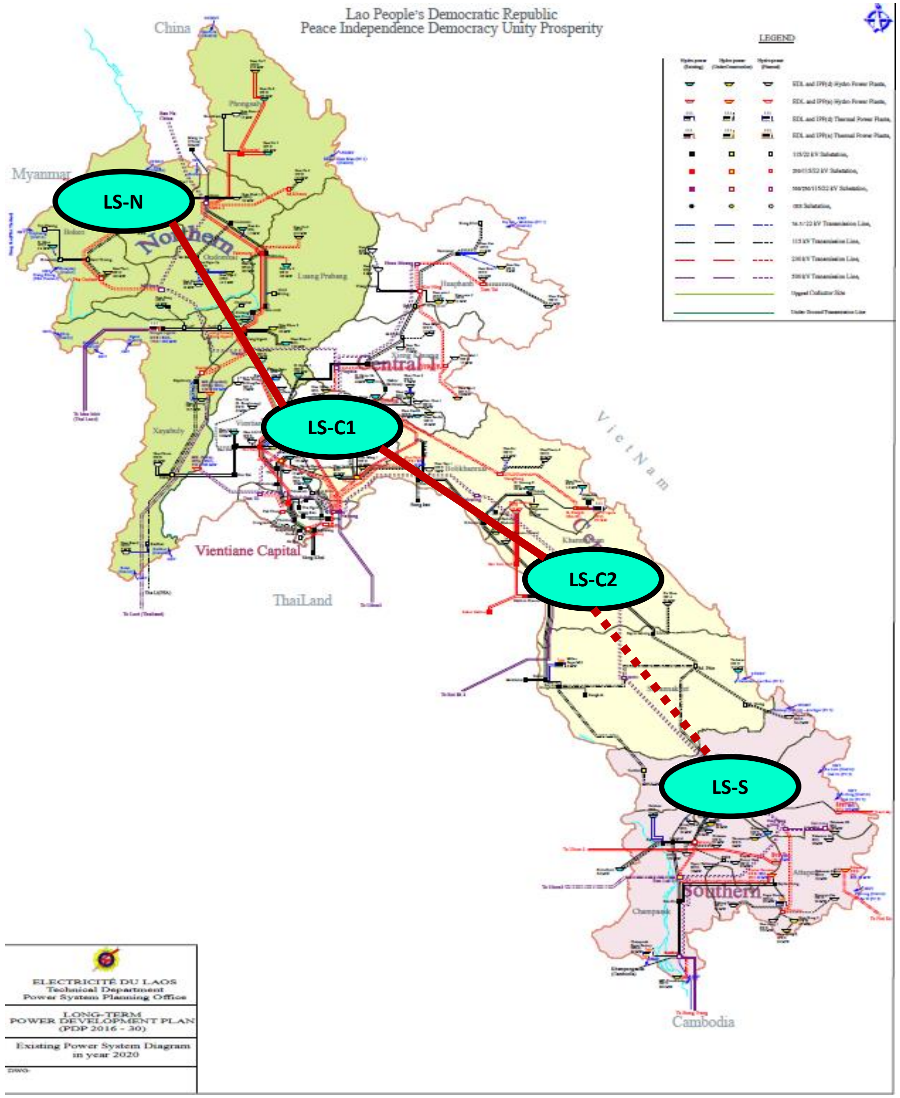
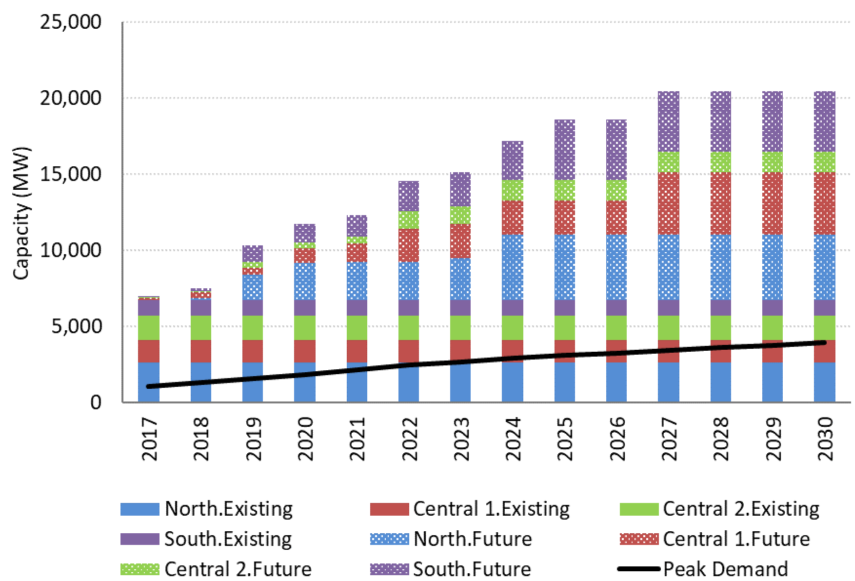
Laos Power System

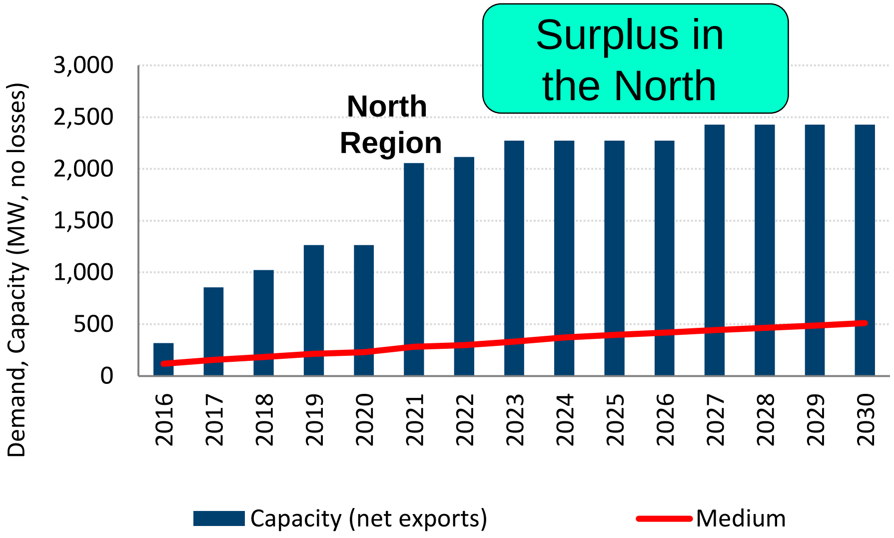


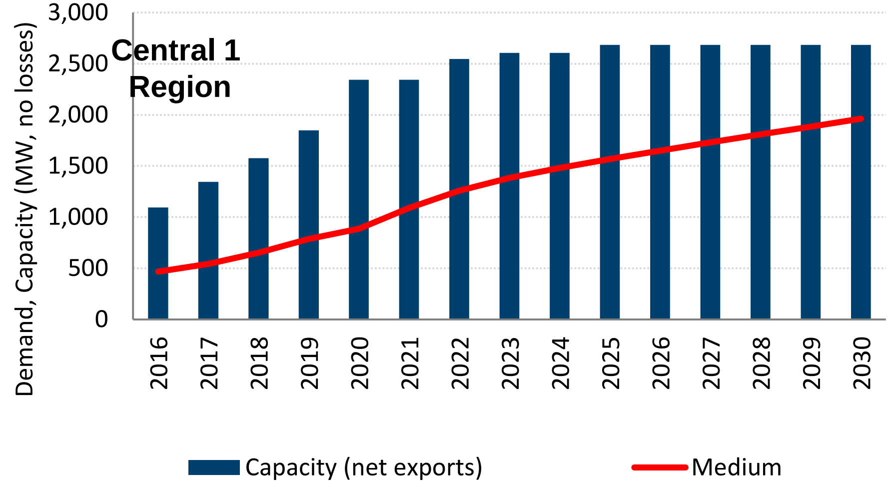
- Significant hydro resources in Laos across the country with various existing and committed hydro projects dedicated to exports to Thailand (North and Central) and Vietnam (to Central region).
- Development plans assume up to 20 GW of capacity developed to meet domestic and exporting requirements
- Currently 1,200 MW committed for exports to Vietnam (centre region) by 2021 and approximately 4,000 MW into Thailand
  - Dedicated connections into Thailand along the border
- Demand expected to continue growing at 10% per annum with additional industrial loads

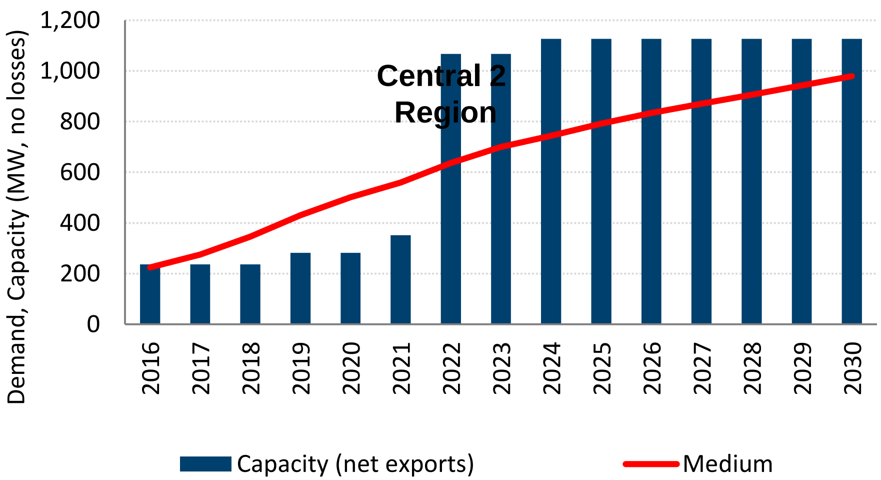
System-wide Installed Capacity & Peak Demand

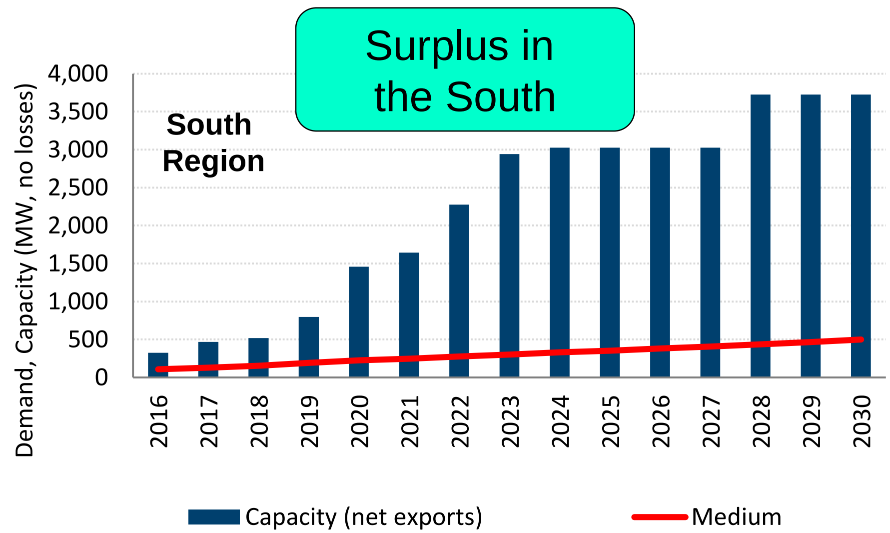


Regional Laos Supply & Demand Outlooks









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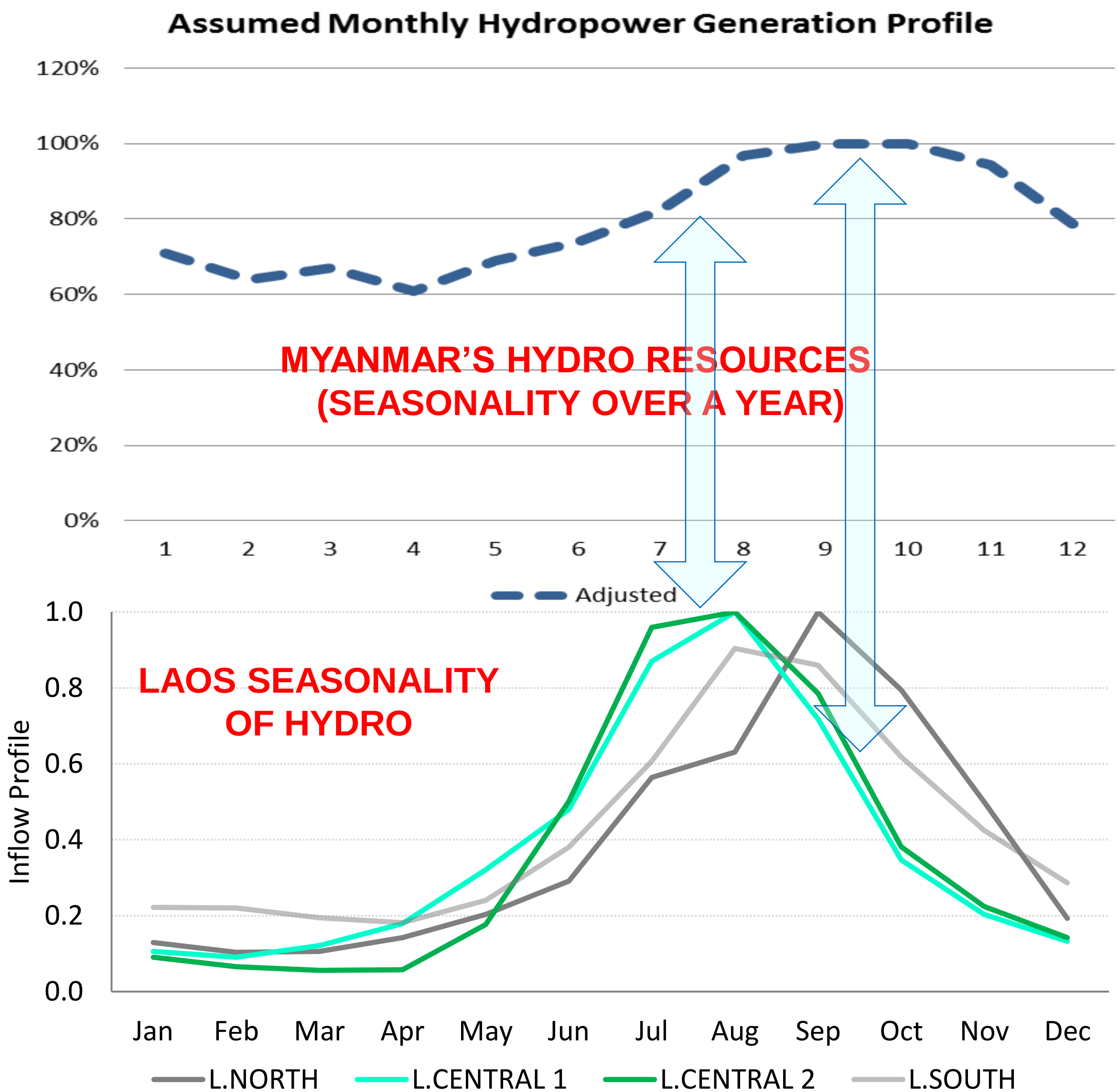
Regional Laos Supply & Demand Outlooks



SOME DIVERSIFICATION IN HYDROLOGICAL CONDITIONS BETWEEN NORTH LAOS & MYANMAR

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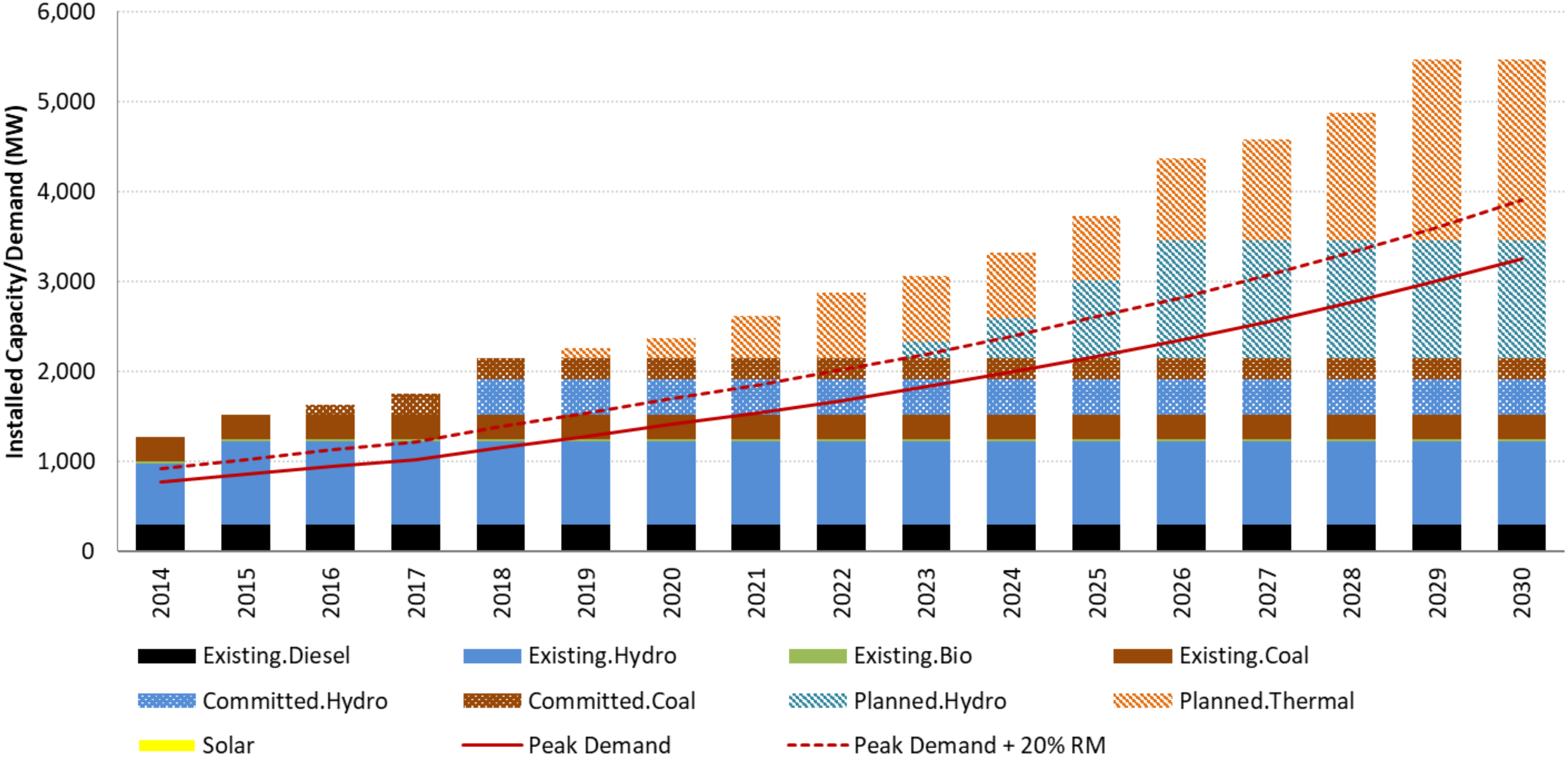
Cambodia Power System – Outlook



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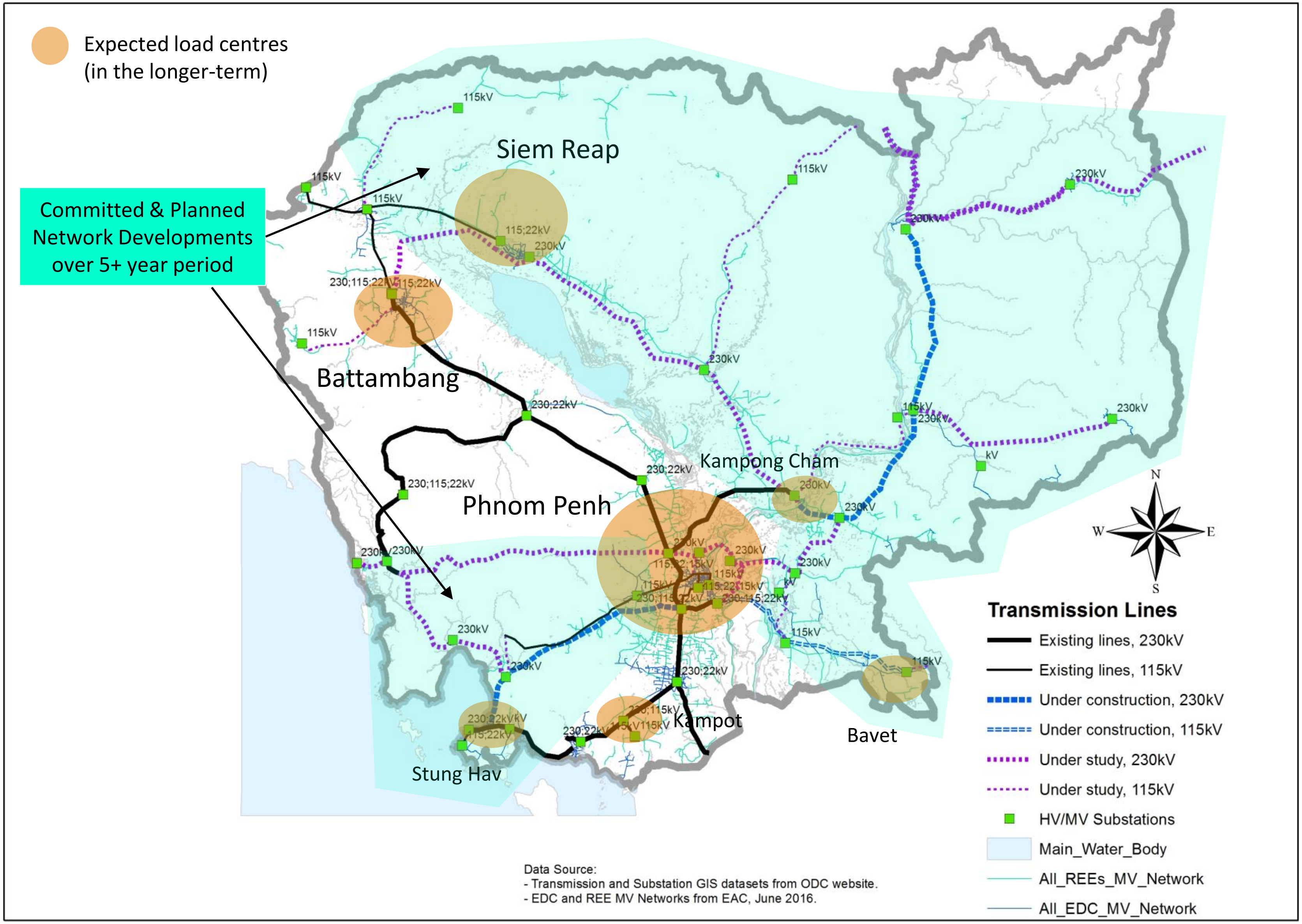
Cambodia Power System – Load Centres



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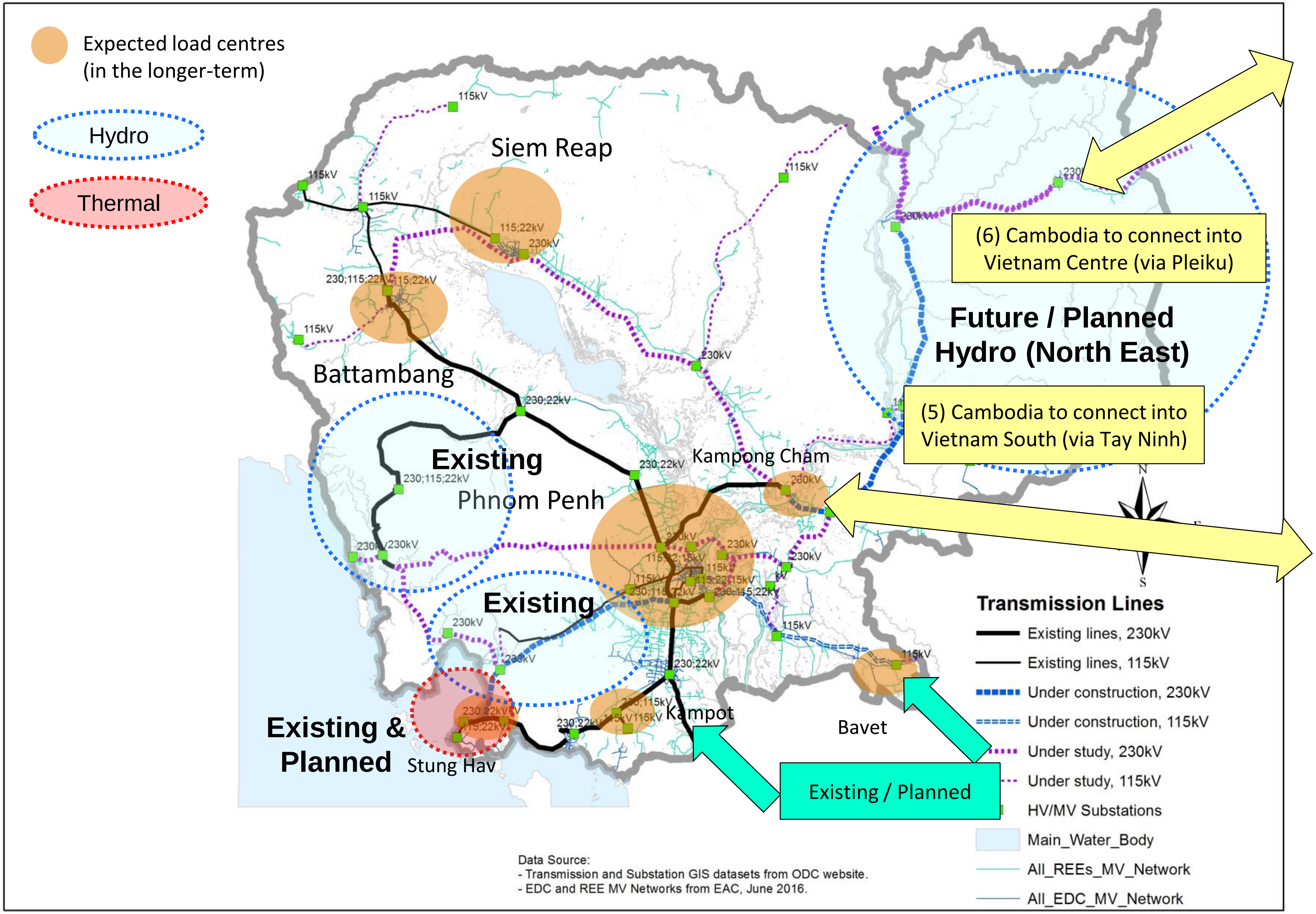
Cambodia Power System - Generation

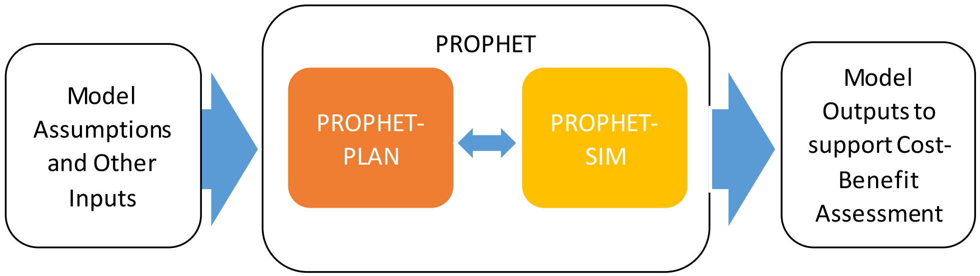


APPENDIX C: MODEL APPROACH + GENERAL ASSUMPTIONS

Reference: Modelling Platform

Key Inputs:

- Generators + existing (regional) transmission system
- Demand
- Fuel prices and cost structures of generators
- Hydro availabilities based on wet and dry seasons
- Renewable resource seasonality across the year based on analysis of monthly GMS irradiance and wind speed measurements converted to generation profiles
- Transmission cases being studied



Scenarios:

- Base Case based on existing PDPs
- Business case scenarios for different transfer capabilities – e.g. 500 MW, 1000 MW, 2000 MW
- Possible scenarios to stress test the business case:
  - Low hydro availability (to analyse the benefits of reserve sharing)
  - Higher RE cases to understand whether the business case is complementary to higher RE development in the GMS
- Model period: 2016-2035
- Model typical days (hourly) per month in each year to reflect: seasonality and daily profiles

Key Outputs:

- Fuel costs
- Operational costs
- Capital costs
- Transmission flows (at the regional level)
- Emissions
- Generator dispatch

PROPHET:

- PROPHET-PLAN is a least cost generation expansion planning tool
- PROPHET-SIM is a Monte Carlo economic dispatch simulation model

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Reference: Key Assumptions

- Base Case assumes the GMS countries continue to develop projects as per their power development plans (generally standalone with limited connectivity with neighbouring countries). 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 models 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

ASSUMPTION	VIETNAM	LAOS	CAMBODIA	THAILAND	MYANMAR
NEW ENTRY (THERMAL AND HYDRO)	- 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.	- 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	- 3000 MW of hydro allowed from 2020 - 2500 of coal allowed from 2025	- Minimal gas and coal allowed in North region. - Gas and coal allowed from 2022	- 3500 and 2500 MW of hydro in the north and centre region from 2022 - Coal capacity allowed in the centre from 2025 - Around 1500 MW of gas and diesel allowed in both regions from 2020
NEW ENTRY RENEWABLES	Renewable plants (except hydro) have fixed based on intended RE targets				
CAPITAL COST	Hydro: $2150/kW Coal: $2,000/kW Gas CCGT: $950/kW				
FUEL PRICES	Coal: $3/GJ Gas/LNG: $7.5/GJ Diesel: $13/GJ				
INTRA-COUNTRY LINK AUGMENTATION	Least-cost expansion	Least-cost expansion	Modelled as single region	3000 MW increasing to 6000 MW by 2030 between North and Central	400 MW increasing to 1200 MW by 2030 between North and Central
HYDRO CONSTRAINTS	- Monthly energy constraints based on historical generation profiles (or inflow profiles). New hydro units follow the average regional generation shape.	- Minimum monthly generation constraints and a maximum annual energy limit to reflect the inflows across the seasons and its ability to store water	- Monthly energy constraints based on historical generation profiles (or inflow profiles). New hydro units follow the average regional generation shape.	- Monthly energy constraints based on historical generation profiles (or inflow profiles). New hydro units follow the average regional generation shape.	- Monthly energy constraints based on historical generation profiles (or inflow profiles). New hydro units follow the average regional generation shape.

Reference: Transmission Cost Assumptions

- To avoid complications in having to specify the detail configuration for the candidate transmission lines (i.e. conductor type, number of circuits, voltage level of the transmission lines), the cost estimates for HVAC and HVAC transmission lines used in the modelling are represented based on distance and capacity (USD/MW/km).
- 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.
- There is an additional 10% to reflect annual fixed operating and maintenance costs

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

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