Chapter 2

Preliminary Feasibility Assessment of Selected Routes

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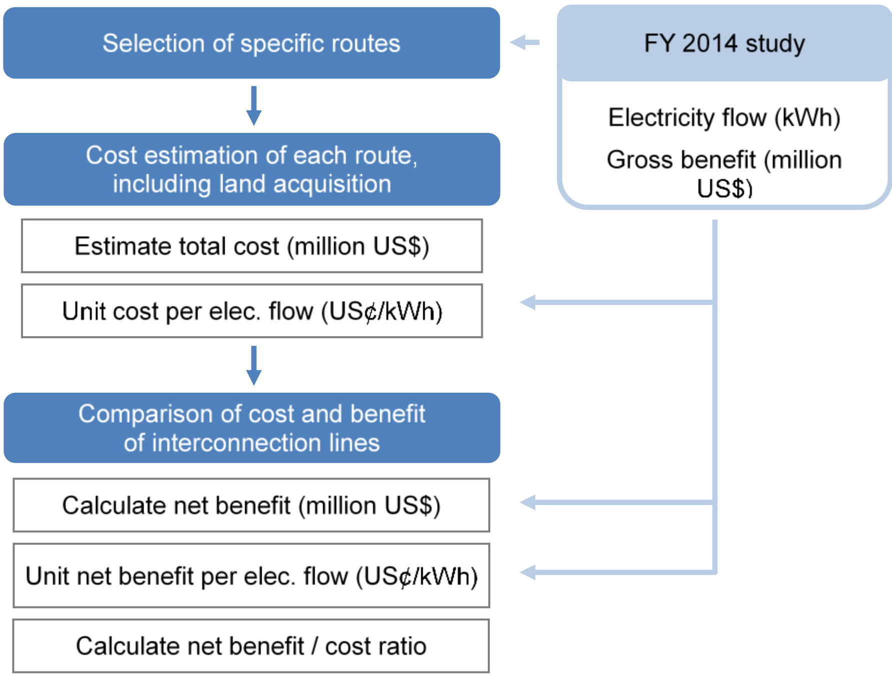
CHAPTER 2

Preliminary Feasibility Assessment of Selected Routes

1. Overview of Study

Regarding the three most economically beneficial routes from 2014 study, Chapter 2 covers the selection of specific cross-border interconnection routes and estimation of construction costs for transmission lines and land acquisition costs for each interconnection route.

Figure 2-1. Study Flow



Source: Author.

1.1. Top Three Economically Beneficial Routes

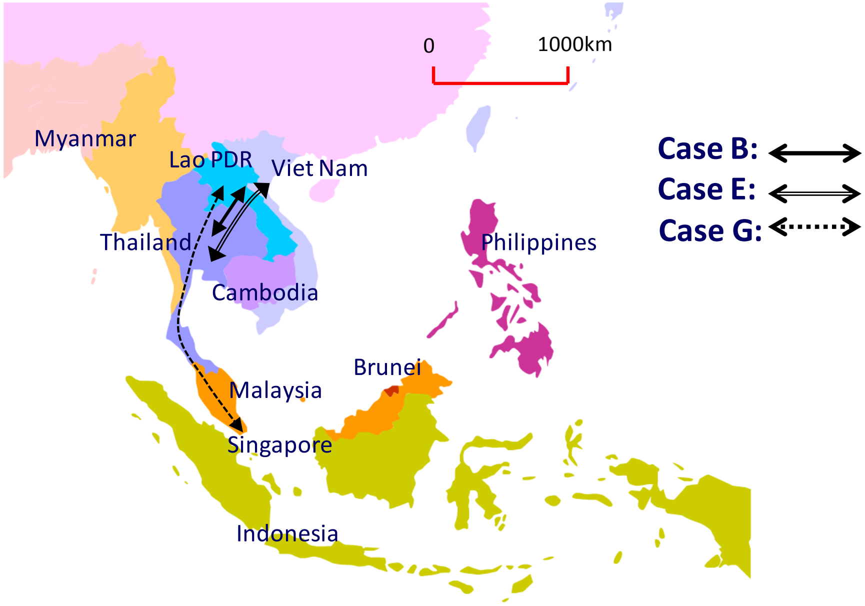
In last year's study, these routes are estimated to bring larger economic benefits from power grid interconnection:

Case B: Thailand–Lao PDR

Case E: Viet Nam–Lao PDR–Thailand

Case G: Lao PDR–Thailand–Malaysia–Singapore

Figure 2-2. Three Economically Beneficial Routes



km = kilometre, Lao PDR = Lao People's Democratic Republic.
Source: Prepared by the working group.

Sorting through the three most economically beneficial routes, cross-border interconnection sections can be summarised into four. From the east, these interconnection sections are 1) Viet Nam–Lao PDR, 2) Lao PDR–Thailand, 3) Thailand–Malaysia, and 4) Malaysia–Singapore.

1.2. Researching the Status of Cross-border Interconnections

To select the most promising interconnection route, the current state and future plans for the aforementioned four sections are investigated.

1.2.1. Viet Nam–Lao PDR

Table 2-1. Cross-border Interconnection (Lao PDR–Viet Nam)

No.	Project	System	Type	SCOD	MW
10	**Lao PDR -Vietnam**				
	Existing				
	• Xekaman 3 - Thanhmy	HVAC: kV	PP: La->Vn	2013	248
	•				
	Ongoing				
	• Xekaman 1- Ban Hat San - Pleiku	HVAC: kV	PP: La->Vn	2016	1000
	• Nam Mo - Ban Ve	HVAC: kV	PP: La->Vn	TBC	TBC
	• Luang Prabang - Nho Quan	HVAC: kV	PP: La->Vn	2020	1410
	•				
	Future				
	• Ban Hat San - Stung Treng - Tay Ninh	TBC	TBC	TBC	TBC
	•				

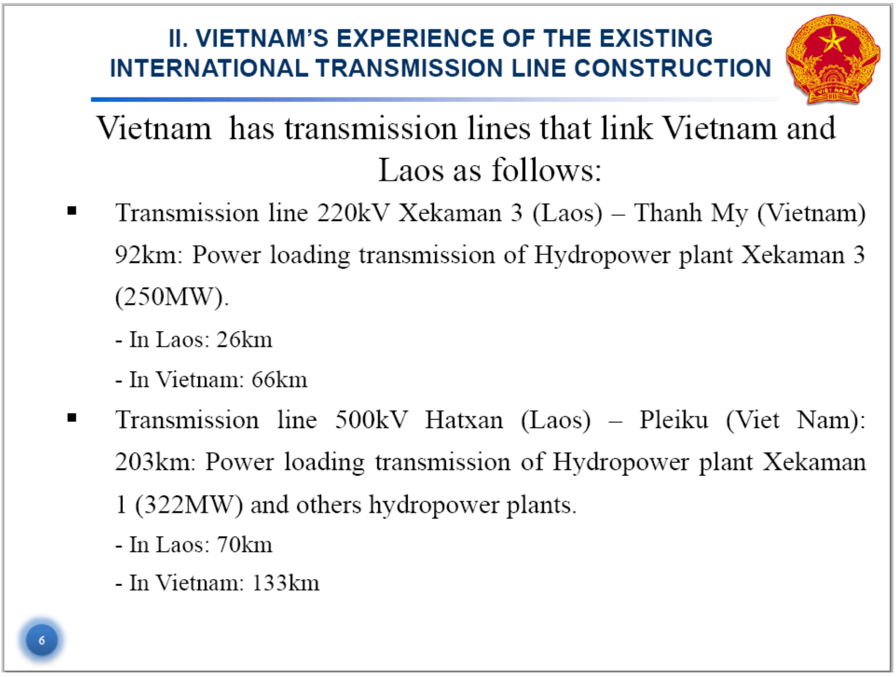
HVAC = high-voltage alternating current, kV = kilovolt, MW = megawatt, PP = power plant, SCOD = schedule commercial operation date, TBC = to be confirmed.
Source: Development of Cross-Border Trade between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

As shown in Table 2-1, a cross-border interconnection currently exists to export power from some hydropower plants in Lao PDR to Viet Nam (Xekaman 3–Thanhmy). Three cross-border interconnections are being constructed to export power from Laotian hydropower plants to Viet Nam, and one future connection (unclear whether from hydropower plants or between substations) is proposed.

Memorandums of agreements (MOUs) have been signed for ongoing work from the Nam Mo hydropower plant (Lao PDR) to Ban Ve (Viet Nam), and from the Luang Prabang hydropower plant (Lao PDR) to Nho Quan (Viet Nam), and deliberations are currently under way. However, according to the latest Electricite du Laos (EDL) plans (see Figure 2-10), the Luang Prabang P/P–Nho Quan plan is missing. This plan seems to have been terminated as its feasibility was not so high.

Figure 2-3 was presented by the Electricity Viet Nam in the first working group meeting on 11 November 2014. Two Viet Nam–Lao PDR interconnections exist: the Xekaman 3 (Lao PDR)–Thanh My (Viet Nam) line, which has been completed, and the Hatxan (Lao PDR)–Pleiku (Viet Nam) line, which should currently be under construction. These lines are consistent with data from Table 2-1.

Figure 2-3. Viet Nam's Experience on the Existing International Transmission Line Construction



km = kilometre, kV = kilovolt, MW = megawatt.
Source: FY2014 1st EIPI presentation material by the Electricity Viet Nam.

1.2.2. Thailand–Lao PDR

Table 2-2. Cross-border Interconnection (Thailand–Lao PDR)

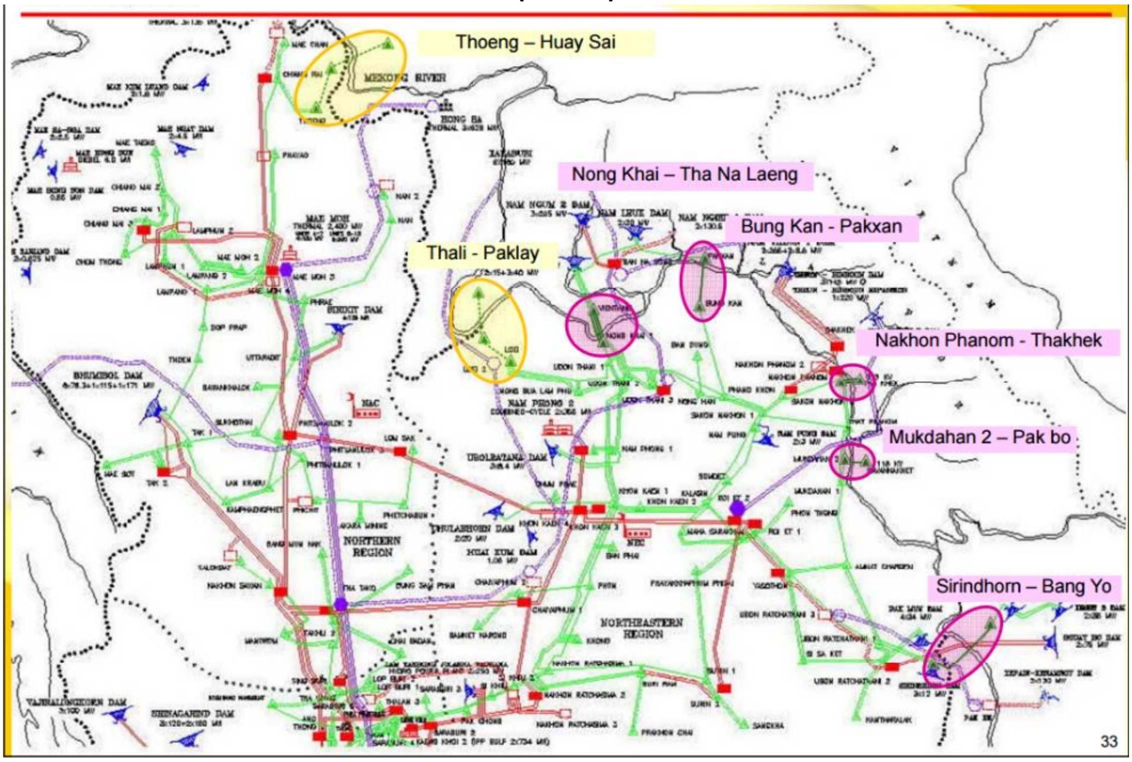
No.	Project	System	Type	SCOD	MW
9	**Thailand - Lao PDR**				
	Existing				
	• Nakhon Phanom - Thakhek - Theun Hinboun	HVAC: 230 kV	PP: La->Th	1998	220
	• Ubon Ratchathani 2 - Houay Ho	HVAC: 230 kV	PP: La->Th	1999	126
	• Roi Et 2 - Nam Theun 2	HVAC: 230 kV	PP: La->Th	2010	948
	• Udon Thani 3 - Na Bong - Nam Ngum 2	HVAC: 500 kV	PP: La->Th	2011	597
	• Nakhon Phanom 2 - Thakhek - Theun Hinboun (Expansion)	HVAC: 230 kV	PP: La->Th	2012	220
	•				
	Ongoing				
	• Mae Moh 3 - Nan 2 - Hong Sa	HVAC: 500 kV	PP: La->Th	2015	1473
	• Udon Thani 3 - Na Bong - Nam Ngiep 1	HVAC: 500 kV	PP: La->Th	2019	269
	• Ubon Ratchathani 3 - Pakse - Xe Pien Xe Namnoi	HVAC: 500 kV	PP: La->Th	2018	390
	• Khon Kaen 4 - Loei 2 - Xayaburi	HVAC: 500 kV	PP: La->Th	2019	1220
	•				
	Future				
	• Nong Khai – Khoksa-at (Selected by AIMS-II)				
	• Nakhon Phanom – Thakhek (Selected by AIMS-II)	HVAC: 230 kV	EE	2015	600
	• Thoeng – Bo Keo (Selected by AIMS-II)				
	• Udon Thani 3 - Na Bong - Future project	HVAC: 500 kV	PP: La->Th	2018	510
	• Ubon Ratchathani 3 - Pakse - Future project	HVAC: 500 kV	PP: La->Th	2019	315
	• Nan 2 - Tha Wang Pha - Nam Ou	HVAC: 500 kV	PP: La->Th	2023	1040
	•				

EE = substation, HVAC = high-voltage alternating current, kV = kilovolt, La = Lao PDR, MW = megawatt, PP = power plant, SCOD = schedule commercial operation date.
Source: Development of Cross-Border Trade Between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

As shown in Table 2-2, all interconnection lines will be from Laotian hydropower plants to Thailand, except the cross-border interconnections selected by the ASEAN Interconnection Master Plan Study (AIMS)-II listed under future connections. Given that the AIMS-II lines are scheduled with commercial operation date in 2015, it seems the plan is likely to be not progressing.

While not listed in Table 2-2, it appears that there are some cross-border interconnections between substations at 115 kV, as shown in Figure 2-3. An example is the 115-kV interconnection between Pak Bo (Thailand) and Mukdahan2 (Lao PDR).

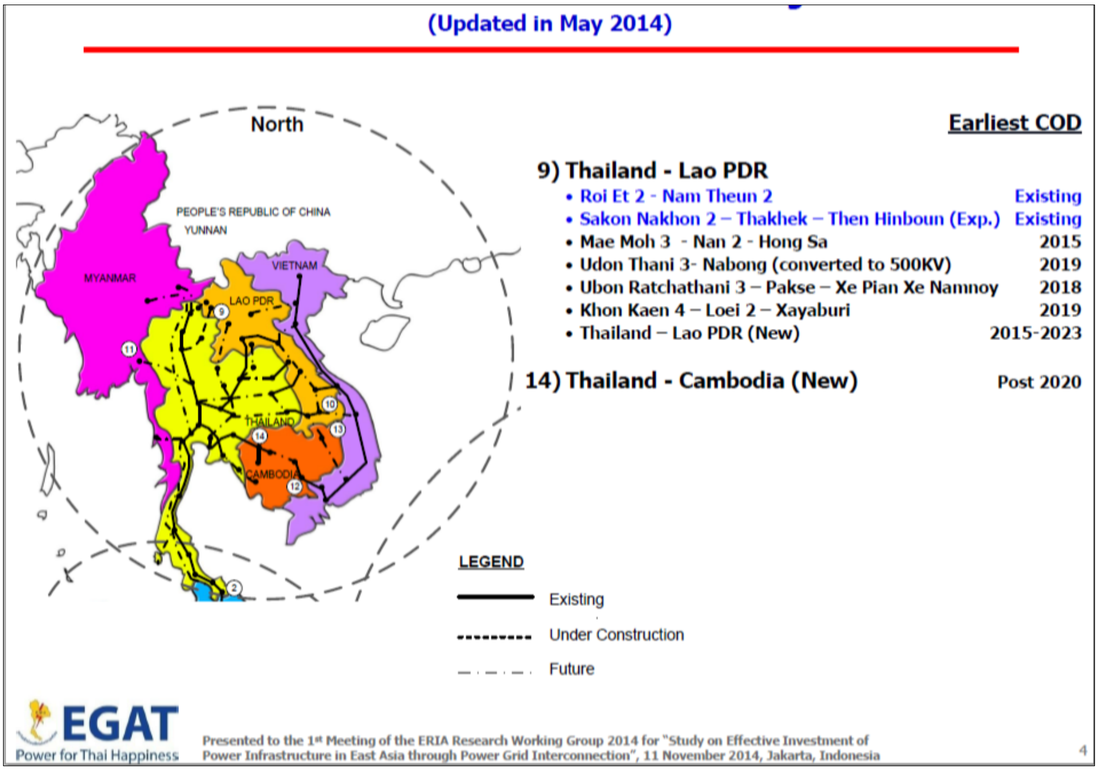
Figure 2-4. Interconnections Between Thailand and Lao PDR (115 kV)



Source: Electricity Generating Authority of Thailand (accessed 23 March 2015).

Figure 2-5 was presented by the Electricity Generating Authority of Thailand (EGAT) in the first working group meeting on 11 November 2014.

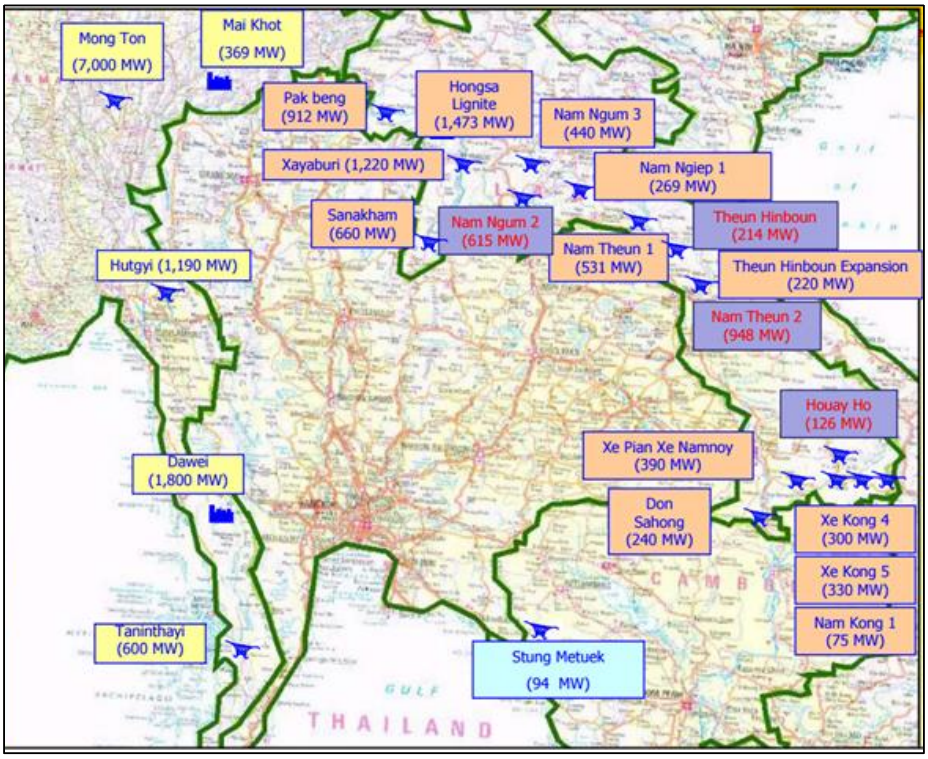
Figure 2-5. ASEAN Interconnection Projects (Thailand–Lao PDR)



COD = commercial operation date
Source: FY2014 1st EIPI presentation material by the Electricity Generating Authority of Thailand.

Figure 2-6 shows potential power plants exporting to Thailand from its neighbouring countries. It is easy to understand the locations of the potential projects in Lao PDR.

Figure 2-6. Potential Power Projects in Thailand's Neighbouring Countries



Source: Electricity Generating Authority of Thailand, (Accessed 23 March 2015).

1.2.3. Thailand–Malaysia

Table 2-3. Cross-border Interconnection (Thailand–Malaysia)

No.	Project	System	Type	SCOD	MW
2	**Thailand - P.Malaysia**				
	Existing				
	• Sadao - Chuping	HVAC: 132/115 kV	EE	1980	80
	• Khlong Ngae - Gurun	HVDC: 300 kV	EE	2002	300
	Ongoing				
	• Su - ngai Kolok - Rantau Panjang	HVAC: 132/115 kV	EE	2015	100
	•				
	Future				
	• Khlong Ngae - Gurun (Addition)	HVDC: 300 kV	EE	2016	300
	•				

EE = substation, HVAC = high-voltage alternating current, HVDC = high-voltage direct current, MW = megawatt, MYS = Malaysia, SCOD = schedule commercial operation date, THA = Thailand.
Source: Development of Cross-Border Trade Between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

All THA–MYS cross-border interconnections are between substations, with both high-voltage alternating current (HVAC) and high-voltage direct current (HVDC) systems. Also, an increase in HVDC capacity is planned for 2016.

1.2.4. Malaysia–Singapore

Table 2-4. Cross-border Interconnection (Malaysia–Singapore)

No.	Project	System	Type	SCOD	MW
1	**P.Malaysia - Singapore**				
	Existing				
	• Plentong - Woodlands	HVAC: kV	EE	1985	450
	•				
	Ongoing				
	• -	-	-	-	-
	•				
	Future				
	• Selected by AIMS-II	HVDC: kV	PP: PM->Sg	2018	600
	•				

EE = substation, HVAC = high-voltage alternating current, HVDC = high-voltage direct current, kV = kilovolt, MW = megawatt, MYS = Malaysia, PM = Peninsula Malaysia, PP = power plant, SCOD = schedule commercial operation date, Sg = Singapore, SGP = Singapore.
Source: Development of Cross-Border Trade between Thailand and Neighbouring Countries/Electricity Generating Authority of Thailand (accessed 3 March 2015).

There is an HVAC MYS–SGP cross-border interconnection between substations. HVDC lines are also planned to carry power to Singapore from a thermal power plant in the Malaysian peninsula.

1.3. Capacity of Cross-border Interconnection Facilities

From the grid interconnection materials of each country discussed, the interconnection capacity in each country can be summarised as follows:

Table 2-5. Existing and Future Plan of Interconnection Capacity

Unit: GW	VNM–LAO	LAO–THA	THA–MYS	MYS–SGP
Existing	0.2	2.1	0.4	0.5
Ongoing	2.4	3.4	0.1	0.0
Future	0.0	2.5	0.3	0.6
Total	**2.6**	**7.9**	**0.8**	**1.1**

GW = gigawatt, LAO = Lao PDR, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

In 2014 study, the totals (in gigawatt [GW]) in Table 2-5 were set as upper limits for interconnection capacity in Case 2b, which is described later.

1.4. Annual Power Trade Flows for Interconnection Lines

The estimated power trade flows in 2035 are shown in Table 2-6. A detail of these case settings (please refer to Table 1-1) and calculated numbers are described in ERIA's 2014's 'Study on Effective Investment of Power Infrastructure in East Asia Through Grid Interconnection'.

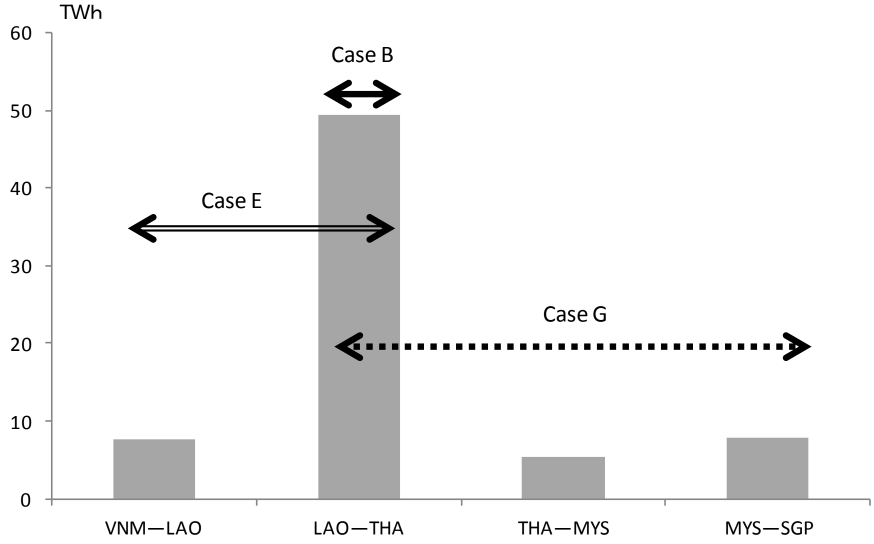
Table 2-6. Power Trade Flows in 2035

Unit: TWh	VNM-LAO	LAO-THA	THA-MYS	MYS-SGP
Case 2b	7.6	49.4	5.4	7.8
Case 3	0	54.7	136.6	35.8

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, TWh = tera watt hour, VNM = Viet Nam.
Herein with Case 2b and Case 3 are defined as follows:
Case 2b: Additional grid connections available, but additional hydro-potential for export purposes only.
Case 3: Same as Case 2b, with no upper limit for international grid connection capacity.
Source: Prepared by the working group.

Case 3 eliminates the upper limits on interconnection capacity in Case 2b, resulting in unrealistically large amounts of power trade flow. (For example, the 136.6 tera watt hour (TWh) between Thailand and Malaysia is equivalent to 36.7 percent of Malaysia's estimated 372 TWh power consumption in 2035, and the 35.8 TWh between Malaysia and Singapore is equivalent to 54.2 percent of Singapore's estimated 66 TWh power consumption in 2035. As such, 2014 study took Case 2b as a possible future scenario and estimated its economic benefits. Figure 2-7 depicts power trade flow for Case 2b.

Figure 2-7. Power Trade Flows in 2035 (Case 2b)



LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

Figure 2-7 shows that the LAO-THA power trade flow is much greater than that between other countries, making it the main component that can provide economic benefits.

1.5. Necessity for Increase in Interconnections

An estimated interconnection line and relevant facilities' capacity required to transmit electricity are shown in Table 2-7. The minimum capacity requirement is calculated at the premise that a constant amount of electricity is flowing 24 hours a day. It should be noted that actual electricity flow varies greatly between wet and dry seasons and between night-time and daytime. As such, the capacity for interconnection facilities will need to be larger than the estimated minimum capacity requirement.

The formula used for calculations is: Traded volume [TWh] * 1,000 / 24 / 365 = GW.

Table 2-7. Minimum Interconnection Capacity Requirement in 2035

Unit: GW	VNM–LAO	LAO–THA	THA–MYS	MYS–SGP
Case 2b	0.9	5.6	0.6	0.9
Case 3	0	6.2	15.6	4.1

GW = gigawatt, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

By comparing Tables 2-5 and 2-7, we can understand an investment gap for interconnection lines.

1.5.1. Viet Nam–Lao PDR

Table 2-8. Investment Gap of Interconnection Capacity (Viet Nam–Lao PDR)

VNM—LAO			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	0,2 0,9	2,6 0,9	2,6 0,9
Case 3	0,2 0	2,6 0	2,6 0

GW = gigawatt, LAO = Lao People's Democratic Republic, VNM = Viet Nam.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

In Case 2b, the minimum capacity requirement is 0.9 GW, while the planned interconnection capacity will reach 2.6 GW. Planned capacity addition seems sufficient as it is three times the minimum capacity. This shows that no additional new interconnection lines will be required if all future connection lines progress smoothly as planned. However, with the status of the plans for the Luang Prabang-Nho Quan line unclear as mentioned, it is uncertain whether any new interconnection lines will be required.

Meanwhile, minimum capacity requirement for Case 3 is 0 GW. No increase in interconnection would be required whatsoever. Following construction, cross-border interconnections would be for emergency use.

The reason for the relatively small trade flow of VNM–LAO is that a large amount of it will come from South China and Cambodia into Viet Nam.

1.5.2. Lao PDR–Thailand

Table 2-9. Investment Gap of Interconnection Capacity (Lao PDR–Thailand)

LAO—THA			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	2,1 5,6	5,5 5,6	7,9 5,6
Case 3	2,1 6,2	5,5 6,2	7,9 6,2

GW = gigawatt, LAO = Lao People's Democratic Republic, THA = Thailand.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

In Case 2b, the minimum capacity requirement is 5.6 GW, while the planned interconnection (including ongoing and future) capacity will reach 7.9 GW. It means that if future projects are implemented as planned, the interconnection line will have sufficient capacity to transmit estimated electricity flow. The same can be said in Case 3.

The minimum capacity requirement, however, does not account for seasonal and daily variations of electricity flow. Thus, the actual interconnection capacity will need to be several times higher than the minimum capacity requirement, necessitating additional new interconnection lines in this route.

1.5.3. Thailand–Malaysia

Table 2-10. Investment Gap of Interconnection Capacity (Thailand–Malaysia)

THA—MYS			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	0,4 0,6	0,5 0,6	0,8 0,6
Case 3	0,4 15,6	0,5 15,6	0,8 15,6

GW = gigawatt, MYS = Malaysia, THA = Thailand.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

The planned transmission capacity is 0.8 GW, which is almost the same as the 0.6 GW of minimum required capacity for Case 2b. A reason of this similarity in capacity is that the Case 2b simulation set a certain cap (upper limit) in the interconnection capacity. On the other hand, the result of Case 3, which is not set a cap in a calculation, shows very large requirement of capacity (15.6 GW) between the Thailand and Malaysia interconnection. These two facts indicate a large potential of electricity trade between the nations. Therefore, it is expected to increase interconnection capacity beyond existing plan as larger capacity may bring more economical benefit.

1.5.4. Malaysia–Singapore

Table 2-11. Investment Gap of Interconnection Capacity (Malaysia–Singapore)

MYS—SGP			
Unit: GW	Existing	Existing and Ongoing	Existing,Ongoing, and Future
Case 2b	0,5 0,9	0,5 0,9	1,1 0,9
Case 3	0,5 4,1	0,5 4,1	1,1 4,1

GW = gigawatt, MYS = Malaysia, SGP = Singapore.
Note: Upper right numbers in each box stand for the interconnection capacity in Table 2-5, and lower left numbers stand for calculated interconnection capacity requirement for each case.
Source: Prepared by the working group.

The planned interconnection capacity is 1.1 GW, almost the same as the 0.9 GW minimum required capacity in Case 2b. Results here show that planned capacity is not enough to transmit estimated electricity trade flow in 2035. It is the upper limit in interconnection capacity in Case 3 is removed, the estimated trade flow increases to 4.1 GW. As this route can potentially further increase electricity trade, which will also increase the economic benefits, it is recommended to expand an interconnection capacity to a level that will enable it.

1.6. Lao PDR, Thailand, Malaysia, and Singapore Power Integration Project

The Lao PDR, Thailand, Malaysia, Singapore Power Integration Project (LTMS PIP) is a joint statement of the relevant agencies of Lao PDR, Thailand, Malaysia and Singapore in September 2014. LTMS PIP is exactly the same as Case G from last year's study (see Chapter 1 for reference), a project for Lao PDR to export power to Singapore via Thailand and

Malaysia. The joint statement is shown in Figure 2-7.

As a first step, the plan will trade up to 100 MW from Lao PDR to Singapore, and some media reveal that the final target of trade flow would be about 10 percent of demand in Singapore.

Figure 2-8. Joint Statement of the Lao PDR, Thailand, Malaysia, and Singapore Power Integration Project

23 September 2014
Vientiane, Lao PDR

1. The Ministry of Energy and Mines of the Lao People's Democratic Republic, Ministry of Energy of the Kingdom of Thailand, Ministry of Energy, Green Technology and Water of Malaysia, and Ministry of Trade and Industry of the Republic of Singapore agreed today on a pilot project entitled "Lao PDR, Thailand, Malaysia, Singapore (LTMS) Power Integration Project (PIP)" to study cross border power trade from Lao PDR to Singapore.

2. Launched during Lao PDR's chairmanship of the ASEAN energy track, this pilot project will serve as a pathfinder to complement existing efforts towards realizing the ASEAN Power Grid (APG) and the ASEAN Economic Community (AEC), by creating opportunities for electricity trading beyond neighboring borders. This initiative will contribute towards energy security by strengthening the power integration network and enhancing the economic prosperity of the region. The project is also expected to help identify and resolve issues affecting cross – border electricity trading in ASEAN.

3. As a first step, the four countries will set up the LTMS PIP Working Group to study the technical viability of cross border power trade of up to 100 MW from Lao PDR to Singapore through existing interconnections. The working group is also expected to examine policy, regulatory, legal and commercial issues relating to cross border electricity trading.

4. The completion of the pilot study is envisaged to illustrate the feasibility of cross border electricity trade among all four countries of Lao PDR, Thailand, Malaysia and Singapore.

Source: Singapore Ministry of Trade and Industry News Room (accessed 3 March 2015).

2. Method of Selecting New Line Routes

2.1. Overview of Power Grids in the Five Countries

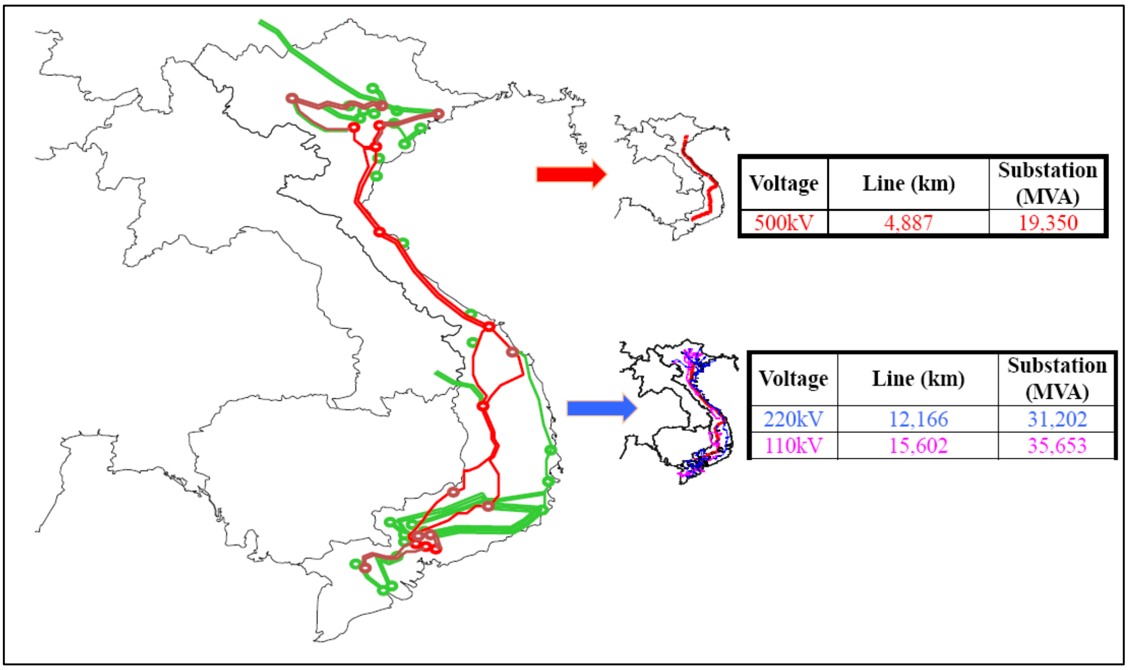
In deciding specific connection points (substations) along the interconnection routes, power transmission and demand for each country were examined.

Table 2-12. Transmission and Demand in Five Countries

	Transmission Voltage (kV)	Frequency (Hz)	Demands as of 2010 (TWh)
VNM	500/220/110	50	92.17
LAO	(500)/230/115*	50	8.45
THA	500/230/115	50	147.01
MYS	500/275/132	50	124.10
SGP	400/230	50	45.38

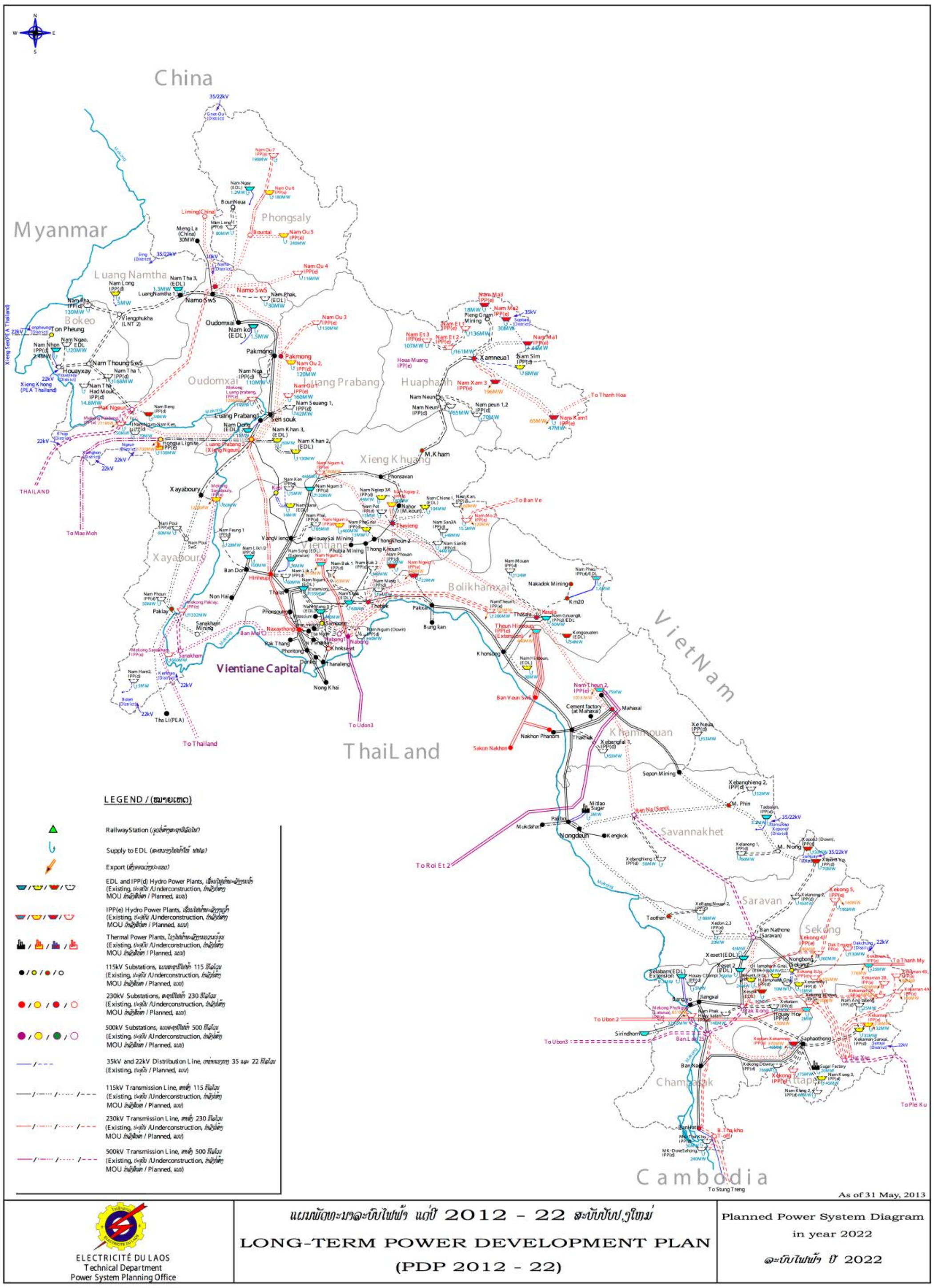
Hz = hertz, kV = kilovolt, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, TWh = tera watt hour, VNM = Viet Nam.
Note: 500 kV in Lao PDR is only for IPP grids to Thailand.
Source: Prepared by the working group.

Figure 2-9. Transmission Lines in Viet Nam



km = kilometre, kV = kilovolt, MVA = million volt ampere.
Source: Presentation material by the Electricity Viet Nam in the first meeting of ERIA on the 'Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection' in 2014.

Figure 2-10. Long-term Power Development Plan (2012–2022) in Lao PDR

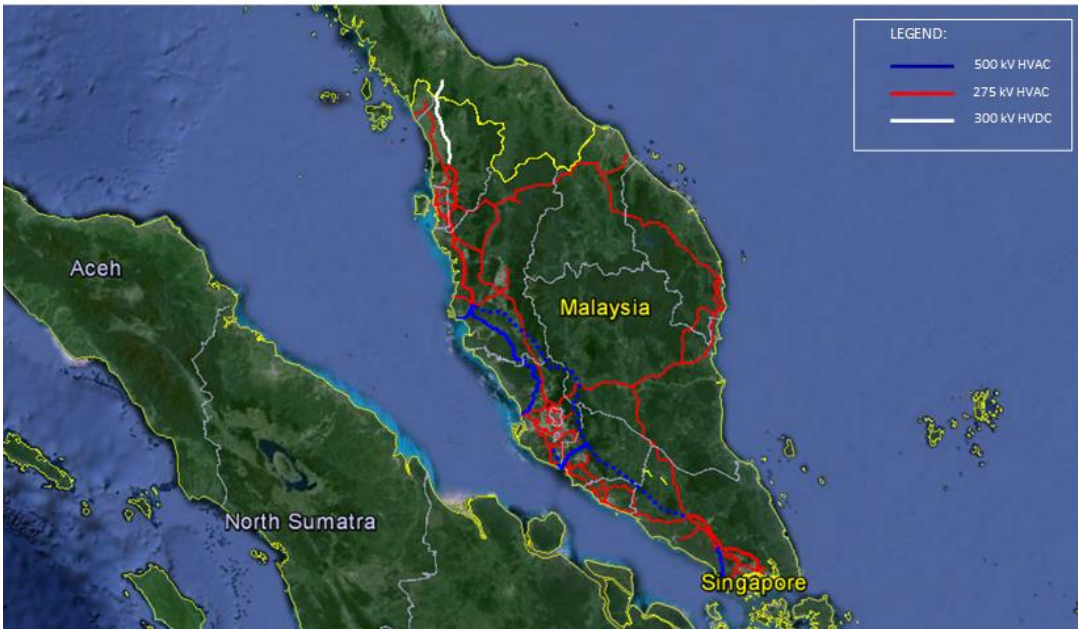


Source: Electricité du Laos (accessed 23 March 2015).

Figure 2-11. Transmission Lines in Thailand

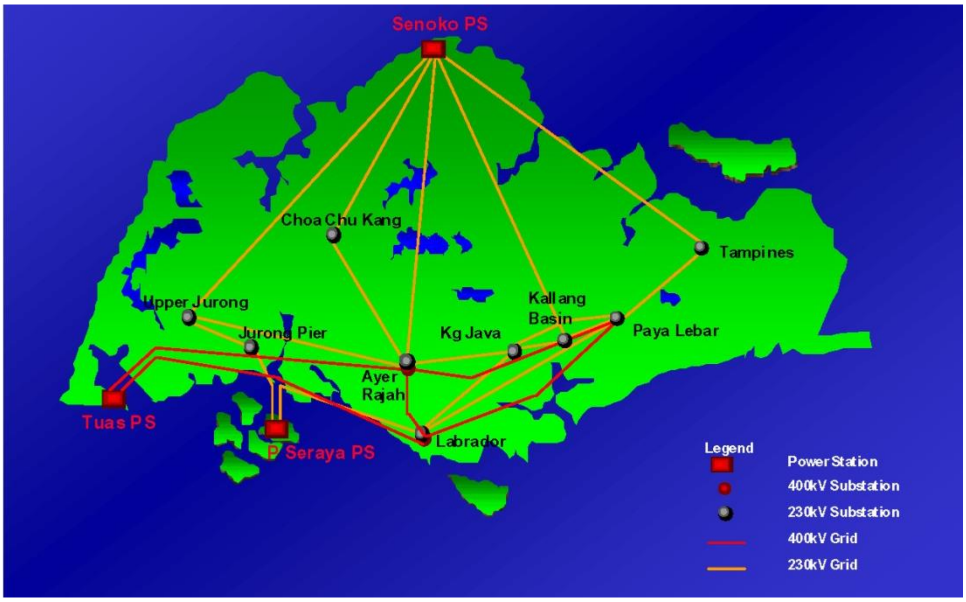
Source: Global Energy Network Institute (accessed 23 March 2015).

Figure 2-12. Transmission Lines in Malaysia



Source: Presentation material by the Tenaga Nasional Berhad in the first meeting of ERIA on the 'Study on Effective Investment of Power Infrastructure in East Asia through Power Grid Interconnection', 2014.

Figure 2-13. Transmission Lines in Singapore



Source: Global Energy Network Institute (accessed 23 March 2015).

2.2. Route Selection Method

The following guidelines were used in deciding interconnection points (substations) along specific interconnection routes:

- Select from existing substations for interconnection points.
- Select from 500-kV substations or ultra-high voltage substations.

- Avoid selecting exclusive substations for certain IPP.
- Prioritise substations not discussed in the past.
- Select shorter linear distance route.
- Avoid crossing high mountains and wide rivers in the routes.
- Avoid crossing natural reserves or national parks in the routes.
- Consider future planned line routes or substations.

The following guidelines were used in deciding specific interconnection routes:

- In general, select the shortest linear distance route.
- Account for existing plans (urban planning, transmission line plans, etc.)
- Avoid crossing cities and communities. No residences within 50 metres of right of way.
- Avoid crossing natural parks (valuable natural resources), protected forests, valuable biological habitats, landing zones for migratory birds, etc.
- Avoid passing areas near airports.
- Avoid crossing wide rivers (one kilometre or greater), if possible.
- Consider crossing points with roads, rail, and other transmission lines.
- For workability in future construction work and convenience of maintenance work, select routes near roads.
- Select flatlands and avoid mountains.
- Select routes that pass close to planned hydropower plants, if any.

3. Selected Interconnection Routes

3.1. Viet Nam–Lao PDR

Between Viet Nam and Lao PDR, the Luang Prabang 2 (Lao PDR) and Nho Quan (Viet Nam) substations are selected for the following reasons:

- Connection location near Viet Nam's high-power consumption areas, i.e. Hanoi in the north or Ho Chi Minh City in the south.
- High concentration of natural parks in Viet Nam, southern Lao PDR, and north-eastern Cambodia, thus the route connecting northern Lao PDR and Viet Nam instead.

- The route between the Luang Prabang plant (IPP) and Nho Quan substation was discussed in the past but not implemented, thus the preference for this route.

Luang Prabang 2 (Lao PDR)	Luang Prabang 2 is a 230-kV substation scheduled for construction on the Mekong River in northern Lao PDR. It will be a large substation, collecting power from multiple hydropower plants in Nam Ou. Power is transmitted to the capital in Vientiane via Luang Prabang 2.
Nho Quan (Viet Nam)	Nho Quan is an existing 500-kV substation located about 100 km south of Hanoi.

The following guidelines were used in selecting the route: avoid national parks and mountains 1,500 m or higher in elevation.

3.2. Thailand–Lao PDR

Between Thailand and Lao PDR, the Luang Prabang 2 (Lao PDR) and Nan (Thailand) substations are selected for the following reasons:

- The Thailand side uses 500-kV transmission lines.
- There are three existing 500-kV circuits, and four planned circuits from Lampang in northern Thailand to Bangkok.
- The expansion of existing 500-kV lines will be minimal once the interconnection between northern Thailand and Lao PDR is realised.
- The Thailand substation is close to the Laotian border, with 500-kV transmission lines running from northern Thailand to Bangkok.
- On the Lao PDR side is a 230-kV substation near the Thai border.
- The route has the shortest linear distance between the Thai substation and the Laotian substation.

Nan (Thailand)	Nan is a new 500-kV substation located on transmission lines roughly halfway between the Hong Sa lignite thermal power station (IPP), currently under construction in Lao PDR, and the Lampang substation in Thailand.
Luang Prabang 2 (Lao PDR)	Refer to 3.1

The following guidelines were used in selecting the route:

- Avoid close national parks.
- Avoid close mountains 1,500 m or higher in elevation.
- Pass close to the planned Pakbeng hydropower plant.

3.3. Thailand–Malaysia

Currently, there is a 300-kV, 300-MW HVDC system between Thailand and Malaysia scheduled for expansion to a total of 600 MW in 2016. Thus, instead of exploring a new route, this line expansion is considered as the Thailand–Malaysia interconnection line.

The Thailand–Malaysia HVDC interconnection project establishes a new efficient interconnection between Khlong Ngae converter station in southern Thailand and Gurun converter station in northern Malaysia. Both converter stations are linked by a 300 kV DC overhead line of 110 km (approximately 24 km on the Thai side and 86 km on the Malaysian side). Initially, the converter stations were configured as a monopolar converter with a power transfer capacity of 300 MW. Provision has also been made for adding a second 300 MW pole to extend the system into a bipolar configuration with a total transfer capability of 600 MW.

Project implementation started in August 1997. A joint implementation committee was set up by EGAT and Tenaga Nasional Berhad (TNB) to oversee and ensure the consistent project implementation by both utility companies. Each utility is responsible for the HVDC station and the DC transmission line in each country. On Thailand's side, the project involves the construction of a new DC transmission system and the reinforcement of the existing high-voltage AC transmission system.

Figure 2-14. Map of Thailand–Malaysia HVDC

HVDC = high-voltage direct current.
Source: Electricity Generating Authority of Thailand (accessed 3 March 2015).

Table 2-13. Specifications of Thailand–Malaysia HVDC

Smoothing reactor	100 mh,single core
Converter transformers	3 x 116 MVA, 1 phase – 3 winding 230/122.24/122.24 kv
Thyristor valves	T 1501 N75T-S34 12 group valves indoor air insulation suspension type No. of thyristor per valve : 48 Blocking voltage : 8 kv /1550 A
DC hybrid filters	Passive part filter (12/24 harmonics) Active part filter (6/15/21/24/27/33/36/42/48 harmonics)
Transmission line	DC, 110 km (24 km on Thailand's border and 86 km on Malaysia's boder) Pole conductor : 546 mm^2 (ASCR Cardinal) Neutral conductor :298 mm^2 (ASCR Hen)
Main contractor	Siemens AG ,Germany
Consultant	Teshmont Consultants Inc..,Canada

ASCR = aluminum conductor steel reinforced, DC = direct current, HVDC = high-voltage direct current, km = kilometre, kv = kilo volt, mh = milli henry, MVA = mega volt ampere
Source: Electricity Generating Authority of Thailand (accessed 3 March 2015).

3.4. Malaysia–Singapore

Currently, there is a 450-MW HVAC system between Malaysia and Singapore . Additionally, a 600 MW HVDC line is planned to connect from a thermal power plant on the Malaysian side. Thus, instead of exploring for a new route, this planned HVDC line is considered the Malaysia–Singapore interconnection line.

The TNB and the Singapore Power are interconnected from Plentong in the southern Malaysian Peninsula to the Senoko Power Station in Singapore via 2x250 MVA, 275 (TNB side)/230 (SP side) kV of AC overhead line (12 km) and submarine cables (4 km). The project was commissioned in 1985 to provide a source of power supply during extreme system emergencies for both interconnected power systems.

3.5. Thailand–Singapore (Direct Connection Line)

As part of the Lao PDR, Thailand, Malaysia, and Singapore power integration project, TNB proposed a transmission route across Malaysia, whose feasibility appears to be low due to high costs, although estimates have been made in this study for both HVAC and HVDC proposals. The dashed line in Figure 2-15 represents the proposed transmission line across Malaysia.

Figure 2-15. Thailand–Singapore Route through Malaysia

HVAC = high-voltage alternating current, HVDC = high-voltage direct current, kV = kilovolt.
Source: Tenaga Nasional Berhad.

4. Transmission Line Construction Costs

Conditions for cost estimation and calculated result are listed below:

Table 2-14. Conditions for Cost Estimation

No.	Items	Cost (Million US$)	Unit
1	**AC Transmission Lines 500 kV**		
	＊Capacity;:Maximum 1.8 GW/circuit		
	Overhead Transmission Lines	0.45	/km/circuit
	Submarine Cable Transmission Lines	5	/km/circuit
2	**DC Transmission Lines ±300 kV**		
	＊Capacity: Maximum 3.0 GW/circuit		
	Overhead Transmission Lines	0.3	/km/circuit
3	**Substations (every 160 km-line)**		
	Land, Civic, Buildings, Common Facilities	20	/location
	Equipment	10	/circuit
	Existing extensions	10	/circuit
4	**AC-DC Converters**	150	/GW/location

AC-DC = alternating current-direct current, GW = gigawatt, km = kilometre, kV = kilovolt.
Source: Prepared by the working group.

4.1. Viet Nam–Lao PDR

[Assumption]

- Type: HVAC 500 kV Overhead
- Number of circuits: Two (one circuit + one backup circuit)
- Number of routes: 0.9 GW/1.8 GW = 0.5, rounded up to one route
  *0.9 GW is minimum requirement capacity between Viet Nam and Lao PDR.
  *1.8 GW is typical AC circuit capacity.
- Transmission distance: 420 km
- Number of new substations: Two

[Cost]

Total: US$498 million

- Transmission: US$0.45M /km × 420 km × 2 circuits = US$378M
- Number of new substation: (US$20M + US$10M × 2 circuits) × 2 locations = US$80M
- Existing substation extension: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$378M + US$80M + US$40M) × 1 route = US$498M

4.2 Thailand–Lao PDR

[Assumption]

- Type: HVAC 500 kV Overhead
- Number of circuits: Two (one circuit + one backup circuit)
- Number of routes: 5.6 GW/1.8 GW = 3.11, rounded up to four routes

*5.6 GW is minimum requirement capacity between Thailand and Lao PDR.
*1.8 GW is typical AC circuit capacity.

- Transmission distance: 270 km
- Number of new substations: One

[Cost]

Total: US$1,292 million

- Transmission: US$0.45M /km × 270 km × 2 circuits = US$243M
- New substation: (US$20M + US$10M × 2 circuits) × 1 location = US$40M
- Existing substation extension: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$243M + US$40M + US$40M) × 4 routes = US$1,292M

4.3 Thailand–Malaysia

[Assumption]

- Type: HVDC ±300 kV Overhead
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.6 GW/3.0 GW = 0.2, rounded up to 1 route
  *0.6 GW is minimum requirement capacity between Thailand and Malaysia.
  *3.0 GW is typical DC circuit capacity.
- Transmission distance:110 km
- Number of AC-DC converters: Two
- Capacity of AC-DC converter: 0.6GW

[Cost]

Total: US$286 million

- Transmission: US$0.3M / km × 110 km × 2 circuits = US$66M
- AC-DC converter: US$150M/GW × 0.6 GW × 2 locations = US$180M
- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$66M +US$180M + US$40M) × 1 route = US$286M

4.4 Malaysia–Singapore

[Assumption]

- Type: HVAC 500 kV Overhead＋Submarine cable
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.9 GW/1.8 GW = 0.5, rounded up to 1 route
  *0.9 GW is minimum requirement capacity between Malaysia and Singapore.
  *1.8GW is typical AC circuit capacity.
- Transmission distance — Overhead: 12 km, Submarine cable: 4 km
- Number of new substations: zero

[Cost]

Total: US$91 million

- Transmission: US$0.45M/km × 12 km × 2 circuits + US$5M /km × 4 km × 2 circuits =

US$50.8M

- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (5US$0.8M + US$40M) × 1 route = US$90.8M

4.5 Thailand–Singapore

4.5.1 HVAC System

[Assumption]

- Type: HVAC 500 kV Overhead
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.9 GW/1.8 GW = 0.5, rounded up to 1 route
  *Grounds for capacity of 0.9 GW: As direct link between Thailand and Singapore is regarded as a dedicated line to meet import requirement of Singapore, necessary line capacity may be equivalent to that of export capacity from Malaysia to Singapore.
  *1.8 GW is typical AC circuit capacity.
- Transmission distance: 800 km
- Number of new substations: Five

[Cost]

Total: US$960 million

- Transmission: US$0.45M / km × 800 km × 2 circuits = US$720M
- Number of new substations: (US$20M + US$10M × 2 circuits) × 5 locations = US$200M
- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$720M + US$200M + US$40M) × 1 route = US$960M

4.5.2 HVDC System

[Assumption]

- Type: HVDC ±300 kV Overhead
- Number of circuits: Two (1 circuit + 1 backup circuit)
- Number of routes: 0.9 GW/3.0 GW = 0.3, rounded up to 1 route
  *Grounds for capacity of 0.9 GW: As direct link between Thailand and Singapore is regarded as a dedicated line to meet the import requirements of Singapore, necessary line capacity may be equivalent to that of export capacity from Malaysia to Singapore.
  *3.0 GW is typical DC circuit capacity.
- Transmission distance: 800 km
- Number of AC-DC converters: Two
- Capacity of AC-DC converter: 0.9 GW

[Cost]

Total: US$790 million

- Transmission: US$0.3M/km × 800 km × 2 circuits = US$480M
- AC-DC converter: US$150M /GW × 0.9 GW × 2 locations = US$270M
- Existing substation expansion: US$10M × 2 circuits × 2 locations = US$40M
- Total: (US$480M + US$270M + US$40M) × 1 route = US$790M

5. Land Acquisition Costs and Easement for Power Transmission

Because of the great difference in laws and costs, it is difficult to assume the accurate costs of land acquisition for transmission lines in each country covered in this study. Therefore, the following assumptions were made to come up with estimates. Note that estimates may vary greatly from actual costs.

- Interval of transmission tower: 400 m
- Foundation area of transmission towers: 200 m^2 (to be purchased)
- Right of way: 30 m (portion for easement to be acquired)
- Land acquisition costs: US$20/$m^2$ in rural areas; US$60/$m^2$ in urban areas
- Ratio of easement acquisitions: 10 percent usage rights in rural areas, 30 percent in urban areas

5.1. Viet Nam–Lao PDR

Of the total 420 km interconnection lines, 378 km (90 percent) are estimated to be in rural areas and 42 km (10 percent) in urban areas. Estimate results are shown in Table 2-15.

Table 2-15: Land Acquisition and Easement (Viet Nam–Lao PDR)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	378	42	420
Number of transmission towers	-	945	105	1050
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	3,780,000	1,260,000	5,040,000
Easement (under power lines)	US$	21,886,200	21,886,200	43,772,400
Total land acquisition cost (US$)				**48,812,400**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$49 million.

5.2. Thailand–Lao PDR

Of the total 270 km transmission interconnection lines, about 243 km (90 percent) are in rural areas and 27 km (10 percent) in urban areas. Estimates are shown in Table 2-16.

Table 2-16. Land Acquisition and Easement (Lao PDR–Thailand)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	243	27	270
Number of transmission towers	-	608	68	676
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	2,432,000	816,000	3,248,000
Easement (under power lines)	US$	14,069,280	14,065,920	28,135,200
Total land acquisition cost (US$)				**31,383,200**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$31 million for one route. As this location consists of four routes, grand total cost will be US$124 million.

5.3. Thailand–Malaysia

Of the total 110 km transmission interconnection lines, about 99 km (90 percent) are in rural areas and 11 km (10 percent) in urban areas. Estimates are shown in Table 2-17.

Table 2-17: Land Acquisition and Easement (Thailand–Malaysia)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	99	11	110
Number of transmission towers	-	248	28	276
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	992,000	336,000	1,328,000
Easement (under power lines)	US$	5,731,680	5,728,320	11,460,000
Total land acquisition cost (US$)				**12,788,000**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$13 million.

5.4. Malaysia–Singapore

It is assumed that no land acquisition and easements will be necessary for submarine portions of the transmission interconnection lines. All 12 km of the interconnection on land is estimated as urban line. Estimate results are shown in Table 2-18.

Table 2-18: Land Acquisition and Easement (Malaysia–Singapore)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km		12	12
Number of transmission towers	-	0	30	30
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	0	360,000	360,000
Easement (under power lines)	US$	0	6,253,200	6,253,200
Total land acquisition cost (US$)				**6,613,200**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$ 124 million.

5.5. Thailand–Singapore

Of the total 800 km transmission interconnection lines, about 720 km (90 percent) are estimated to be in rural areas and 80 km (10 percent) in urban areas. Estimates are shown in Table 2-19.

Table 2-19. Land Acquisition and Easement (Thailand–Singapore)

Item	Unit	Rural Areas	Urban Areas	Total
Distance	km	720	80	800
Number of transmission towers	-	1800	200	2000
Land price	US$/m2	20	60	
Ratio of easement	%	10	30	
Land acquisition (transmission basement)	US$	7,200,000	2,400,000	9,600,000
Easement (under power lines)	US$	41,688,000	41,688,000	83,376,000
Total land acquisition cost (US$)				**92,976,000**

Source: Prepared by the working group.

Total land acquisition and easement costs are estimated at US$ 93 million.

6. Total Transmission Line Costs

6.1. Total Cross-border Transmission Line Costs

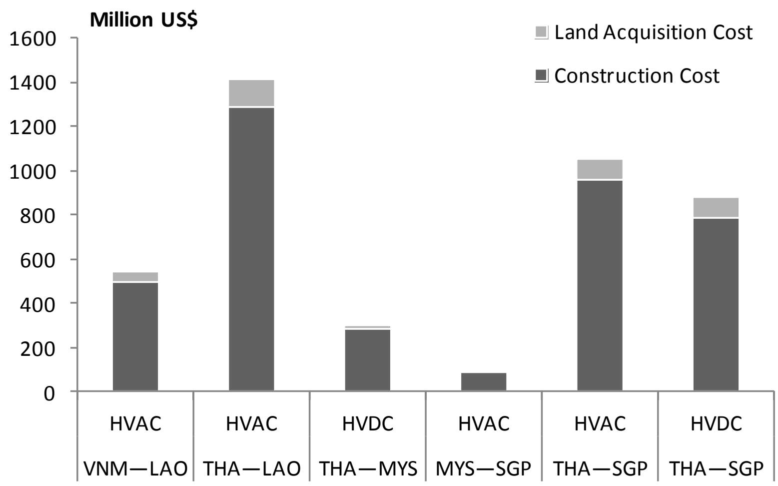
The costs of construction and land acquisition for each route are summarised in Table 2-20. With regard to direct connection between Thailand and Singapore, calculated results show that both HVAC and HVDC options are costly than an extension of existing interconnections in THA–MYS and MYS–SGP. Therefore, we are not going to discuss these expensive options.

Table 2-20. Costs of Interconnection and Land Acquisition

Interconnection Location	Type	Construction Cost	Land Acquisition Cost	Total Cost
VNM–LAO	HVAC	498	49	547
THA–LAO	HVAC	1,292	124	1,416
THA–MYS	HVDC	286	13	299
MYS–SGP	HVAC	91	7	98
THA–SGP	HVAC	960	93	1,053
	HVDC	790	93	883

HVAC = high-voltage alternating current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: US$ million.
Source: Prepared by the working group.

Figure 2-16. Line Construction and Land Acquisition Costs



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

6.2. Total Transmission Line Costs, by Case

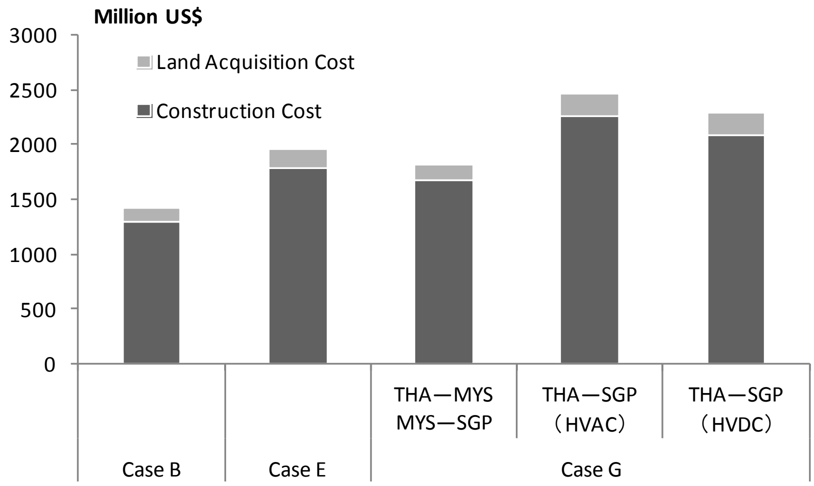
Table 2-21 summarises cost estimation for cases B, E, and G.

Table 2-21. Line Construction and Land Acquisition Costs, by Case

Case	Interconnection	Type	Construction Cost	Land Acquisition Cost	Total Cost
B	THA–LAO	—	1,292	124	1,416
E	VNM–LAO–THA	—	1,790	173	1,963
G	LAO–THA–MYS–SGP	THA–MYS MYS–SGP	1,669	144	1,813
		THA–SGP (HVAC)	2,252	217	2,469
		THA–SGP (HVDC)	2,082	217	2,299

HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: Million US$.
Source: Prepared by the working group.

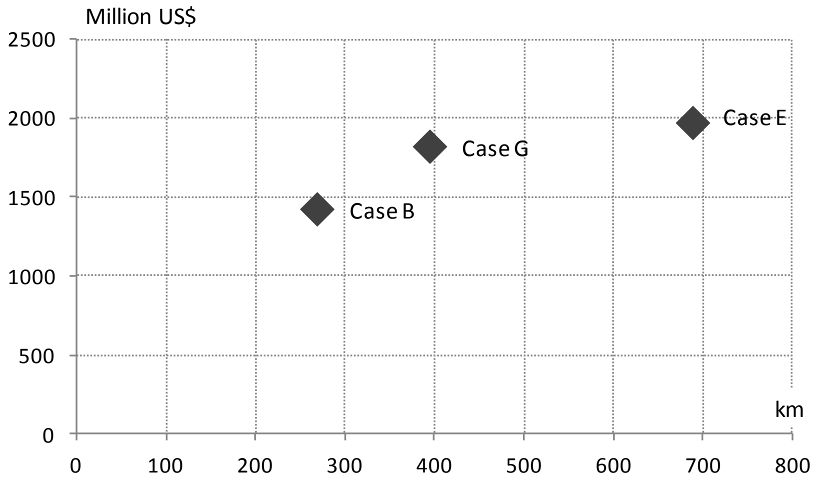
Figure 2-17. Interconnection Construction and Land Acquisition Costs, by Case



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, MYS = Malaysia, SGP = Singapore, THA = Thailand.
Source: Prepared by the working group.

Figure 2-18 describes a relationship between line distances and construction costs for each case.

Figure 2-18. Distances and Construction Costs, by Case



km = kilometre.
Source: Prepared by the working group.

From Figure 2-18, we can conclude the following:

- For Case E, the VNM–LAO–THA route has the longest distance (700 km) and the highest construction costs.
- As Case G spans Lao PDR, Thailand, Malaysia, and Singapore, the total distance seems to be the longest. However, as discussed before, direct connection between Thailand and Singapore is quite expensive; thus, extending the existing AC line is cheaper and realistic. Therefore, the combined distance will be roughly equivalent to the VNM–LAO segment at approximately 400 km.
- Case G is costly despite its distance as it uses HVDC lines for the THA–MYS section, and a submarine HVAC cable for MYS–SGP.

7. Transmission Line Construction Costs per Kilowatt-hour

7.1. Power Trade Flow and Equations

The transmission line construction cost per kWh, *CkWh,* excluding line maintenance costs and management fees, is calculated with the simple expression.

$$C_{kWh} = C_{US\$} / T \; / W_{2035}$$

Where,

C_{kWh} : Transmission line construction costs per kWh (US¢/kWh)

$C_{US\$}$: Transmission line construction costs for each route (Million US$)

T : Service life of new interconnection lines (years), assumed at 30 years

W_{2035} : Average annual power trade flow in 2035 of all cross-border interconnection lines (TWh)

7.2. Calculation

By using above-mentioned equation, we calculated cost per unit electricity flow for each cross-border line, and then summed up each unit cost by case.

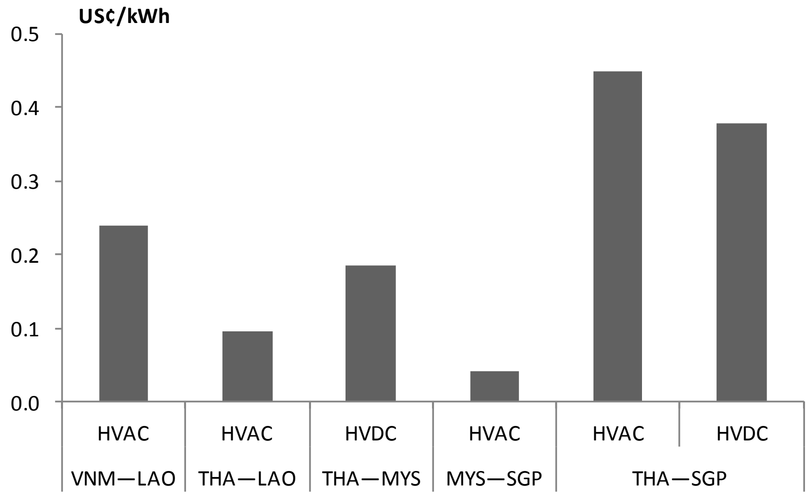
In terms of initial investment cost, the VNM-LAO route seems lower in feasibility due to its overall transmission line cost per kWh of over US¢ 0.2.

Table 2-22. Transmission Line Costs per Kilowatt-hour, by Route

Interconnection Location	Type	Total Flow (TWh)	Total Cost (Million US$)	Total Cost per kWh
VNM–LAO	HVAC	7.6	547	0.240
THA–LAO	HVAC	49.4	1,416	0.096
THA–MYS	HVDC	5.4	299	0.185
MYS–SGP	HVAC	7.8	98	0.042
THA–SGP	HVAC	7.8	1,053	0.450
	HVDC	7.8	883	0.377

kWh = kilowatt-hour, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, TWh = tera watt hour, VNM = Viet Nam.
Unit: US¢/kWh.
Grounds for total flow of THA–SGP (7.8 TWh): As direct link between Thailand and Singapore is regarded as a dedicated line to meet the import requirement of Singapore, necessary line capacity may be equivalent to that of export capacity from Malaysia to Singapore.
Source: Prepared by the working group.

Figure 2-19. Transmission Line Costs per Kilowatt-hour, by Route



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

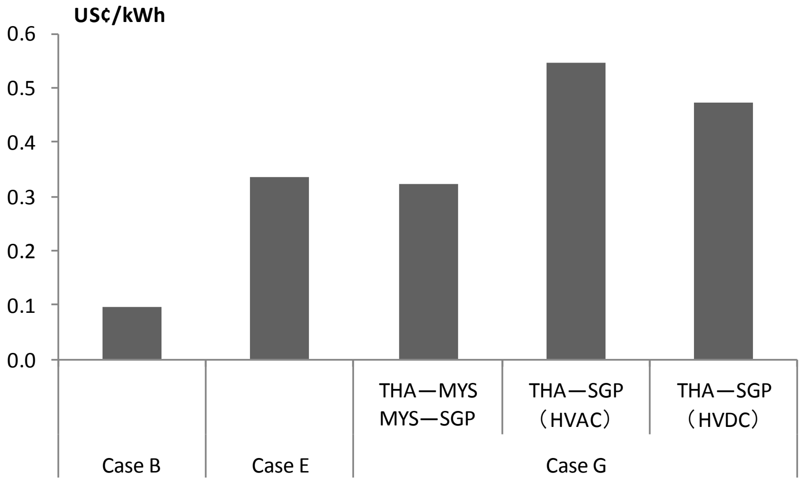
Feasibility is lower for Cases E and G, due to the high overall transmission line cost per kWh in terms of initial investment cost. If the project can strictly control and keep construction costs low, Case B is the lowest in necessary capital.

Table 2-23. Transmission Line Costs per Kilowatt-hour, by Case

Case	Interconnection	Type	Total Cost (Million US$)	Total Cost per kWh
B	THA–LAO	—	1,416	0.096
E	VNM–LAO–THA	—	1,963	0.335
G	LAO–THA–MYS–SGP	THA–MYS MYS–SGP	1,813	0.322
		THA–SGP (HVAC)	2,469	0.546
		THA–SGP (HVDC)	2,299	0.473

HVAC = high-voltage alternating current, HVDC = high-voltage direct current, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: US¢/kWh
Source: Prepared by the working group.

Figure 2-20. Transmission Line Costs per Kilowatt-hour, by Case



HVAC = high-voltage alternating current, HVDC = high-voltage direct current, kWh = kilowatt-hour, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

8. Costs and Benefits of Interconnections

This section compares costs and benefits of each interconnection case.

8.1. Cost and Benefit Comparison from 2025 to 2035

The cost of the new interconnection lines was estimated in the following manner. This methodology is the same as that taken in the 2014 study.

- The transmission lines will be constructed in 2025, with the full cost added that year.
- The operation and maintenance (O&M) cost (0.3 percent of the construction cost) is added annually starting the following year, 2026.
- With a discount rate of 10 percent, the net present value in 2025 is calculated.

With regard to the benefit of having a new line, reduction of fuel cost and power plant investment cost, the study used the same number which was estimated in a 2014 study.

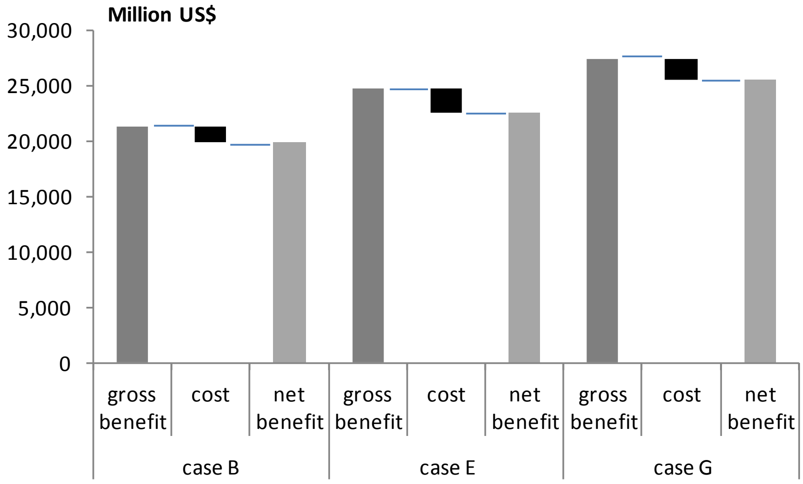
Table 2-24 shows the results of the above-mentioned calculations. The results indicate that net benefits seem high enough compared to line addition costs (capital expenditure + operating expenditure).

Table 2-24. Costs and Benefits of Interconnection Lines (2025–2035)

Case		Gross Benefit	Cost	Net Benefit
B	THA–LAO	21,387	(1,506)	**19,881**
E	VNM–LAO–THA	24,707	(2,097)	**22,610**
G	LAOTHAMYSSGP	27,490	(2,000)	**25,490**

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: Million US$.
* Plus value in the table means gain in benefit.
Source: Prepared by the working group.

Figure 2-21. Costs and Benefits of Interconnection Lines (2025–2035)



Source: Prepared by the working group.

8.2. Unit Cost and Benefit Comparison from 2025 to 2035

The trade flow from 2025 to 2035 under Case 2b is shown in Table 2-25.

Table 2-25. Trade Flow from 2025 to 2035, by Route

Route	Trade flow from 2025 to 2035
VNM–LAO	105
LAO–THA	567
THA–MYS	52
MYS–SGP	91

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: TWh
Source: Prepared by the working group.

Table 2-26. Trade Flow from 2025 to 2035, by Case

Case		Trade flow from 2025 to 2035
B	THA–LAO	567
E	VNM–LAO–THA	672
G	LAO–THA–MYS–SGP	709

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: TWh
Source: Prepared by the working group.

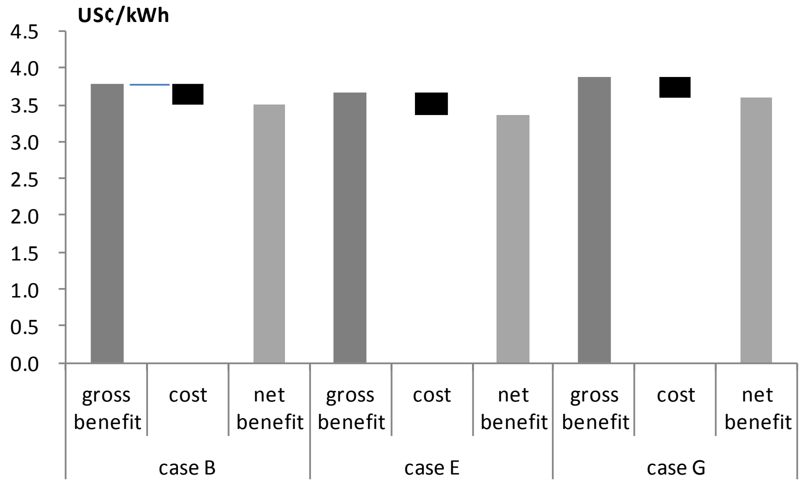
The cumulative benefit of transmissions per kilowatt-hour is shown in Table 2-27, and the formula of the calculation is simply: Benefit [M US$]/Flow[TWh].

Table 2-27. Unit Cost and Benefit of Interconnection Lines (2025–2035)

Case		Gross Benefit	Cost	Net Benefit
B	THA–LAO	3.77	0.26	**3.51**
E	VNM–LAO–THA	3.68	0.32	**3.36**
G	LAO–THA–MYS–SGP	3.88	0.28	**3.60**

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Unit: US¢/kWh
Source: Prepared by the working group.

Figure 2-22. Unit Cost and Benefit of Interconnection Lines (2025–2035)



kWh = kilowatt-hour, LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

8.3. Return on Investment

The return on investment on the interconnections is calculated with the formula:

Cumulative benefit from 2025 to 2035 [Million US$]

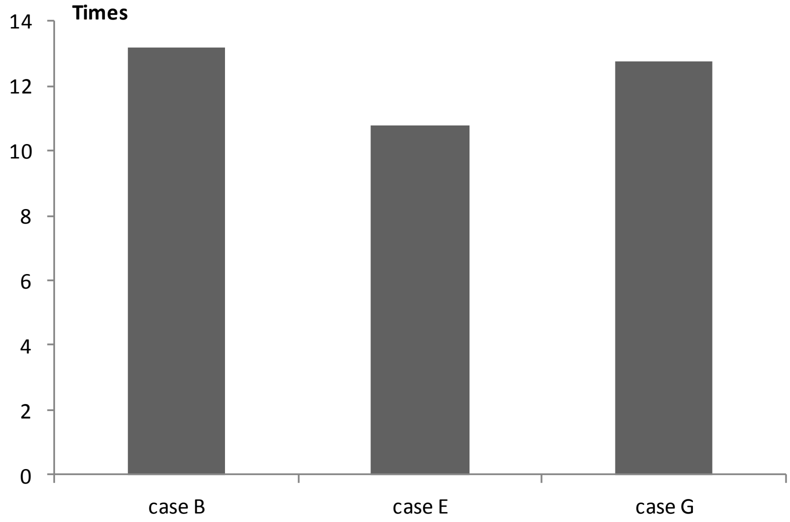
÷ Construction Cost with land [Million US$]

Table 2-28. Return on Investment (2025–2035)

Case		Net Benefit [Million US$]	Construction Cost [Million US$]	Benefit/Cost [-]
B	THA–LAO	19,881	1,506	13.2
E	VNM–LAO–THA	22,610	2,097	10.8
G	LAO–THA–MYS–SGP	25,490	2,000	12.7

LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

Figure 2-23. Return on Investment (2025–2035)



LAO = Lao People's Democratic Republic, MYS = Malaysia, SGP = Singapore, THA = Thailand, VNM = Viet Nam.
Source: Prepared by the working group.

8.4. Summary of Cost and Benefit Comparison

- Case G provides the largest net benefit.
- In terms of unit net benefit, Cases B and G are performing better than the others.
- In terms of return on investment, Case B is the most beneficial.