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Seeking Optimal Solutions for Delivering Liquefied Natural Gas to Mid-Sized and Large Islands in the Philippines

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Disclaimer

This report was prepared by the Study Group for Seeking Optimal Solutions for Delivering Liquefied Natural Gas to Mid-Sized and Large islands in the Philippines, which was formulated under the Economic Research Institute for ASEAN and East Asia (ERIA). The key assumptions and modelling approaches used in the report were decided upon by the authors and may differ from those of the country. Therefore, the simulation results presented here should not be viewed as the official national plan of the country.

Foreword

The Philippines uses natural gas produced in the Malampaya gas field for power generation. However, supplies from this field will be depleted by 2022 and the gas sales and purchase agreement will end in 2024. Unless a new gas field is developed, the Philippines will become more dependence on imports of gas for power generation. Coal is the main fuel imported for power generation, but it will be overtaken by liquefied natural gas (LNG). Coal has low generation costs but it is a major emitter of carbon dioxide. In the small and mid-sized islands, power is mainly generated from diesel fuels, but diesel has higher power generation costs and higher carbon dioxide emissions than natural gas.

A shift to LNG in the Philippines would entail high infrastructure costs. However, advances in technology have reduced this hurdle. In particular, floating storage and regasification units lower the cost of using LNG for medium-scale power generation by making domestic navigation from the LNG import terminal (the ‘primary terminal’) to terminals near natural gas power plants (‘subsidiary terminals’) more efficient.

In this study, assuming the electricity demand of each province and LNG consumption for power generation in 2040 as the target year, we analysed the optimal LNG transport solutions in term of their cost using static (optimisation) and dynamic simulation models. Because LNG transport by ship is interrupted by natural disasters such as typhoons, the dynamic simulation includes typhoon strike scenarios.

I hope this report will serve a useful reference to assist policymakers in the Philippines in preparing appropriate power development plans for natural gas power plants in the country.

Shigeru Kimura

Leader of the Study Group, ERIA

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CAPEX	capital expenditure
ERIA	Economic Research Institute for ASEAN and East Asia
FSRU	floating storage regasification unit
GPP	gas-fired power plant
IEEJ	Institute for Energy Economics, Japan
LNG	liquified natural gas
MW	megawatt
Mtpa	million tonnes per annum
OPEX	operational expenditure

Executive Summary

The Philippines consists of many small, medium-sized, and large islands and there is large potential to increase electricity demand in future. The country's main power source is coal, followed by domestic natural gas produced by the Malampaya gas field. Imports of liquefied natural gas (LNG) will increase due to depletion of this gas field and a shift in power generation from coal to gas. Consequently, it is essential to devise an economic system for delivery of small and medium-scale LNG from primary to subordinate (secondary and tertiary) terminals located near the islands' gas-fired power plants (GPPs). The following approaches are applied to determine the optimal small- and medium-scale LNG delivery solutions.

1. Estimation of electricity demand at the provincial level in 2040 based on the Philippines' Power Development Plan
2. Estimation of LNG consumption and location of GPPs
3. Optimal (minimum-cost) LNG delivery from a primary terminal to a subordinate terminal near GPPs using the linear programming model
4. Based on the delivery results from the linear programming model, computerised simulation of LNG delivery using a dynamic simulation model under assumptions including LNG barge operation, tank size of the subordinate terminals, and in the case of typhoon strike

The three major regions in the Philippines are Luzon, Visayas, and Mindanao. Our assumptions were as follows.

(i) A transmission line will be completed in the Luzon region by 2040. By then it will no longer be necessary to deliver LNG to GPPs in this region.

(ii) Cebu and Zamboanga are the two primary terminals in the Visayas and Mindanao regions; and Tacloban, Tagbilaran, Surigao, Bislig, Iligan, and General Santos are the six ports with subordinate terminals near GPPs.

The results of the optimisation model suggest the following points.

(i) Having two primary ports (Cebu and Zamboanga) is a lower-cost solution than having one primary port.

(ii) The hub-and-spoke delivery method is a lower-cost solution than the milk-run method.

The results of the dynamic simulation model yielded the following points on the size of LNG barges and LNG tanks at subordinate terminals.

(i) Large LNG barges are recommended to reduce number of vessels, especially small barges (capital cost), as well as running costs (operation cost) due to scale merits. But barge size depends on water depth in the ports.

(ii) Large tank size increases capital costs, but should be a key parameter to mitigate the influence of typhoons by avoiding a tank shortage.

The simulations recommend the following scenario as a minimum-cost solution for delivering LNG for small- and medium-scale power generation in the Visayas and Mindanao regions.

(i) Choosing Cebu and Zamboanga as the primary terminals;

(ii) using three large (30,000-cubic metre) LNG barges;

(iii) using a large (27-kilotonne) tank at each subordinate terminal; and

(iv) in case of a typhoon, six large LNG barges are required.

However, the assumptions for the two simulation studies are preliminary. It is recommended that when the Department of Energy undertakes feasibility studies it applies these simulation approaches to obtain optimal and feasible solutions for small-scale LNG delivery using appropriate and reasonable assumptions.

This study was successful, but several issues remain.

(i) Due to data limitations, electricity demand and LNG demand for each GPP and secondary port were estimated to be the same.

(ii) Assumptions for the optimisation approach using the linear programming model, especially capital costs for LNG ship (or barges) could be optimistic. We assumed lower capital costs for LNG ships applying simple structures that are just LNG tanks on barges.

(iii) Assumptions for the dynamic simulation were also simplified. The speed of LNG ships and the time taken for loading and unloading was assumed to be the same, whether they were large or small.

When the Department of Energy decides to increase the number of GPPs in the country, appropriate assumptions can be applied for both approaches to obtain more realistic solutions.

Chapter 1

Introduction

1.1 Background and Objective of the Study

1.1.1 Many islands, many diesel generators

The Philippines consists of more than 7,000 islands and their electricity supply depends mostly on diesel generators due to the high cost of constructing transmission lines, especially submarine cables. Diesel generation is useful as the technology is well established and oil is easy to manage. However, it has the disadvantages of higher generating costs, depending on the crude oil price, and higher emissions compared to natural gas.

1.1.2 Substitution by liquefied natural gas

The advantages of LNG compared to diesel oil as a fuel for power generation are its lower fuel cost and lower emissions. Until recently, countries had moved away from using LNG because of its larger up-front cost and the extremely low temperature needed to store it. But technological developments, particularly floating storage and regasification units (FSRUs), are reducing such challenges. The Philippines can enjoy the economic and environmental benefits of LNG by adopting such technologies to supply LNG for power generation in mid-sized and large islands.

1.1.3 The study

The study aims to analyse such opportunities by identifying possible configurations for a small-scale LNG supply chain for power generation. This will support the national power development efforts in the Philippines and help provide a stable and affordable supply of electricity in a sustainable way.

1.2 Study Method

1.2.1 Electricity and liquefied natural gas demand estimation by grid and island

The study will forecast electricity demand in selected mid-sized and large islands in the Philippines. The study referred to the Philippines' Power Development Plan 2016–2040 to identify prospective electricity demand by region – Luzon, Visayas, and Mindanao.

Regional electricity demand will be broken down to the major islands using available socio-economic data. Then, the study will identify the islands where electricity demand exceeds a threshold level, and where an LNG-based power plant could be installed, including a gas-fired combined-cycle gas turbine power generator. Electricity demand will be converted to LNG fuel demand to run an LNG-based power plant including a combined cycle-gas turbine power generator.

1.2.2 Identify how to introduce liquefied natural gas-based power plants

The study will develop an optimisation model applying the linear programming approach to determine where and what kind of LNG supply chain is needed for LNG delivery solutions between the islands.

1.2.3 Simulation of physical liquefied natural gas delivery

The study will develop a computerised dynamic simulation model to simulate LNG delivery from primary terminals to subordinate terminals.

1.2.4 Conclusion and policy recommendation

The study will deliver policy recommendations for the supply of LNG between small and mid-sized islands in the Philippines.

Chapter 2

Estimation of Electricity Demand Distribution and Liquefied Natural Gas Demand

To conduct a simulation of the delivery of LNG by ship to natural gas-fired power plants (GPPs), possible locations of the GPPs and LNG import terminals must be assumed. In this chapter, we envision electricity demand, the location of GPPs, and LNG demand in 2040. We use various sources of information, including the Transmission Development Plan and Port Statistics, to estimate the distribution of electricity demand for each province. Then we define the locations of GPPs and calculate the LNG demand for each GPP.

2.1 Electricity Demand Distribution by Grid

First, we envisioned electricity demand of the regional grids – Luzon, Visayas, and Mindanao – in 2040. Table 2.1 presents gross electricity demand calculated based on peak demand, station use or own consumption, and transmission loss data obtained from the Power Development Plan 2016–2024.

2.2 Electricity Demand Distribution by Region

Next, we envisioned electricity demand by region in 2040. We assume that the percentage share of total electricity demand of a certain region will be the same in 2040 as it was in 2015. Table 2.2 shows the estimated regional electricity demand in 2040.

Table 2.1. Electricity Demand Distribution by Grid in 2040

Grid	a **Peak Demand** (MW)	b **SU/TL** (%)	c=a*(1+b) **Gross Peak Demand** (MW)	d **Load Factor** (%)	e=c*d **Gross Average Demand** (MW)	f=e*24*365 **Gross Electricity Demand (MWh)**
Luzon	29,852	7.15	31,986	74.6	23,862	**209,029,962**
Visayas	9,210	5.88	9,752	71.6	6,982	**61,163,269**
Mindanao	10,225	3.84	10,618	72.6	7,708	**67,525,642**

MW = megawatt, MWh = megawatt-hour, SU/TL = station use/transmission losses.

Source: Government of the Philippines, Department of Energy (2016), *Power Development Plan 2016–2024*. Manila. Table 20: Grind Peak Demand Forecast, 2016–2040.

Table 2.2. Electricity Demand Distribution by Region in 2040

Grid	Region	g **2015 Electricity Sales** (MWh)	h **Share within Grid** (%)	i **2040 Gross Electricity Demand by Grid** (MWh)	j=i*h **2040 Gross Electricity Demand by Region** (MWh)
Luzon	Metro Manila	23,967,048	46.2	209,029,962	**96,517,417**
	Cordillera	524,593	1.0		**2,112,582**
	Ilocos	1,943,746	3.7		**7,827,637**
	Cagayan Valley	1,088,391	2.1		**4,383,047**
	Central Luzon	5,514,639	10.6		**22,207,938**
	Calabarzon	16,888,957	32.5		**68,013,320**
	Mimaropa	647,674	1.2		**2,608,240**
	Bicol	1,330,932	2.6		**5,359,781**

Visayas	Western Visayas	1,579,353	18.4	61,163,269	**11,246,619**
	Central Visayas	4,601,673	53.6		**32,768,649**
	Negros Island	1,502,521	17.5		**10,699,496**
	Eastern Visayas	905,558	10.5		**6,448,505**
Mindanao	Zamboanga Peninsula	1,063,568	11.8	67,525,642	**7,961,924**
	Northern Mindanao	2,340,389	25.9		**17,520,270**
	Davao	3,067,712	34.0		**22,965,047**
	Soccsksargen	1,433,742	15.9		**10,733,065**
	Caraga	834,842	9.3		**6,249,669**
	Muslim Mindanao	279,943	3.1		**2,095,667**
Philippines			100.0	337,718,874	**337,718,874**

MWh = megawatt-hour.

Source: Government of the Philippines, Department of Energy. Electricity sales.

2.3 Electricity Demand Distribution by Province

The electricity demand of each province is allocated according to the size of its population as of 1 July 2016. In other words, the provincial electricity demand is calculated by multiplying the regional electricity demand by the province's share of the population of the region. Table 2.3 provides the estimated result of provincial electricity demand in 2040.

Table 2.3. Electricity Demand Distribution by Province in 2040: Luzon

Region	**Province**	k **Population As of 1 July 2016**	l **Share within Region** (%)	m **2040 Gross Electricity Demand by Region** (MWh)	n=l*m **2040 Gross Electricity Demand by Province** (MWh)

Metro Manila		1,750,930	100	96,517,417	**96,517,417**
Cordillera	Abra	243,731	13.9	2,112,582	**294,073**
	Apayao	121,377	6.9		**146,447**
	Benguet	804,975	46.0		**971,242**
	Ifugao	206,714	11.8		**249,411**
	Kalinga	216,511	12.4		**261,231**
	Mountain	157,622	9.0		**190,179**
Ilocos	Ilocos Norte	595,075	11.7	7,827,637	**916,895**
	Ilocos Sur	694,252	13.7		**1,069,708**
	La Union	793,088	15.6		**1,221,995**
	Pangasinan	2997,806	59.0		**4,619,038**
Cagayan Valley	Batanes	17,535	0.5	4,383,047	**21,998**
	Cagayan	1,212,759	34.7		**1,521,415**
	Isabela	1,612,532	46.2		**2,022,933**
	Nueva Vizcaya	458,465	13.1		**575,148**
	Quirino	192,549	5.5		**241,554**
Central Luzon	Aurora	219,064	1.9	22,207938	**428,360**
	Bataan	769,699	6.8		**1,505,077**
	Bulacan	3,343,157	29.4		**6,537,242**
	Nueva Ecija	2,174,419	19.1		**4,251,880**
	Pampamga	2,637,063	23.2		**5,156,539**
	Tarlac	1,379,600	12.1		**2,697,683**
	Zambales	834,176	7.3		**1,631,156**
Calabarzon	Batangas	2,757,358	18.7	68,013,320	**12,717,226**
	Cavite	3,754,702	25.5		**17,317,081**
	Laguna	3,099,964	21.0		**14,267,361**
	Quezon	2,185,282	14.8		**10,078,751**
	Rizal	2,949,391	20.0		**13,602,902**

Mimaropa	Occidental Mindoro	496,635	16.5	2,608,240	**429,093**
	Oriental Mindoro	859,665	28.5		**742,750**
	Marinduque	238,468	7.9		**206,036**
	Romblon	298,015	9.9		**257,485**
	Palawan	1,126,014	37.3		**872,876**
Bicol	Albay	1,335,680	22.6	5,359,781	**1,212,864**
	Camarines Norte	594,506	10.1		**539,841**
	Camarines Sur	1,989,172	33.7		**1,806,268**
	Catanduanes	266,321	4.5		**241,833**
	Masbate	908,231	15.4		**824,719**
	Sorsogon	808,606	13.7		**734,255**

MWh = megawatt-hour.

Source: Government of the Philippines, Department of Energy, Population.

Table 2.4. Electricity Demand Distribution by Province in 2040: Visayas

Region	**Province**	k **Population As of 1 July 2016**	l **Share within Region** (%)	m **2040 Gross Electricity Demand by Region** (MWh)	n=l*m **2040 Gross Electricity Demand by Province** (MWh)
Western Visayas	Aklan	582,793	12.9	11,246,619	**1,446,076**
	Antique	593,149	13.1		**1,471,772**
	Capiz	768,965	17.0		**1,908,022**
	Guimaras	176,860	3.9		**438,840**
	Iloilo	2,410,811	53.2		**5,981,910**

Central Visayas	Bohol	1,336,079	21.8	32,768,649	**7,143,064**
	Cebu	4,695,311	76.6		**25,102,488**
	Siquijor	97,843	1.6		**523,097**
Negros Island	Negros Occidental	4,474,495	69.3	10,699,496	**7,413,005**
	Negros Oriental	3,100,095	30.7		**3,286,491**
Eastern Visayas	Biliran	175,761	4.1	6,448,505	**265,250**
	Eastern Samar	475,599	11.1		**717,752**
	Leyte	1,754,201	41.1		**2,647,360**
	Northern Samar	645,300	15.1		**973,857**
	Samar	792,633	18.6		**1,196,205**
	Southern Leyte	429,433	10.1		**648,081**

MWh = megawatt-hour.

Source: Government of the Philippines, Department of Energy, Population.

Table 2.5. Electricity Demand Distribution by Province in 2040: Mindanao

Region	**Province**	k **Population As of 1 July 2016**	l **Share within Region** (%)	m **2040 Gross Electricity Demand by Region** (MWh)	n=l*m **2040 Gross Electricity Demand by Province** (MWh)
Zamboanga Peninsula	Zamboanga del Norte	1,026,204	27.8	7,961,924	**2,215,374**
	Zamboanga del Sur	1,026,855	27.8		**2,216,780**
	Zamboanga Sibugay	1,520,457	41.2		**3,282,370**
	City of Isabela	114,600	3.1		**247,399**

Northern Mindanao	Bukidnon	4,755,277	30.1	17,520,270	**5,282,144**
	Camiguin	1,433,657	1.9		**330,990**
	Lanao del Norte	89,836	21.8		**3,814,024**
	Misamis Occidental	1,035,186	12.8		**2,247,832**
	Misamis Oriental	1,586,501	33.4		**5,845,280**
Davao	Compostela Valley	749,009	16.3	22,965,047	**3,737,975**
	Davao del Norte	963,505	20.9		**4,808,431**
	Davao del Sur	2,362,043	51.3		**11,787,921**
	Davao Oriental	527,139	11.5		**2,630,720**
Soccskasargen	North Cotabato	1,404,340	30.4	10,733,065	**3,259,431**
	Sarangani	553,417	12.0		**1,284,464**
	South Cotabato	1,535,559	33.2		**3,563,986**
	Sultan Kudarat	826,349	17.9		**1,917,931**
	Cotabato City	304,723	6.6		**707,253**
Caraga	Agusan del Norte	704,419	26.6	6,249,669	**1,663,568**
	Agusan del Sur	717,617	27.1		**1,694,737**
	Surigao del Norte	492,228	18.6		**1,162,454**
	Surigao del Sur	602,445	22.8		**1,422,745**
	Dinagat Islands	129,642	4.9		**306,165**
Muslim Mindanao	Basilan	355,230	9.2	2,095,667	**192,513**
	Lanao del Sur	1,071,349	27.7		**580,606**
	Maguindanao	1,197,836	31.0		**649,154**
	Sulu	842,656	21.8		**456,668**
	Tawi-Tawi	399,911	10.3		**216,727**

MWh = megawatt-hour.

Source: Government of the Philippines, Department of Energy, Population.

2.4 Liquefied Natural Gas Demand by Grid

We envisioned LNG demand for power generation in each grid based on the assumptions listed in Tale 2.6.

Table 2.6. Assumptions of Liquefied Natural Gas Demand Forecast

- All the natural gas supply for power generation will come from liquefied natural gas. (There will be no domestic natural gas source in 2040.)
- No electricity will be imported in 2040.
- The share of natural gas in power generation will be 33.4% (business-as-usual scenario, ERIA Energy Outlook).
- The share of natural gas in power generation is same for all grids.
- The gross thermal efficiency of gas-fired power plants (GPPs) is 54% (business-as-usual scenario, ERIA Energy Outlook).
- The electricity own use of GPPs is 4% (net thermal efficiency of GPPs is 50%).

Source: Author.

2.5 Selection of Liquefied Natural Gas Terminals

We selected GPPs and LNG terminals according to (i) electricity demand by province, (ii) current and future transmission lines and location of substations, (iii) ideal power plant locations (with reference to the Transmission Development Plan), and (iv) the operational situation of ports (i.e. whether bulk fuels are unloaded).

2.5.1 Luzon grid

Electricity demand in the Luzon grid is concentrated in the National Capital Region, Metro Manila, and its vicinity. The Transmission Development Plan 2014–2015 states that San Manuel (300 megawatts [MW]), Muntinlupa (300 MW), and Malaya (300 MW) are ideal locations of power plants. However, these three locations are far from the coastline. Given the distribution of the Luzon grid's electricity demand, the fact that the island of Mindoro is currently off-grid but will be connected to the Luzon grid, and that connection with the Visayas grid through Mindoro is planned, it is preferable that new GPPs are constructed on the southern coastline of the Luzon grid.

LNG demand by grid in 2040 is shown in Table 2.7.

Table 2.7. Liquefied Natural Gas Demand by Grid in 2040

	o	p=o*33.4%	q=p/ 11630	r=q/50%	s=r*1.047	t=s*0.735
Region	**Net Electricity Generation** (MWh)	**Allocated Natural Gas Power Generation** (MWh)	(ktoe)	**Required Natural Gas Input** (ktoe)	(Mcm)	('000 tonnes)
Luzon	209,029,962	69,816,007	6,003	12,006	12,570	9,239
Visayas	61,163,269	20,428,532	1,757	3,513	3,678	2,703
Mindanao	67,525,642	22,553,564	1,939	3,879	4,061	2,985
Philippines	337,718,874	112,798,104	9,699	19,398	20,309	14,927
Mindanao	10,225	3.84	10,618	72.6	7,708	**67,525,642**

ktoe = thousand tonnes of oil equivalent, Mcm = million cubic metres, MWh = megawatt-hour.

Notes: Net electricity generation = gross electricity demand. Conversion factors are as follows.

1 toe = 11,630 kWh (1kWh = 859.845kcal), 1 ktoe = 1.047 Mcm (40 megajoules/cublic metre)

1,000 tonne of liquefied natural gas = 0.735 Mcm.

Source: Author.

The Luzon grid's LNG demand in 2040 is estimated to exceed 9 million tonnes annually. This volume is too large for one LNG terminal to handle. Therefore, considering the locations and sizes of ports and locations of substations, we envisioned a scenario in which, in the case of the Luzon grid, the amount LNG received would be distributed amongst the ports of Batangas, Limay, and Pagbilao (Figure 2.1, Table 2.8).

We allocated LNG demand equally amongst the three GPPs. Each GPP will consume more than 3 million tonnes annually, which is a volume that can be handled by a primary LNG terminal (LNG import terminal). Accordingly, it is thought that developing the Luzon grid's three LNG import terminals to provide a dedicated supply of regasified natural gas to their respective nearby GPP would be effective. (There would be no LNG supply to other secondary LNG terminals.)

LNG delivery would take place entirely within the Luzon grid, without any secondary LNG transaction between other grids. Thus, we exclude small-scale LNG delivery in the Luzon grid in this study.

2.5.2 Visayas grid

The Transmission Development Plan 2014–2015 states that Calbayog (100 MW), Babatngon (100 MW), Daanbantayan (100 MW), Compostela (200 MW), Maasin (100 MW), and Bohol (100 MW) (a total of 700 MW) are ideal locations for power plants. However, these six locations are far from ports. Within the Visayas grid, Cebu has the largest electricity demand. This makes it preferable to locate GPPs in or near Cebu to reduce electricity transmission loss. Considering the locations and sizes of ports and the locations of substations, we envisioned a scenario in which GPPs would be constructed at Cebu, Tagbilaran, and Tacloban in the Visayas grid (Figure 2.2, Table 2.8).

We allocated three-sevenths of LNG demand to Cebu and two-sevenths each to Tagbilaran and Tacloban.

2.5.3 Mindanao grid

The Transmission Development Plan 2014–2015 states that Placer (100 MW), Auropa (100 MW), Pitogo (100 MW), Tacurong (100 MW), and Bislig (100 MW) (a total of 500 MW) are ideal locations for power plants. The Mindanao grid's electricity demand is more dispersed than that of the Luzon and Visayas grids. Therefore, considering the ideal locations of power plants, locations and sizes of ports, and locations of substations, we envisioned a scenario in which GPPs would be constructed at Zamboanga, Iligan, Bislig, Surigao, and General Santos in the Mindanao grid (Figure 2.2). We allocated 20% of LNG demand to each GPP (Table 2.8).

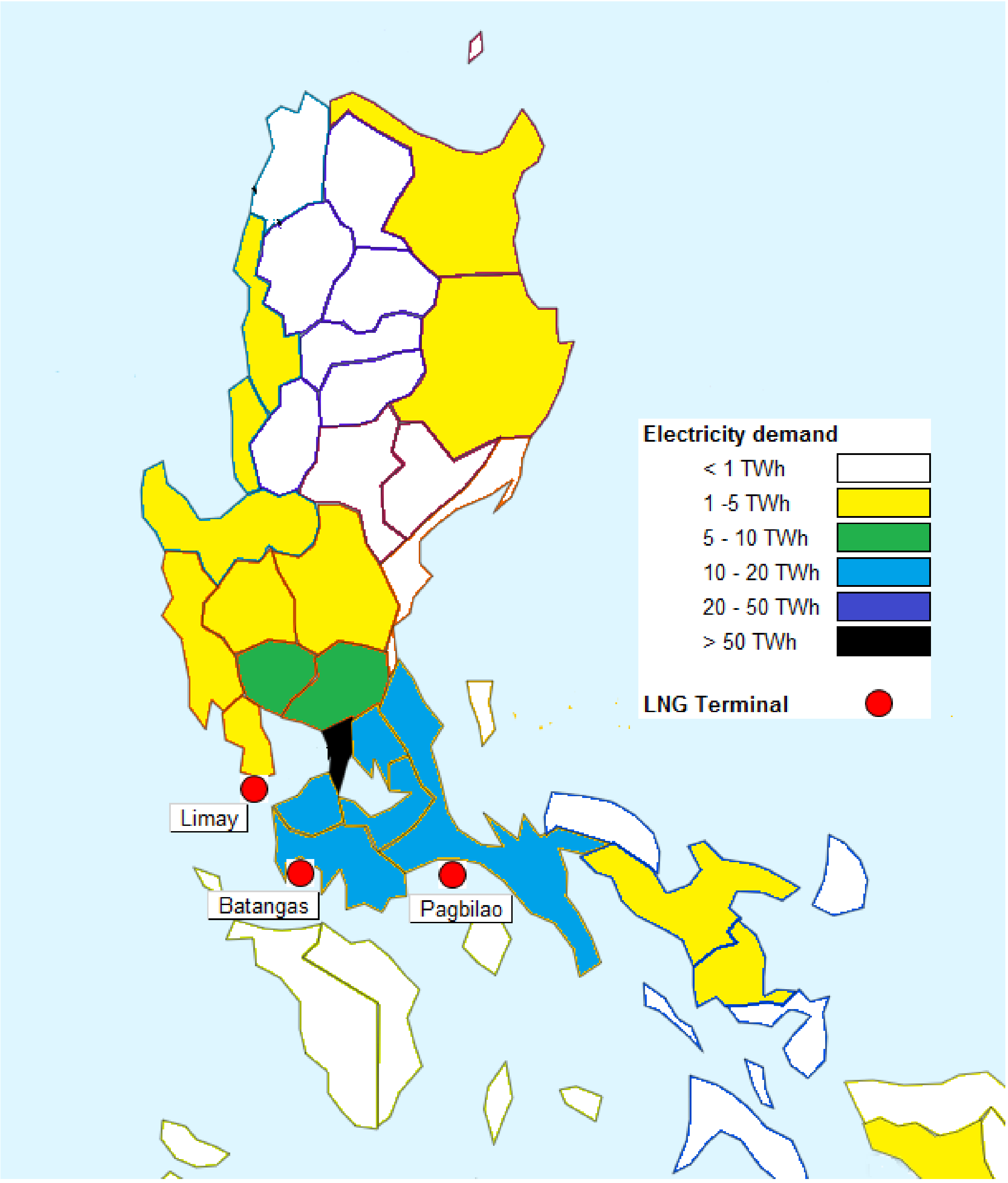
Table 2.8. Liquefied Natural Gas Demand by Secondary Liquefied Natural Gas Terminal in 2040

Grid	Terminal	Liquefied Natural Gas Demand ('000 tonnes)	Required Generation Capacity* (megawatts)
Luzon	Batangas	3,080	13,257
	Limay	3,080	13,257
	Pagbilao	3,080	13,257
	Subtotal	9,240	39,770
Visayas	Cebu	1,159	4,990
	Tagbilaran	772	3,324
	Tacloban	772	3,324
	Subtotal	2,703	11,637
Mindanao	Zamboanga	597	2,569
	Iligan	597	2,569
	Bislig	597	2,569
	Surigao	597	2,569
	General Santos	597	2,569
	Subtotal	2,985	12,847
Philippines		14,927	64,257

* Calculated using a capacity factor of 60%.

Source: Author.

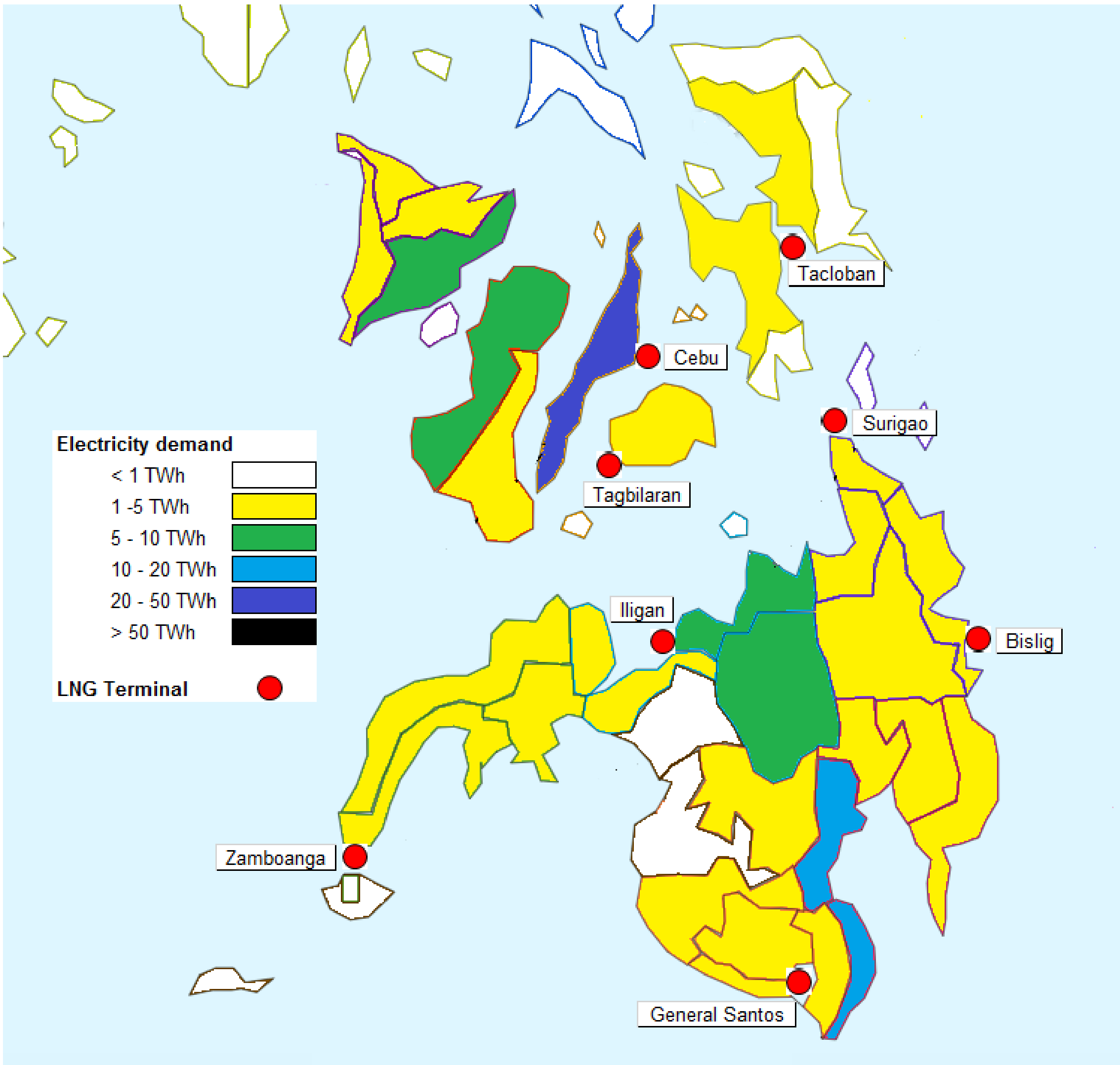
Figure 2.1. Electricity Demand by Province and Location of Liquefied Natural Gas Terminal: Luzon



LNG = liquefied natural gas, TWh = terawatt-hour.

Source: Author.

Figure 2.2. Electricity Demand by Province and Location of Liquefied Natural Gas Terminal: Visayas and Mindanao



LNG = liquefied natural gas, TWh = terawatt-hour.

Source: Author.

Chapter 3

Economic Delivery Route:

Technical Report on the Modelling of a Small Liquefied Natural Gas Distribution Network in the Philippines

3.1 Introduction

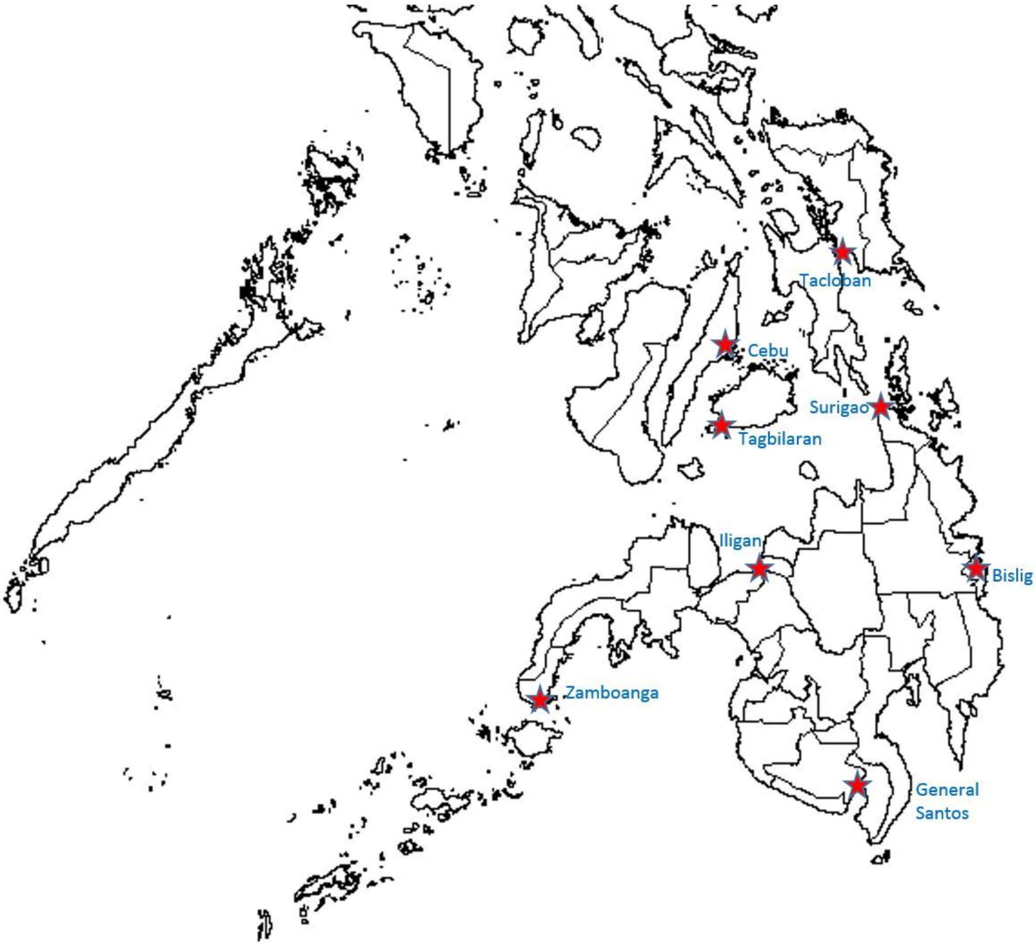
The purpose of this study is to shed light on the necessary infrastructure investment for small-scale LNG distribution in the Visayas and Mindanao regions of the Philippines.[1] Such investment needs to (i) be able to satisfy all future demand for LNG in these regions, (ii) fully consider all technical constraints during operation (such as water depth of the port and availability of land for onshore LNG receiving terminals), and (iii) be optimised to incur minimum capital expenditure (CAPEX) and operational expenditure (OPEX).

The LNG demand forecast for these regions by 2040 is conducted by the Institute for Energy Economic, Japan (IEEJ), based on forecast of power generation from GPPs, and considering conditions of grid interconnection between regions and islands. For the Visayas and Mindanao regions, demand is estimated to concentrate around eight ports: Cebu, Tagbilaran, Tacloban, Zamboanga, Iligan, Bislig, Surigao, and General Santos (Figure 3.1).

Based on whether the port is an international port and its location in relation to other ports, four of the eight ports – Cebu, Zamboanga, Bislig, and General Santos – are selected as candidate locations for primary LNG receiving terminals.

[1] The Luzon region of the Philippines either consists of a large island or is connected in terms of the power grid. Thus, it is assumed that gas-fired power plants in Luzon region will be served by primary LNG receiving terminals located in Batangas and its neighboring ports. These terminals will have their capacity almost fully consumed by local demand, with no extra capacity available to supply demand in Visayas or Mindanao. Thus, this report does not study the Luzon case, and instead focuses only on the distribution network in Visayas and Mindanao.

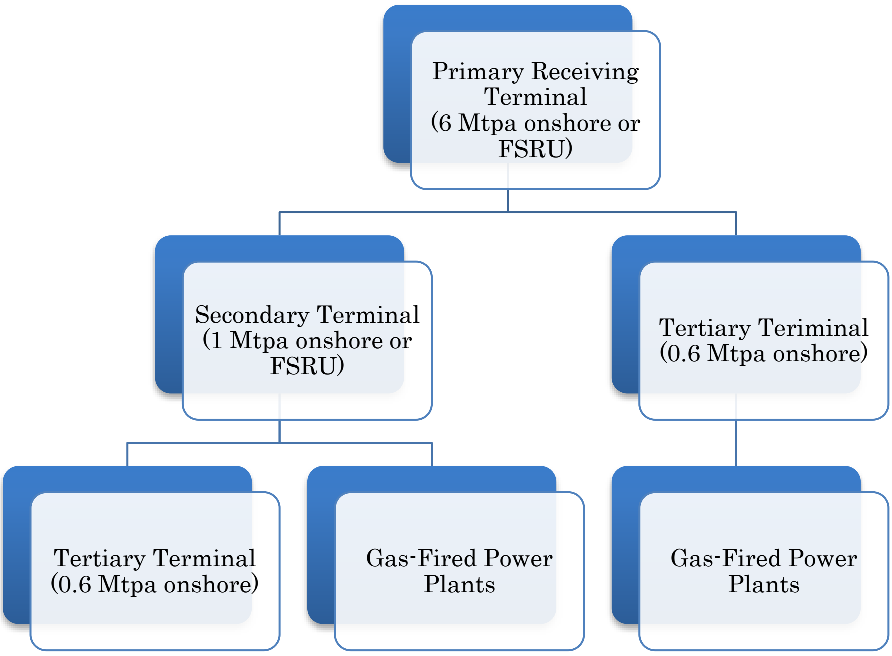
Figure 3.1. Candidate Ports as Liquefied Natural Gas Receiving Terminals in Visayas and Mindanao



Source: Developed by the author using DIVA-GIS software.

Scenarios in which one or two of the ports become the primary terminals (capacity of 6 million tonnes per annum [Mtpa]) are analysed in the following sections of the report. The remaining ports will be built with secondary (1 Mtpa capacity) or tertiary (0.6 Mtpa capacity) LNG receiving terminals. It is assumed that GPPs will be built near the LNG terminals. Figure 3.2 illustrates the conceptual structure of a regional LNG distribution network. Small-capacity (12,000 cubic metre) or large-capacity (30,000 cubic metre) LNG barges are used to connect the terminals.

Figure 3.2. Conceptual Structure of a Liquefied Natural Gas Distribution Network



FSRU = floating storage regasification unit, Mtpa = million tonnes per annum.

Source: Author.

As Figure 3.2 shows, LNG barges can depart from a primary LNG terminal and make delivery to secondary or tertiary terminals. Secondary terminals can either directly distribute gas to GPPs or serve as supply points to tertiary terminals.[2]

Our study thus aims to identify the optimal location and type of terminals to be built, and the kind of transportation equipment and onsite storage capacity that should be constructed to meet the projected demand.

[2] However, in reality, due to the boil-off during loading and off-loading of LNG between barges and terminals, as well as the increased number of port calls by delivery barges, it is not economically reasonable to make the secondary terminal a transit storage location for serving tertiary terminals. Thus, in this study, delivery from the primary terminal directly to the secondary and tertiary terminals is considered.

3.2 Methodology

The nature of the research problem is to minimise the costs (CAPEX and OPEX) of the LNG distribution network while satisfying the demand for natural gas at all delivery points. The nature of the LNG supply chain also determines the embedded transportation planning and inventory planning problems: if transportation is cheap, less storage capacity would be necessary; but if transportation is expensive, more storage capacity should be built. Considering the possibility of interruption of transportation due to typhoons and storms, an appropriate level of inventory should also be maintained. Thus, the research also involves a classical feedstock planning problem.

The activities along the supply chain in an LNG distribution network are thus modelled and solved as a mixed integer linear programming process. The model thus minimises the CAPEX and OPEX of terminals and transportation capacities. Key drivers of costs in the system include the type and number of terminals to be built, the type and number of LNG barges needed, and the frequencies and distances travelled by the barges in delivering LNG to subordinate terminals. Technical constraints of the optimisation typically include water depth at the port, availability of land for onshore facilities, and frequency of typhoons and storms.

Considering the typical operation models of an LNG distribution network, two types of delivery model are considered in this study. The first is the hub-and-spoke model, in which all deliveries are made by direct trips between primary terminals and the subordinate terminals. Figure 3.3 illustrates this model, with Cebu as the primary terminal. The second is the milk-run model, in which barges run through a list of destinations and feed into the subordinate terminals one by one, after departing from the primary terminal, as long as capacity allows and it makes economic sense. Figure 3.4 illustrates the idea, assuming that Cebu as the primary terminal.

Figure 3.3. Hub-and-Spoke Model

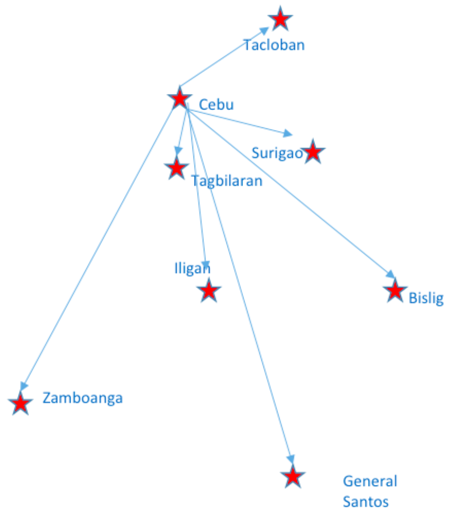
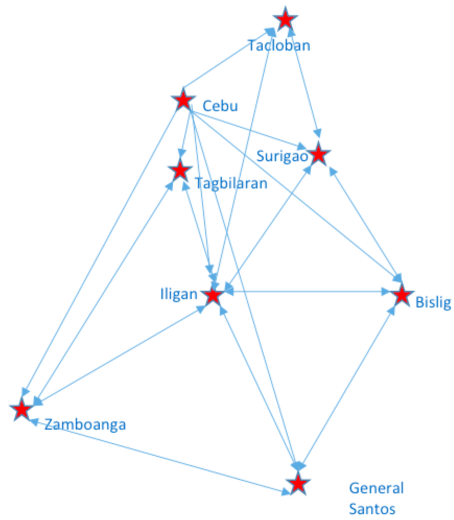


Figure 3.4. Milk-Run Model



Source: Author.

Different scenarios are modelled to reflect the outcome of different combinations of operation model and primary terminal locations. Table 3.1 lists the scenarios.

Table 3.1. List of Scenarios to Select an Operation Model and Locations for Primary Terminals

Scenario	Operation Model	Location of Primary Terminal
Scenario 1	Hub-and-spoke	Cebu
Scenario 2	Hub-and-spoke	Bislig
Scenario 3	Hub-and-spoke	Zamboanga
Scenario 4	Hub-and-spoke	General Santos
Scenario 5	Hub-and-spoke	Cebu and Zamboanga
Scenario 6	Milk-run	Cebu and Zamboanga

Source: Author.

The model simulates the operation of the distribution network over a single year (52 weeks) – 2040. Its results could thus imply the infrastructure needed by 2040.

3.3 Data Description

Table 3.2 lists the CAPEX and OPEX assumptions.

Table 3.2. Capital Expenditure and Operational Expenditure Assumptions

Description	Specification	CAPEX	OPEX
Primary terminal	6 Mtpa (storage: 188,000 m^3)	$1,272 million (inclusive of storage)	$500,000 per week
Secondary terminal	1 Mtpa (storage: 50,000 m^3)	$212 million (inclusive of storage)	$100,000 per week
Tertiary terminal	0.6 Mtpa (storage: 30,000 m^3)	$127 million (inclusive of storage)	$60,000 per week
Floating storage regasification unit	360 mmscfd (storage: 172,000 m^3)	$624 million (inclusive of storage)	$460,000 per week
Large barge	30,000 m^3	$300,000	$0.059 per tonne per nautical mile
Small barge	12,000 m^3	$180,000	$0.083 per tonne per nautical mile

CAPEX = capital expenditure, m^3 = cubic metre, Mtpa million tonnes per annum, mmscfd = million standard cubic feet per day, OPEX = operational expenditure.

Source: Author.

Table 3.3 lists the navigation distances between the ports.

Table 3.3. Navigation Distances between Ports (nautical miles)

Port	Cebu	Tagbilaran	Tacloban	Zamboanga	Iligan	Bislig	Surigao	General Santos
Cebu	0	83	190	279	172	267	119	475
Tagbilaran	83	0	226	273	89	238	143	469
Tacloban	190	226	0	422	208	226	101	475
Zamboanga	279	273	422	0	279	451	344	220
Iligan	172	89	208	279	0	285	154	487
Bislig	267	238	226	451	285	0	137	273
Surigao	119	143	101	344	154	137	0	350
General Santos	475	469	475	220	487	273	350	0

Source: Institute of Energy Economics, Japan.

Table 3.4 lists the water depth in the selected ports. It is assumed that the draught depth of a large LNG barge is 8.8 metres, thus only Bislig, Surigao, and General Santos can accommodate deliveries by large barges.

3.4 Results

The total costs of the system derived from the model can be understood as the overnight CAPEX of all necessary infrastructure plus the OPEX of the first year. Table 3.5 compares the total system costs of all scenarios, as well as the results of the key variables that drive the total system costs.

Table 3.4. Cargo Pier Water Depth of Ports (metre)

Port	Water Depth
Cebu	8
Tagbilaran	8
Tacloban	8
Zamboanga	8
Iligan	8
Bislig	9
Surigao	9
General Santos	9

Source: Institute of Energy Economics, Japan.

Table 3.5. Key Results

Variables	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Total system costs ($ million)	2,963.94	2,969.27	2,967.51	2,969.66	2,093.45	2,168.07
Number of primary onshore terminals	Ceb×1	Bis×1	Zam×1	San×1	0	0
Number of primary floating storage regasification units	Ceb×1	Bis×1	Zam×1	San×1	Ceb×1 Zam×1	Ceb×1 Zam×1
Number of secondary terminals	Sur×1	San×1	Sur×1	Bis×1	0	0

Number of tertiary terminals	Tag×1 Tac×1 Zam×1 Ili×1 Bis×1 San×1	Ceb×1 Tag×1 Tac×1 Zam×1 Ili×1 Sur×1	Ceb×1 Tag×1 Tac×1 Ili×1 Bis×1 San×1	Ceb×1 Tag×1 Tac×1 Ili×1 Zam×1 Sur×1	Ceb×1 Tag×1 Tac×1 Ili×1 Zam×1 Sur×1	Ceb×1 Tag×1 Tac×1 Ili×1 Zam×1 Sur×1
Number of large barges	3	2	3	2	3	3
Number of small barges	12	17	14	17	9	8

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Scenarios 1 to 4, simulate the case of one port – Cebu, Bislig, Zamboanga, or General Santos – as the primary LNG terminal, with a hub-and-spoke transportation model applied. According to the results, Cebu offers the lowest total system costs, followed by Zamboanga. This result is mainly caused by the different pattern of transportation applied in the different cases. The results suggest that, from transportation point of view, Cebu and Zamboanga should be prioritised as candidates for primary LNG terminals.

Interestingly, due to the combined volume of demand for LNG from all eight ports, more than one primary terminal seems to be needed. However, it is unlikely that one port would be developed with two onshore primary LNG terminals, so one FSRU is recommended if just one port is to be developed as the primary terminal.

Scenario 5 tests the idea of developing both Cebu and Zamboanga as the primary terminals. In this case, if a hub-and-spoke transportation model is adopted, the total system cost drops significantly, and about $800 million could be saved compared to scenarios 1 to 4. The cost savings are driven partly by introducing an FSRU in each of the two primary ports, and partly by the reduced costs of transportation in delivering to other ports.

In all scenarios, the application of large barges is more limited than small barges, because only the ports of Bislig, Surigao, and General Santos have enough water depth to cater to large barges.

In scenario 5, besides the reduction in CAPEX for the terminals, the number of LNG barges required is also significantly reduced, as two primary terminals are made available to distribute LNG. Accordingly, all CAPEX and OPEX items are reduced compared to previous scenarios with only one primary terminal available. These details are illustrated in Table 3.6, which compares the main cost components of Scenarios 1 and 5.

Table 3.6. Decomposed Capital Expenditure and Operational Expenditure in Scenarios 1 and 5 ($ million)

Expenditure	Scenario 1	Scenario 5
CAPEX: Onshore terminal	1,272 × 1	0
CAPEX: Offshore FSRU	624 × 1	624 × 2
CAPEX: Secondary terminal	212 × 2	0
CAPEX: Tertiary terminal	127.6 × 6	127.6 × 6
CAPEX: LNG barges	0.3 × 4 + 0.18 × 12	0.3 × 3 + 0.18 × 9
OPEX: Onshore terminal and FSRU	73.84	66.56
OPEX: LNG barges	15.84	13.17

CAPEX = capital expenditure, FSRU = floating storage and regasification unit, LNG = liquefied natural gas, OPEX = operational expenditure.

Source: Author.

However, when this idea of two primary ports – Cebu and Zamboanga – is tested applying the milk-run transportation model, the operational costs of transportation rebound significantly. This is because of the greater distance covered in each delivery run and the much more frequent calls to port, which imply more port service costs. These details are illustrated in Table 3.7, which compares the main cost components of Scenarios 5 and 6.

Table 3.7. Decomposed Capital Expenditure and Operational Expenditure in Scenarios 5 and 6 ($ million)

Expenditure	Scenario 5	Scenario 6
CAPEX: Onshore terminal	0	0
CAPEX: Offshore FSRU	624 × 2	624 × 2
CAPEX: Secondary terminal	0	0
CAPEX: Tertiary terminal	127.6 × 6	127.6 × 6
CAPEX: LNG barges	0.3 × 3 + 0.18 × 9	0.3 × 3 + 0.18 × 8
OPEX: Onshore terminal and FSRU	66.56	66.56
OPEX: LNG barges	13.17	87.97

CAPEX = capital expenditure, FSRU = floating storage and regasification unit, LNG = liquefied natural gas, OPEX = operational expenditure.

Source: Author.

In summary, our simulation results recommend the development of both Cebu and Zamboanga as the primary LNG terminals, applying FSRU solutions and a hub-and-spoke transportation model. In addition, a reduced number of LNG barges is recommended.

Table 3.8 shows the infrastructure capacity required in Scenarios 5 and 6. The difference between the two scenarios in terms of required infrastructure capacity is minimal (a difference of one small barge): Scenario 5 requires three large barges and nine small barges, while scenario 6 requires three large barges and eight small barges.

Table 3.8. Required Terminal Capacity and Shipping Capacity in Scenarios 5 and 6

Parameters	Scenario 5	Scenario 6
Throughput capacity at primary terminals	Ceb: 360 mmscfd (about 4.6 mtpa) Zam: 360 mmscfd (about 4.6 mtpa)	Ceb: 360 mmscfd (about 4.6 mtpa) Zam: 360 mmscfd (about 4.6 mtpa)
Storage capacity at primary terminals	Ceb: 85,000 t Zam: 85,000 t	Ceb: 85,000 t Zam: 85,000 t
Throughput capacity at non-primary terminals	Tag: 0.6 mtpa Tac: 0.6 mtpa Ili: 0.6 mtpa Bis: 0.6 mtpa Sur: 0.6 mtpa San: 0.6 mtpa	Tag: 0.6 mtpa Tac: 0.6 mtpa Ili: 0.6 mtpa Bis: 0.6 mtpa Sur: 0.6 mtpa San: 0.6 mtpa
Storage capacity at non-primary terminals	Tag: 13,500 t Tac: 13,500 t Ili: 13,500 t Bis: 13,500 t Sur: 13,500 t San: 13,500 t	Tag: 13,500 t Tac: 13,500 t Ili: 13,500 t Bis: 13,500 t Sur: 13,500 t San: 13,500 t
Shipping capacity	Large barge: 13,500 t x 3 Small barge: 5,400 t x 9	Large barge: 13,500 t x 3 Small barge: 5,400 t x 8

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga. m^3 = cubic metre, Mtpa = million tonnes per annum, mmscfd = million standard cubic feet per day, t = tonne.

Source: Author.

More details about the patterns of operation of the terminals and the transportation between the terminals for distribution are presented in the appendix.

3.5 Summary

In conclusion, this study enables several different solutions to be compared in terms of the location of LNG terminals, the type and scale of facilities, and transportation models. Based on the distribution of demand, the pattern of demand near each port, and the physical conditions of the port, our mixed integer programming model is able to indicate the most efficient solution (which meets the demand at minimum cost) for the Visayas and Mindanao regions of the Philippines in 2040.

According to the results of the model and a comparison of several scenarios, it is recommended that Cebu and Zamboanga are developed as the primary LNG receiving terminals, with the capacity to redistribute to other demand centres in the southern districts applying FSRU solutions. An optimal combination of large and small barges is recommended for the operation of a hub-and-spoke transportation model. This solution has the lowest total system costs.

Chapter 4

Necessary Liquefied Natural Gas Delivery System: Dynamic Simulation to Identify Necessary Liquefied Natural Gas Shipping and Storage Capacity

In this chapter, we analyse the cost of LNG delivery by ship using dynamic simulation. First, we discuss the assumptions and conditions of dynamic simulation with reference to the results in Chapter 3. Then, we simulate LNG delivery using a dynamic simulation model. Scenarios are developed in which factors such as the number of ships and the storage capacity of the LNG terminal are changed, and their costs are evaluated. The scenarios include the case of typhoon strikes.

4.1 Outline of the Analysis

4.1.1 Basic concepts of dynamic simulation

The Luzon grid is excluded from the model because, as indicated in Chapter 2, LNG terminals in Luzon are large enough to become LNG import terminals and dedicated gas supply terminals for connected GPPs. Therefore, the study targets only the Visayas and Mindanao grids. The delivery of LNG is executed with LNG barges. New LNG storage facilities are prepared for both at the primary terminal ports, which store LNG for bulk breaking, and subordinate terminal ports where GPPs are located.

LNG for bulk breaking is supplied to primary terminals that receive imported LNG directly from outside the Philippines.

Using simulation techniques, this chapter analyses the delivery plan from the primary terminals to the subordinate (secondary and tertiary) terminals at each port where GPPs are located.

4.1.2 Simulation procedures

Simulation procedures are as follows.

- ✓ Select the location of primary and subordinate LNG terminals.
- ✓ Refer to the minimum-cost distribution plan from the linear programming model analysis.
- ✓ Seek a feasible distribution plan using the dynamic simulation model.
- ✓ Estimate total costs of LNG bulk breaking.

4.2 General Assumptions

4.2.1 Liquefied natural gas distribution ports in the study

The LNG distribution ports in this study are Cebu, Tagbilaran, Tacloban, Zamboanga, Iligan, Bislig, Surigao, and General Santos. Figure 3.1, in Chapter 3, shows their locations.

4.2.2 Ports for delivery

Classification of ports. Ports are divided into primary and subordinate terminals. A primary LNG terminal is one where LNG is imported from outside the Philippines directly to the terminal for storage and continuous reshipment to subordinate LNG terminals. A subordinate LNG terminal one where LNG is delivered from a primary LNG terminal to store LNG, regasify LNG, and supply regasified natural gas to GPPs. The classification of ports is in Table 4.1.

Water depth. Bislig, Surigao, and General Santos have a water depth of 9 metres. The five other ports each have a depth of 8 metres (Table 3.4)

Classification of barges. There are two types of LNG barges – large and small. Large barges require ports with a water depth of 9 metres. Table 4.2 shows barge tank capacity.

Capital expenditure and operational expenditure assumptions. Table 3.2, in Chapter 3, shows the CAPEX and OPEX assumptions for the cost calculation.

Table 4.1. Classification of Ports

Port	Primary Terminal	Subordinate Terminal
1. Cebu	✓	
2. Zamboanga	✓	
3. Tagbilaran		✓
4. Tacloban		✓
5. Iligan		✓
6. Bislig		✓
7. Surigao		✓
8. General Santos		✓

Source: Author.

Table 4.2. Barge Tank Capacity

Barge Type	Tank Capacity	
	cubic metres	tonnes
Large barge	30,000	13,500
Small barge	12,000	5,400

Source: Author.

4.3 Evaluation of Result from Linear Programming Model Analysis

Chapter 3 identified the optimum cost delivery plan using a static approach linear programming model.

4.3.1 Assessment of the result

Selection of delivery method. The two methods of delivering LNG from primary terminal to subordinate terminals are the hub-and-spoke method and the milk-run method (Figures 3.3 and 3.4). Chapter 3 identified the hub-and-spoke model as the cheaper option for LNG delivery.

Section of primary terminal. As discussed in Chapter 3, Cebu and Zamboanga are selected as primary LNG terminals. Scenarios for the location of secondary terminals are listed in Table 4.3 and the expenditure breakdown of Scenario 5 is in Table 4.4.

Table 4.3. List of Scenarios

Scenario	Operation Model	Location of Secondary Terminal
Scenario 1	Hub-and-spoke	Cebu
Scenario 2	Hub-and-spoke	Bislig
Scenario 3	Hub-and-spoke	Zamboanga
Scenario 4	Hub-and-spoke	General Santos
Scenario 5	Hub-and-spoke	Cebu and General Santos

Source: Author.

Table 4.4. Decomposed Capital Expenditure and Operational Expenditure in Scenario 5

($ million)

Scenario	CAPEX: Offshore FSRU	CAPEX: Tertiary Terminal	CAPEX: LNG Barges	OPEX: Onshore Terminal and FSRU	OPEX: LNG Barges
Scenario 5 (Hub-and-spoke)	624 × 2	127.2 × 6	0.3 × 3 + 0.18 × 9	66.56	13.18

CAPEX = capital expenditure, FSRU = floating storage and regasification unit, LNG = liquefied natural gas, OPEX = operational expenditure.

Source: Author.

4.3.2 Barge allocation schedule

The distribution of LNG delivery between primary and subordinate terminals is shown in Table 4.5. Nine small barges and three large barges (12 in total) are required.

- ✓ LNG is delivered from Cebu to Tagbilaran, Tacloban, Bislig, and Surigao. Small barges are used for delivery to Tagbilaran and Tacloban. Large barges are used for delivery to Bislig and Surigao.
- ✓ LNG is delivered from Zamboanga to Iligan and General Santos. Small barges are used for delivery to Iligan. Large barges are used for delivery to General Santos.

Table 4.5. Primary Terminals, Subordinate Terminals, and Barges in Linear Programming Model Analysis

Primary Terminal	Subordinate Terminal	Size of Barge	Remarks
Ceb	Tag	Small	Small barges are distributed at two ports, which causes no shared use of multiple barges and is less effective.
Ceb	Tac	Small	
Ceb	Bis	Large	
Ceb	Sur	Large	
Zam	Ili	Small	Each barge delivers liquefied natural gas only to the designated port (one for one).
Zam	San	Large	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

4.4 Dynamic Simulation

4.4.1 Assumptions

Gas consumption and storage capacity of terminals. Table 4.6 shows the LNG consumption and storage capacity of the terminals.

Table 4.6. Liquefied Natural Gas Consumption and Storage Capacity of Terminals

LNG Terminal	LNG Consumption Annual	Daily	Storage Capacity		Duration of Operational at Full Load
	(kton)	(kton)	(m^3)	(kton)	(days)
Cebu	1,159	3.17	172,000	77.4	
Zamboanga	597	1.63	172,000	77.4	
Tagbilaran	772	2.11	30,000	13.5	6.4
Tacloban	772	2.11	30,000	13.5	6.4
Iligan	597	1.63	30,000	13.5	8.3
Bislig	597	1.63	30,000	13.5	8.3
Surigao	597	1.63	30,000	13.5	8.3
General Santos	597	1.63	30,000	13.5	8.3

kton = kiloton, LNG = liquefied natural gas, m^3 = cubic metre.

Source: Author.

Navigation distances. Table 4.7 shows the navigation distances between the ports in nautical miles.

Table 4.7. Navigation Distances between Ports

(nautical miles)

	Ceb	Zam	Tag	Tac	Ili	Bis	Sur	San
Ceb		279	53	190	148	214	107	475
Zam	279		238	422	261	434	315	220
Tag	53	238		202	89	238	119	469
Tac	190	422	202		208	214	95	475
Ili	148	261	89	208		249	137	487
Bis	214	434	238	214	249		119	255

Sur	107	315	119	95	137	119		350
San	475	220	469	475	487	255	350	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Note: 1 nautical mile = 1,852 metre.

Source: Author.

4.4.2 Developing simulation models

Distribution of barges. In the simulation models, barges are distributed according to the water depth of the ports. LNG is delivered from a primary terminal to a subordinate terminal under the following rules (Table 4.8).

- ✓ LNG is delivered by small barges from Cebu to Tagbilaran, Tacloban, and Iligan. Large barges are used for delivery from Cebu to Surigao.
- ✓ LNG is delivered by large barges from Zamboanga to Bislig and General Santos.

Table 4.8. Primary Terminals, Subordinate Terminals, and Barges in Scenarios

Primary Terminal	Subordinate Terminal	Barge Size	Remarks
Ceb	Tag	Small	Small barges are operated in a group. LNG-loaded barges leave sequentially.
Ceb	Tac	Small	
Ceb	Ili	Small	
Ceb	Sur	Large	Each large barge delivers LNG only to the designated port (one for one).
Zam	Bis	Large	
Zam	San	Large	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Operation rules of barges from Cebu. It is not known how many small barges are required for operations at Cebu. Nine small barges and one large barge are deployed at the initial stage, referring to the result of the linear programming model analysis in Chapter 3. In the dynamic simulation, three small barges make up one group, which covers three subordinate terminals. The relationship of barges to ports is not one-to-one. The operation of three small barges loaded with LNG is as follows. Barges leave port for delivery in sequence (first, second, and third), depending on the LNG delivery requirements of the three ports (i.e. the amount of LNG remaining in their storage tanks). If the first barge returns after finishing the delivery before second and third barges leave port, the first barge might leave port again. As a result, the third barge has almost no chance of leaving the port.

Operation rules for barges from Zamboanga. Two large barges are deployed at Zamboanga. Deliveries to Bislig and General Santos are made on a one-to-one basis, with one barge allocated to deliver to Bislig and the other to General Santos.

Initial storage volume in tanks. All the tanks at subordinate terminals are full of LNG at the beginning of the simulation time.

Voyage speed of barges. Voyage speed is assumed to be 13.3 knots for both small and large barges.[3]

Movement of barges. The initial state of a barge is that LNG is loaded up. When a subordinate terminal orders a delivery, a barge goes into service. LNG is unloaded at the subordinate terminal within 12 hours. After returning to a primary terminal, LNG is loaded onto a barge within 12 hours and the barge waits for a delivery order. The loading facility at a primary terminal is prepared for only one barge. There is a virtual waiting position at a subordinate terminal. If there is no order for delivery, a barge waits in a virtual waiting position.

Term and time resolution of dynamic simulation. The term resolution of the dynamic simulation is 365 days; the time resolution is 1 minute.

[3] Referring to the example of Japanese small barges.

4.4.3 Simulation scenario

Six cases are developed in the simulation. Simulation starts from the scenario equivalent to the linear programming model analysis in Chapter 3, as Case 1.

As summarised in the previous subsections, ports are classified as primary terminals or subordinate terminals. Small barges are deployed at one primary terminal at Cebu. The actual required number of barges is analysed in Case 1.

The simulation results of Case 1 are reflected in cases 2 to 6, which aim to identify better shipping and tank operation to ensure LNG supply. Small barges are used for cases 1 to 3. Large barges are used for all cases.

As the Philippines is hit by many typhoons, LNG supply must be resilient to such natural disasters. Cases 3 and 6 analyse the impact of typhoons. They include provisions for idle barges, and thus require larger tank capacity to meet natural gas demand. Table 4.9 compares case 1 to 6.

Table 4.9. Comparison of Cases

Description	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Transportation system	Hub-and-spoke					
LNG consumption	Refer to Table 4.7					
Storage capacity at primary terminal	172,000 m^3 (= 77.4 kton)					
Storage capacity at subordinate terminal	30,000 m^3 (= 13.5 kton)			60,000 m^3 (= 27.0 kton)		
Number of large barges available	3			6		
Number of small barges available	9			0		
Navigation distances between Ports	Refer to Table 4.8					
Barge voyage speed	13.3 knots					
Loading hours at secondary terminal	12 hours					

Unloading hours at tertiary terminal	12 hours					
Typhoon			Typhoon			Typhoon
Remarks	LP model equiv.	Modified Case 1	Lack of storage capacity	Modified Case 2	Modified Case 4	Typhoon response: Yes

kton = kilotonne, LP = linear programming, m^3 = cubic metres.

Source: Author.

4.5 Simulation Results

4.5.1 Simulation rules of trial case

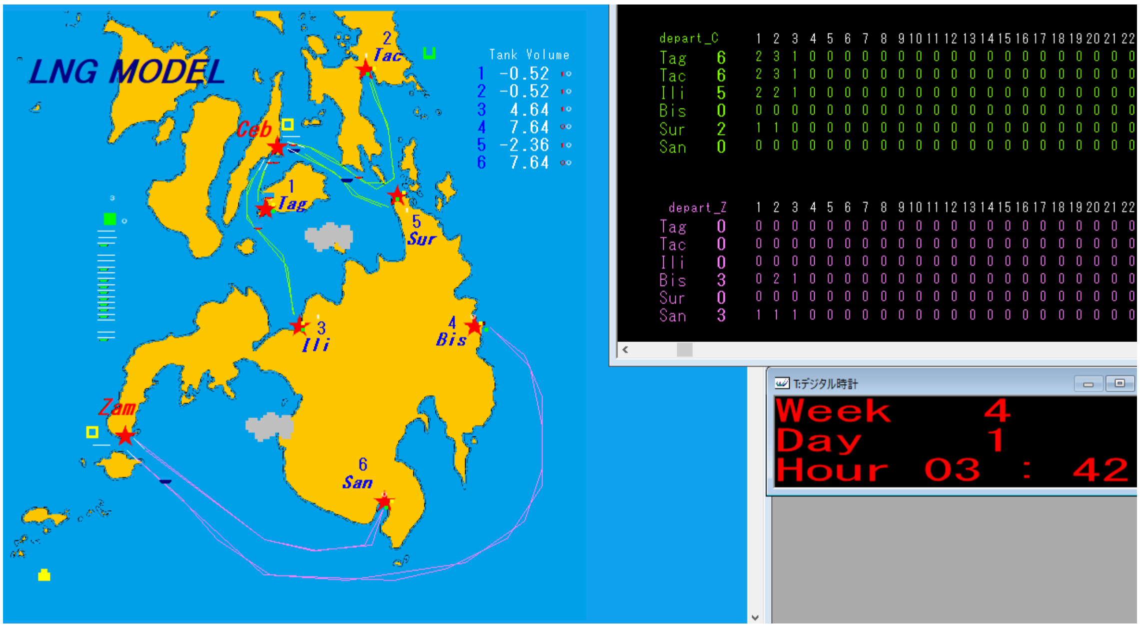
This simulation seeks to compare LNG delivery systems in terms of how barges move over time while maintaining natural gas supply to GPPs. The locations of primary and subordinate terminals are the result of linear programming model analysis in Chapter 3, i.e. they are an exogenous condition. The simulation sets out to review variables such as the combination of primary and subordinate terminals (origin and destination ports), barge operating rules, number of barges, and unit volume of LNG delivery. Before running the cases, a trial simulation was conducted to confirm the delivery rules. The trial simulation tested

- whether barges should be operated as a group (i.e. with flexibility in destination) or one-to-one (i.e. designated a certain destination),
- the thresholds for the remaining LNG tank volume and for the LNG delivery order,
- the unit volume of LNG delivery, and
- the calculation method for the remaining LNG tank volume.

These rules were confirmed and the tuning of the model was repeated.

Figure 4.1 shows the result of the most important elements of the simulation operation – rules of barge group, remaining storage volume, and loading and unloading volumes.

Figure 4.1. Image of Simulation



Source: Author.

Simulation rules

Rule for barge allocation: One large barge and nine small barges are deployed in Cebu. From Cebu, LNG is delivered to Tagbilaran, Tacloban, Iligan, and Surigao (Table 4.10). Two large barges are deployed in Zamboanga. From Zamboanga, LNG is delivered to Bislig and General Santos.

Table 4.10. Terminal and Barge Allocation: Trial Case

Primary Terminal	Subordinate Terminal			
Cebu (Barge)	Tagbilaran (Small)	Tacloban (Small)	Iligan (Small)	Surigao (Large)
Zamboanga (Barge)	Bislig (Large)	General Santos (Large)		

Source: Author.

Rule for LNG delivery orders (calls for LNG delivery):

- Subordinate ports delivered by small barge
  - ✓ Unit volume of LNG delivery: 5.4 kilotonnes (kton) (= capacity of small barge)
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 5.4 = 8.1 kton)
- Subordinate ports delivered by large barge
  - ✓ Unit volume of LNG delivery: 10.0 kton[4]
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 10.0 = 3.5 kton)

Simulation result

In Cebu, nine small barges are deployed and dispatched loaded with LNG, in order (first barge, second barge, etc.). The trial analysis confirmed that the dispatch method will work but that four small barges, rather than nine, would be enough (Table 4.11).

Figure 4.2 shows the daily change in the LNG volume remaining in the subordinate terminal storages. Although the capacity of the large barges (13.5 kton) is underutilised (10.0 kton), all terminals show that no shortage will occur.

[4] 10 kton is smaller than capacity of a large barge (13.5 kton) since 13.5 kton of LNG cannot be received by a tank with a maximum storage capacity of 13.5 kton considering the minimum LNG storage left in the tank.

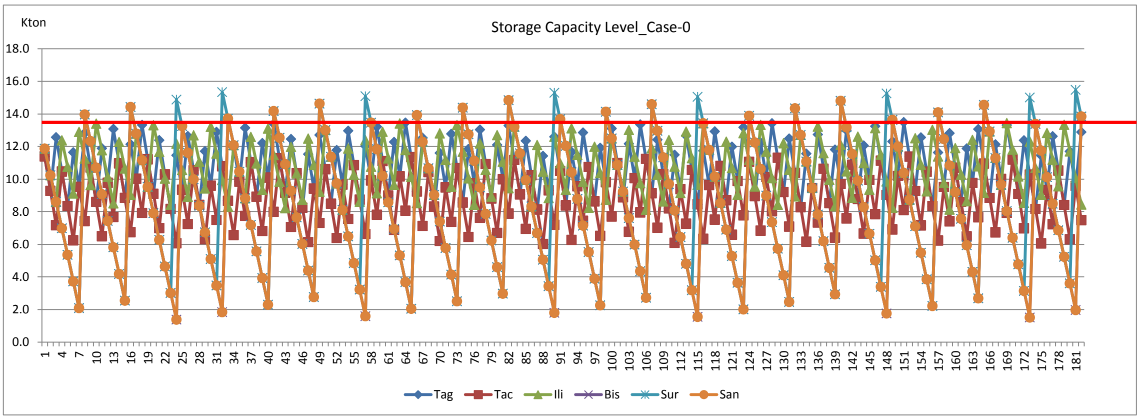
Table 4.11. Results of Dynamic Simulation: Trial Case

Barge Number	Idle (%)	Orders (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
1	42.9	8.5	38.9	9.7	0.0	0.9	20,229	142
2	35.9	14.7	30.3	19.1	0.0	4.2	34,571	111
3	42.0	14.5	27.5	16.0	0.0	1.4	34,008	101
4	76.8	5.9	11.0	6.4	0.0	0.5	13,809	40
5	100.0	0	0	0	0	0	0	0
6	100.0	0	0	0	0	0	0	0
7	100.0	0	0	0	0	0	0	0
8	100.0	0	0	0	0	0	0	0
9	100.0	0	0	0	0	0	0	0
11	78.4	4.0	12.1	5.6	0.0	1.4	9,549	44
12	55.3	16.4	11.9	16.4	0.0	0.0	38,248	44
13	71.3	8.3	12.1	8.4	0.0	0.0	19,493	44

Note: Barge numbers 1–9 = small barge, barge numbers 11–13 = large barge.

Source: Author.

Figure 4.2. Remaining Liquefied Natural Gas Volume in Terminal Storages: Trial Case



Source: Author.

4.5.2 Simulation of Case 1

This case has been simulated under conditions equivalent to the optimised solution of the linear programming model analysis.

Simulation rules

Rule for barge allocation: Three large barges and nine small barges are allocated to Cebu and Zamboanga. Cebu has two large barges that deliver LNG to Surigao and Bislig, and eight small barges that deliver LNG to Tagbilaran and Tacloban. Zamboanga has one large barge for General Santos and one small barge for Iligan (Table 4.12).

Table 4.12. Terminal and Barge Allocation: Case 1

<table>
<tr><th>Primary terminal</th><th colspan="4">Subordinate Terminals</th></tr>
<tr><td>Cebu
(Barge)</td><td colspan="2">Tagbilaran and Tacloban
(Eight small barges)</td><td>Bislig
(Large)</td><td>Surigao
(Large)</td></tr>
<tr><td>Zamboanga
(Barge)</td><td>Iligan
(Small)</td><td>General Santos
(Large)</td><td></td><td></td></tr>
</table>

Source: Author.

Rule for LNG delivery orders:

- Subordinate ports delivered by small barge
  - ✓ Unit volume of LNG delivery: 5.4 kton (capacity of small barge)
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 5.4 = 8.1 kton)
- Subordinate ports delivered by large barge
  - ✓ Unit volume of LNG delivery: 10.0 kton (footnote 4)
  - ✓ Call point: Tank capacity – unit volume of LNG delivery (13.5 – 10.0 = 3.5 kton)

Simulation result

Large barges that load 10 kton of LNG leave a port. It has been proven that it does not exceed the tank storage capacity even if 10 kton of LNG is unloaded.

Three small barges are required at Cebu and one small barge at Zamboanga to deliver LNG, but operational flexibility is not available. If we try to operate barges more efficiently, all small barges need to be placed at the same port.

Table 4.13 shows the results of the simulation. It has been proven that three small barges in Cebu can cover delivery to both Tagbilaran and Tacloban. A small barge from Zamboanga to Iligan is operated independently, with a low idle ratio and a high operation rate at 80%. This means the small barge operation is tight. Three large barges are required for three ports because of their independent operation. In all, seven barges are required.

Table 4.13. Results of Dynamic Simulation: Case 1

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
1	47.9	6.5	38.9	6.8	0.0	0.1	15,479	142
2	51.0	13.1	21.9	14.1	0.0	0.9	30,640	80
3	61.8	10.1	17.0	11.2	0.0	0.9	23,747	62
5	100.0	0	0	0	0	0	0	0
6	100.0	0	0	0	0	0	0	0
7	100.0	0	0	0	0	0	0	0
8	100.0	0	0	0	0	0	0	0
9	100.0	0	0	0	0	0	0	0
11	56.0	10.8	16.2	17.0	0.0	6.1	25,430	59
12	71.6	5.4	16.2	6.8	0.0	1.3	12,804	59
4	19.7	24.6	29.9	25.8	0.0	1.2	57,487	110
13	61.5	11.1	16.2	11.2	0.0	0.0	26,138	59

Note: Barge numbers 1–9 = small barge, barge numbers 11–13 = large barge.

Source: Author.

Table 4.14 shows the detailed operation times of each barge.

Table 4.14. Detailed Operation Time by Barge: Case 1

Primary Terminal	Barge Number	Waiting Time for Shipment	Loading Time	Transport Time	Unloading Time	Operating Time	Total Time	Rate of Operation	Travel Times
		a	b	c	d	e=a+b+c	f=a+e	g=e/f	
		(minute)	(minute)	(minute)	(minute)	(minute)	(minute)	(%)	(No.)
Ceb	1	353,939	102,240	67,739	102,240	272,219	626,158	43	142
Ceb	2	325,743	56,880	135,331	56,880	249,091	574,834	43	79
Ceb	3	369,985	44,640	106,209	44,640	195,489	565,474	35	62
Ceb	11	366,143	42,480	113,868	42,480	198,828	564,971	35	59
Ceb	12	422,165	42,480	56,880	42,480	141,840	564,005	25	59
Zam	4	187,851	78,480	256,584	78,480	413,544	601,395	69	110
Zam	15	363,009	42,480	117,056	42,480	202,016	565,025	36	59
Total		**2,388,834**	**409,680**	**853,668**	**409,680**	**1,673,028**	**4,061,862**	**41**	**570**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 1–4 = small barge; barge numbers 11, 12, 15 = large barge.

Source: Author.

Table 4.15 shows the OPEX for barges in Case 1.

Table 4.15. Barge Operational Expenditure: Case 1

Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	Total
Number of loadings	times	142	142	59	59	110	59	**571**
Point-to-point (one way)	mile	53	190	214	107	261	220	

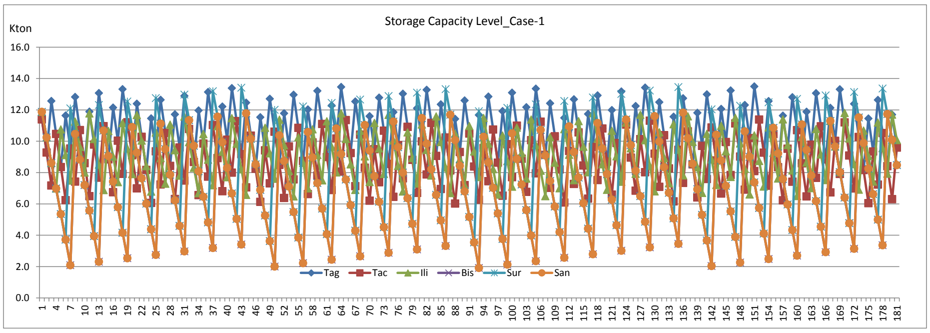
Total navigation distance (one way)	mile	7,526	26,980	12,626	6,313	28,710	12,980	**95,135**
Loading volume	kton/times	5.4	5.4	10.0	10.0	5.4	10.0	
Total transport volume	kton	767	767	590	590	594	590	**3,898**
Travelling unit price of barge	$/tonne/mile	0.083	0.083	0.059	0.059	0.083	0.059	
Total	**$'000/year**	**479**	**1,717**	**440**	**220**	**1,415**	**452**	**4,723**

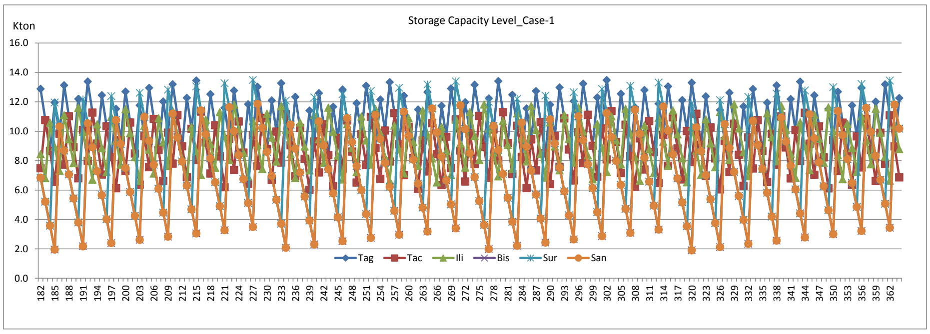
Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.3 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.3. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 1





Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.3 Simulation of Case 2

This case has been simulated under the modified conditions of Case 1.

Simulation rules

Allocation of barges: There are three large barges and four small barges, all of which are allocated to Cebu and Zamboanga. Cebu has one large barge to deliver LNG to Surigao and four small barges to deliver to Tagbilaran, Tacloban, and Iligan. Zamboanga has two large barges for deliveries to Iligan and General Santos (Table 4.16).

Table 4.16. Terminal and Barge Allocation: Case 2

<table>
<tr><th>Primary Terminal</th><th colspan="4">Subordinate Terminals</th></tr>
<tr><td>Cebu
(Barge)</td><td colspan="3">Tagbilaran, Tacloban, and Iligan
(Four small barges)</td><td>Surigao
(Large)</td></tr>
<tr><td>Zamboanga
(Barge)</td><td>Bislig
(Large)</td><td>General Santos
(Large)</td><td></td><td></td></tr>
</table>

Source: Author.

Rules for LNG delivery orders: Same as in Case 1.

Simulation result

Large barges loading 10 kton of LNG leave port. It has been proven that it does not exceed the storage capacity even if 10 ktoe of LNG is unloaded.

Four small barges are capable of delivering LNG from Cebu to three ports: Tagbilaran, Tacloban, and Iligan.

Table 4.17 shows the results of the simulation. The simulation proves that four small barges are sufficient to deliver LNG. However, as the idle ratio of the fourth barge is high, the travel plans should be reviewed. As large barges are operated independently, three large barges are required. In all, seven barges are required.

Table 4.17. Results of Dynamic Simulation: Case 2

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
1	42.8	8.5	38.9	9.8	0.0	1.0	20,229	142
2	35.4	14.7	30.4	19.6	0.0	4.7	34,571	111
3	42.4	14.4	27.3	16.0	0.0	1.6	33,625	100
4	76.1	6.0	11.2	6.7	0.0	0.6	14,192	41
11	71.0	5.4	16.2	7.4	0.0	1.9	12,804	59
12	39.8	22.0	16.2	22.1	0.0	0.0	51,390	59
13	61.5	11.1	16.2	11.2	0.0	0.0	26,138	59

Note: Barge numbers 1–4 = small barge; barge numbers 11–13 = large barge.

Source: Author.

Table 4.18 shows the detailed operation times of each barge.

Table 4.18. Detailed Operation Time by Barge: Case 2

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	1	332,514	102,240	89,164	102,240	293,644	626,158	47	142
Ceb	2	289,025	79,200	152,609	79,200	311,009	600,034	52	110
Ceb	3	301,109	71,280	149,506	71,280	292,066	593,175	49	99
Ceb	4	420,701	29,520	63,413	29,520	122,453	543,154	23	41
Ceb	11	422,165	42,480	56,880	42,480	141,840	564,005	25	59
Zam	12	247,008	41,760	227,068	41,760	312,992	560,000	56	58
Zam	15	363,009	42,480	117,056	42,480	202,016	565,025	36	59
Total		**2,375,531**	**408,960**	**855,696**	**408,960**	**1,676,020**	**4,051,551**	**41**	**568**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 1–4 = small barge; barge numbers 11, 12, 15 = large barge.

Source: Author.

Table 4.19 shows OPEX for barges in Case 2.

Table 4.19. Barge Operational Expenditure: Case 2

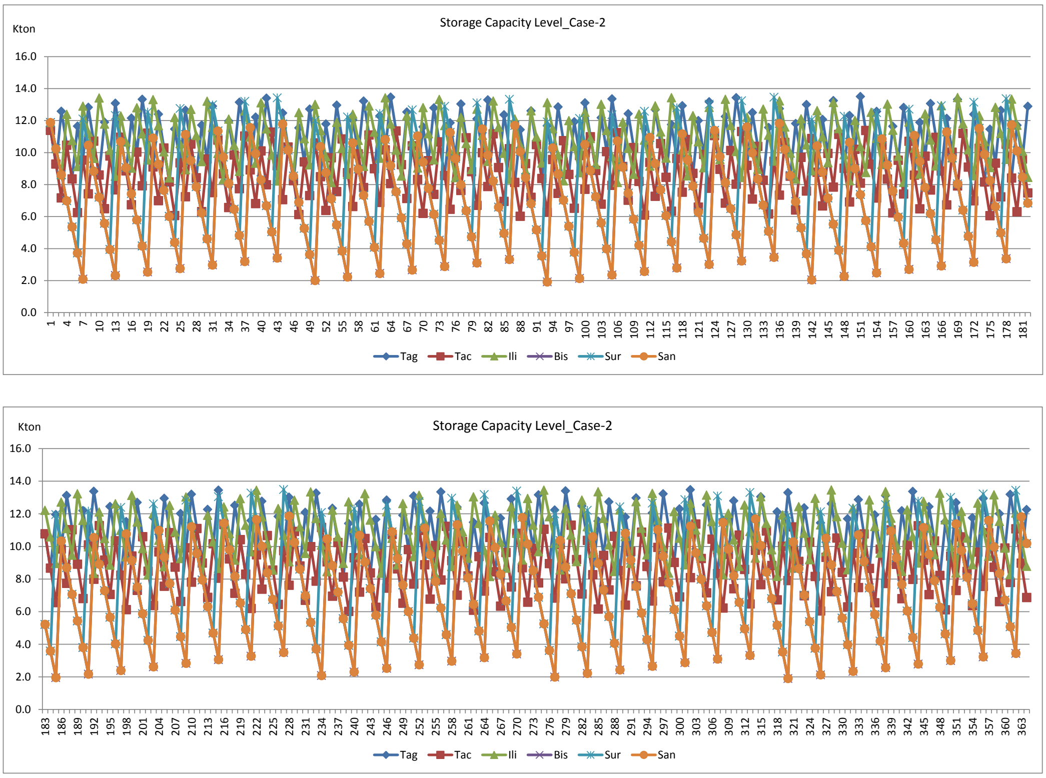
Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	Total
Number of loadings	times	142	142	109	59	59	59	**570**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	7,526	26,980	16,132	12,626	18,585	12,980	**94,829**
Loading volume	kton/times	5.4	5.4	5.4	10.0	10.0	10.0	
Total transport volume	kton	767	767	589	590	590	590	**3,892**
Travelling unit price of barge	$/tonne/ mile	0.083	0.083	0.083	0.059	0.059	0.059	
Total	**$'000/year**	**479**	**1,717**	**788**	**440**	**647**	**452**	**4,523**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton = kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.4 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.4. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 2



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.4 Simulation of Case 3

This case assumes typhoon strikes.

Rules for typhoon strike

Initially, the annual average frequency of typhoon strikes in each region – Luzon, Visayas, and Mindanao – was calculated and the result was less than 1. However, to minimise risk, we decided to employ data from a single year when the Philippines hit by a historically high number of typhoons. This was 2006 for Luzon and 2013 for Visayas and Mindanao.

A typhoon in Visayas will affect the operation of ships departing from Cebu port, and a typhoon in Mindanao will affect shipping in and around Zamboanga port.

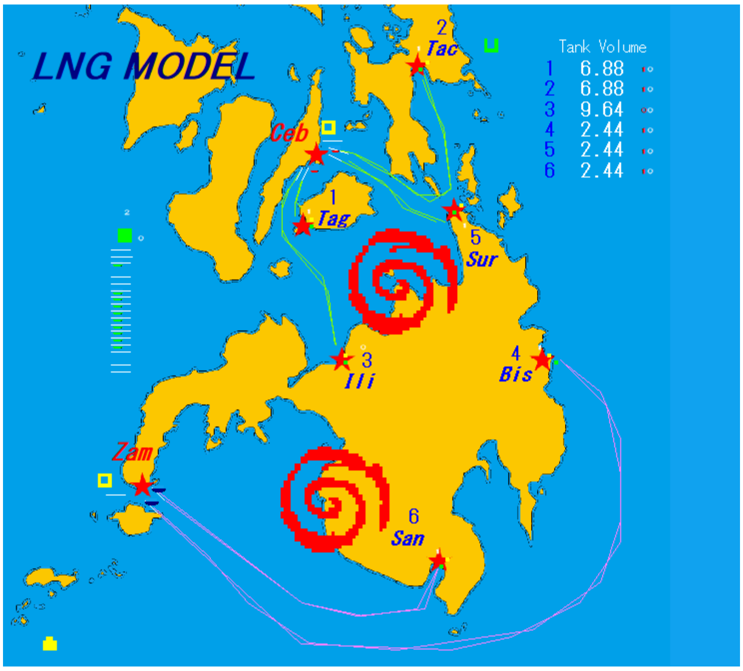
Table 4.20. Dates of Typhoon Strikes, 2006 and 2013

Year	Grid	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	Luzon					9-15	10-14 21-25	28-2	5-9	25-29	10-12 27-30	28-1	
2013	Visayas		30-1	21-25			13-17	18-23		12-15 17-22		26-28	4-10
2013	Mindanao	17-20	30-1	21-25								26-28	4-10

Source: Government of the Philippines, Department of Energy.

Figure 4.5 shows an image from the simulation. Barge operations of are stopped for the duration of the typhoon.

Figure 4.5. Typhoon Strike Simulation Image



Source: Author.

Simulation rules

Rules for allocation of barges: To prepare for typhoon strikes, eight small barges have been deployed at Cebu in a group and the operation rule is that LNG-loaded barges leave port for delivery in sequence (first, second, third, etc.). Eight small barges are assigned to deliver to Tagbilaran, Tacloban, and Iligan, and one large barge is allocated for deliveries to Surigao. Zamboanga has two large barges, which deliver to Bislig and General Santos (Table 4.21).

Table 4.21. Terminal and Barge Allocation: Case 3

<table>
<tr><th>Primary terminal</th><th colspan="4">Subordinate terminal</th></tr>
<tr><td>Cebu
(Barge)</td><td colspan="3">Tagbilaran, Tacloban, and Iligan
(Eight small barges)</td><td>Surigao
(Large)</td></tr>
<tr><td>Zamboanga
(Barge)</td><td>Bislig
(Large)</td><td>General Santos
(Large)</td><td></td><td></td></tr>
</table>

Source: Author.

Rules for LNG delivery orders: Same as in Case 1.

Simulation result

Table 4.22 shows the results of the simulation. It indicates a very low rate of dispatch of orders for barge numbers 5 to 8. As delivery is suspended during the typhoon, the blocking ratio is high compared with Case 2.

Table 4.22. Results of Dynamic Simulation: Case 3

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loading
1	36.1	16	34.52	13.24	0	12.36	19,915	126
2	32.5	18	27.89	21.62	0	13.96	29,962	102
3	37.7	17	26.44	19.19	0	9.18	31,133	97
4	65.7	9	13.42	11.59	0	7.75	15,347	49
5	90.6	3	2.74	3.91	0	3.86	3,315	10
6	94.9	1	1.92	2.23	0	1.26	2,269	7
7	99.0	0	0.27	0.57	0	0.4	385	1
8	99.1	0	0.27	0.47	0	0.34	301	1
11	64.3	10	16.2	9.4	0	8.5	12,863	59
12	35.8	23	16.2	24.6	0	3.9	51,449	59
13	57.1	13	16.2	14.2	0	4.3	26,197	59

Note: Barge numbers 1–8 = small barge; barge numbers 11–13 = large barge.

Source: Author.

Table 4.23 shows the detailed operation times of each barge.

Table 4.23. Detailed Operation Time by Barge: Case 3

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	1	820,807	90,720	128,915	90,720	310,355	1,131,162	27	126
Ceb	2	787,262	73,440	175,216	73,440	322,096	1,109,358	29	102
Ceb	3	770,536	69,120	164,198	69,120	302,438	1,072,974	28	96
Ceb	4	883,986	35,280	89,974	35,280	160,534	1,044,520	15	49
Ceb	5	853,243	7,200	22,451	7,200	36,851	890,094	4	10
Ceb	6	483,689	5,040	10,131	5,040	20,211	503,900	4	7
Ceb	7	385,921	720	1,718	720	3,158	389,079	1	1
Ceb	8	385,921	720	1,665	720	3,105	389,026	1	1
Ceb	11	397,266	42,480	81,784	42,480	166,744	564,010	30	59
Zam	12	230,168	42,480	256,192	42,480	341,152	571,320	60	59
Zam	13	339,721	42,480	140,348	42,480	225,308	565,029	40	59
Total		**6,338,521**	**409,680**	**1,072,591**	**409,680**	**1,891,951**	**8,230,472**	**23**	**569**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 1–4 = small barge; barge numbers 11–13 = large barge.

Source: Author.

Table 4.24 shows the OPEX for barges in Case 3.

Table 4.24. Barge Operational Expenditure: Case 3

Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	**Total**
Number of loadings	times	142	141	110	59	59	59	**570**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	7,526	26,790	16,280	12,626	18,585	12,980	**94,787**
Loading volume	kton/times	5.4	5.4	5.4	10.0	10.0	10.0	
Total transport volume	kton	767	761	594	590	590	590	**3,892**
Travelling unit price of barge	$ tonne/ mile	0.083	0.083	0.083	0.059	0.059	0.059	
Total	**$'000/ year**	**479**	**1,693**	**803**	**440**	**647**	**452**	**4,513**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

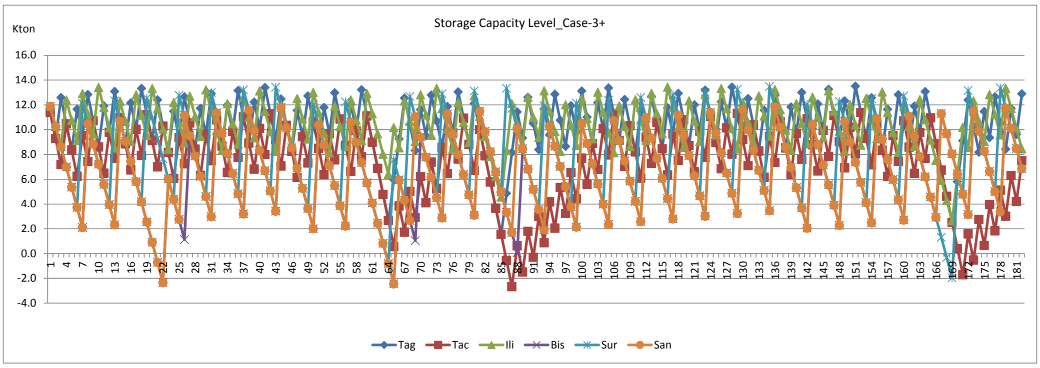
Figure 4.6 shows the daily change in the remaining LNG volume in the subordinate terminal storages.

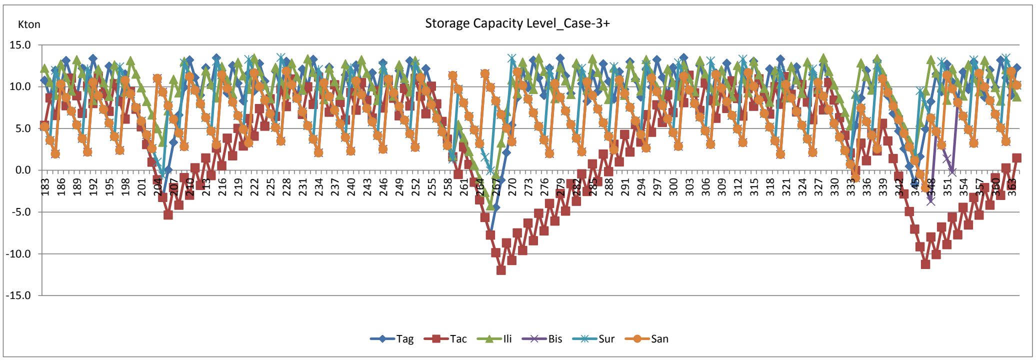
In Tacloban, which consumes a lot of LNG, the remaining LNG volume in the storage tank becomes a negative value for a long period, meaning Tacloban cannot sustain a natural gas supply to the GPP under the assumed storage capacity and ship operation parameters.

In Tagbilaran, which also consumes a lot of LNG, the LNG volume remaining in the storage tank becomes negative as well. However, the period of LNG shortage is shorter in Tagbilaran than it is in Tacloban because Tagbilaran is the first port in the sequence of LNG delivery.

Bislig and General Santos, in Mindanao, are hit by fewer typhoons.

Figure 4.6. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 3





Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.5 Simulation of Case 4

This case is based on and modified from Case 2. In cases 4 to 6, we assumed that LNG is delivered only by large barges and that terminal storage capacity is increased.

Simulation rules

Terminal storage capacity: The terminal storage capacity of subordinate terminals is doubled (Table 4.25).

Table 4.25. Terminal Storage Capacity by Case

Classification of Terminal	Terminal	Cases 1–3		Cases 4–6	
		m^3	kton	m^3	kton
Primary	Cebu	188,000	85.0	188,000	85.0
	Zamboanga	188,000	85.0	188,000	85.0
Suboridnate	Tagbilaran	30,000	13.5	60,000	27.0
	Tacloban	30,000	13.5	60,000	27.0
	Iligan	30,000	13.5	60,000	27.0
	Bislig	30,000	13.5	60,000	27.0
	Surigao	30,000	13.5	60,000	27.0
	General Santos	30,000	13.5	60,000	27.0

kton = kiloton, m^3 = cubic metre.

Source: Author.

Allocation of barges: Only large barges are deployed. Three large barges are deployed at Cebu in a group to deliver LNG to Tagbilaran, Tacloban, Iligan, and Surigao. Two large barges are deployed at Zamboanga in a group to deliver LNG to Bislig and General Santos (Table 4.26).

Table 4.26. Terminal and Barge Allocation: Case 4

Primary Terminal	Subordinate Terminal
Cebu (Barge)	Tagbilaran, Tacloban, Iligan, and Surigao (Three large barges)
Zamboanga (Barge)	Bislig and General Santos (Two large barges)

Source: Author.

Rule for LNG delivery orders:

- ✓ Unit volume of LNG delivery: 13.5 kton
- ✓ Call point: Tank capacity – unit volume of LNG delivery (27.0 – 13.5 = 13.5)

Simulation result

In Case 2, four small barges and one large barge are deployed at Cebu, while Case 4 assumes three large barges instead.

Table 4.27 shows the results of the simulation. It has been proven that three large barges are sufficient to deliver LNG from Cebu to the four islands.

Table 4.27. Results of Dynamic Simulation: Case 4

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loading
11	61	7	23	10	0	2	16,424	84
12	55	11	23	11	0	0	25,089	82
13	83	4	9	4	0	1	8,687	34
14	56	16	12	16	0	0	37,771	43
15	72	8	12	8	0	0	19,270	43

Note: Barge numbers 11–15 = large barge.

Source: Author.

Table 4.28 shows the detailed operation times of each barge.

Table 4.29 shows the OPEX for barges in Case 4. Because the storage capacity of the subordinate terminals was doubled, the number of loadings and navigation time, and consequently their cost, are reduced compared with Case 2.

Table 4.28. Detailed Operation Time by Barge: Case 4

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	11	380,018	59,760	74,917	59,760	194,437	574,455	34	83
Ceb	12	342,857	59,040	114,821	59,040	232,901	575,758	40	82
Ceb	13	456,214	23,760	37,980	23,760	85,500	541,714	16	33
Zam	14	317,973	30,960	168,343	30,960	230,263	548,236	42	43
Zam	15	399,073	30,960	85,312	30,960	147,232	546,305	27	43
Total		**1,896,135**	**204,480**	**481,373**	**204,480**	**890,333**	**2,786,468**	**32**	**284**

Ceb = Cebu, Zam =Zamboanga.

Note: Barge numbers 11–15 = large barge.

Source: Author.

Table 4.29. Barge Operational Expenditure: Case 4

Item	Unit	Navigation Route (From/To)						Total
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	
Number of loadings	times	57	57	44	43	43	44	**288**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	3,021	10,830	6,512	9,202	13,545	9,680	**52,790**
Loading volume	kton/times	13.5	13.5	13.5	13.5	13.5	13.5	
Total transport volume	kton	770	770	594	581	581	594	**3,888**

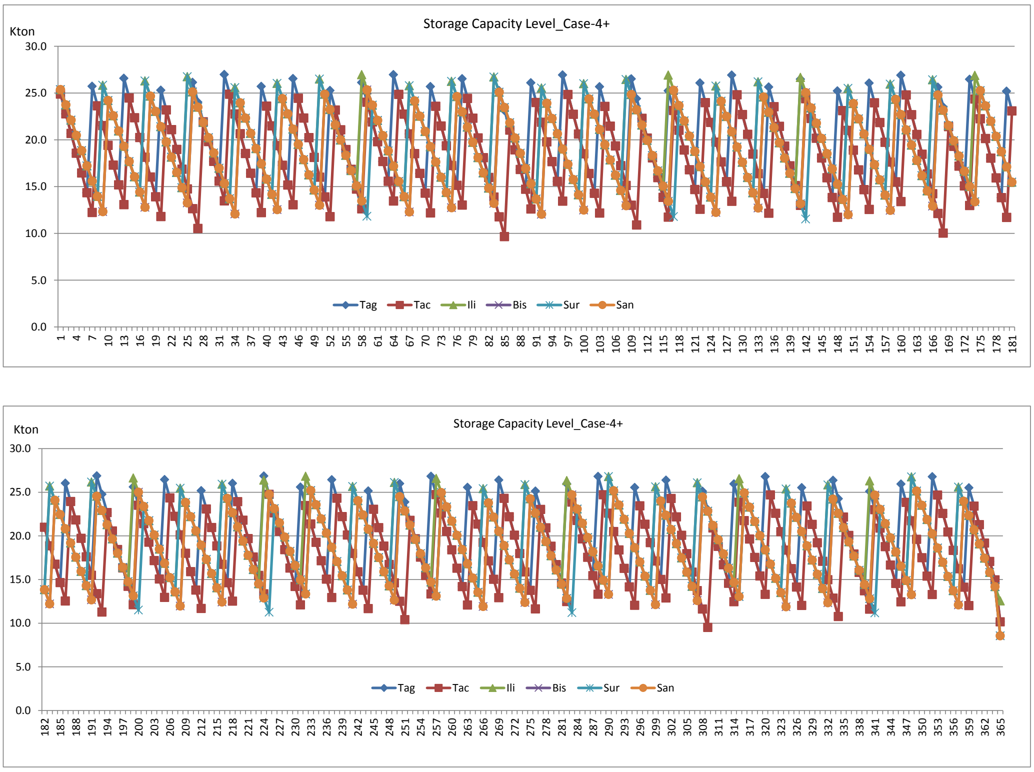
Travelling unit price of barge	$/tonne/mile	0.059	0.059	0.059	0.059	0.059	0.059	
Total	**$'000/year**	**137**	**492**	**228**	**315**	**464**	**339**	**1,975**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton = kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.7 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.7. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 4



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.6 Simulation of Case 5

This case is based on and modified from Case 4.

Simulation rules

Initial condition of remaining storage volume: From Case 1 to Case 4, the initial condition of all storage tanks is set as full. The barge dispatch order is signalled when the amount of LNG left in the tank hits the lower limit after regasified gas is consumed by the GPP. If the subordinate terminals' LNG consumption are the same (Table 4.6), the remaining LNG storage would reach the limit level at the same time. It means that barge dispatch orders for different subordinate terminals would be signalled about the same timing and more barges would be required. To avoid this situation, the remaining LNG storage volume in each subordinate terminal is differentiated. This adjustment is expected to reduce the congestion of dispatch orders and improve the operation of barges.

Allocation of barges: Only large barges are deployed. Two large barges are deployed at Cebu in a group to deliver LNG to Tagbilaran, Tacloban, Iligan, and Surigao. One large barge is deployed at Zamboanga to deliver LNG to Bislig and General Santos (Table 4.30).

Table 4.30. Terminal and Barge Allocation: Case 5

Primary Terminal	Subordinate Terminal
Cebu (Barge)	Tagbilaran, Tacloban, Iligan, and Surigao (two large barges)
Zamboanga (Barge)	Bislig and General Santos (one large barge)

Source: Author.

Rule of LNG delivery order: Same as in Case 4.

Simulation result

By changing the size of the barge fleet and the initial condition of the remaining LNG storage volume in subordinate terminal tanks, the total number of barges can be reduced from five to three.

Table 4.31 shows the results of the simulation. It has been proven that two large barges are satisfactory to deliver LNG from Cebu and one large barge is enough for deliveries from Zamboanga.

Table 4.31. Results of Dynamic Simulation: Case 5

Barge number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation distance	Number of loading
11	41.3	13.0	32.2	13.5	0.0	0.5	30,502	117
12	58.7	8.6	23.4	9.3	0.0	0.6	20,241	86
13	25.9	25.0	24.1	25.0	0.0	0.0	58,329	88

Note: Barge number 11-13: large barge

Source: Author.

Table 4.32 shows the detailed operation times of each barge. The operating rate of barge allocated to Cebu is improved compared with Case 4.

Table 4.32. Detailed Operation Time by Barge: Case 5

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	11	302,264	84,240	135,021	84,240	303,501	605,765	50	117
Ceb	12	444,557	61,200	89,336	61,200	211,736	656,293	32	85
Zam	13	405,951	63,360	320,999	63,360	447,719	853,670	52	88
Total		**1,152,773**	**208,800**	**545,356**	**208,800**	**962,956**	**2,115,728**	**46**	**290**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 11–13 = large barge.

Source: Author.

Table 4.33 shows the OPEX for barges in Case 5.

Table 4.33. Barge Operational Expenditure: Case 5

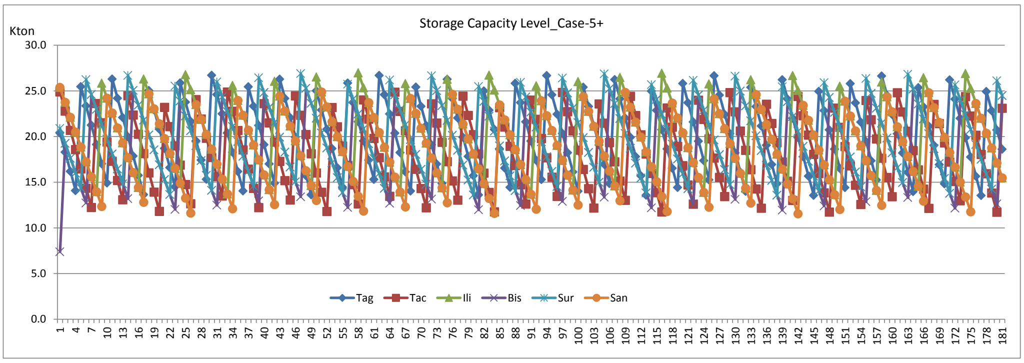
Item	Unit	Navigation Route (From/To)						
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	Total
Number of loadings	times	58	57	44	45	45	43	**292**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance (one way)	mile	3,074	10,830	6,512	9,630	14,175	9,460	**53,681**
Loading volume	kton/times	13.5	13.5	13.5	13.5	13.5	13.5	
Total transport volume	kton	783	770	594	608	608	581	**3,942**
Travelling unit price of barge	$/tonne/mile	0.059	0.059	0.059	0.059	0.059	0.059	
Total	**$'000/year**	**142**	**492**	**228**	**345**	**508**	**324**	**2,039**

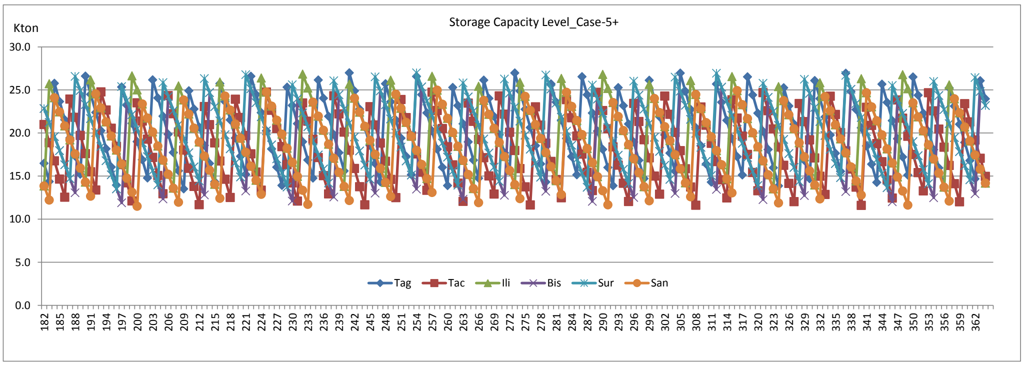
Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton = kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Figure 4.8 shows the daily change in the LNG volume remaining in the subordinate terminal storages. All terminals show that no shortage will occur.

Figure 4.8. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 5





Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.7 Simulation of Case 6

This case assumes typhoon strikes.

Rule of typhoon strike: Same as in Case 3.

Simulation rules

Allocation of barges: To prepare for typhoon strikes, four large barges have been deployed at Cebu in a group operation in which LNG-loaded barges leave port for delivery in sequence (first, second, third, etc.). Zamboanga has two large barges in a group operation, which deliver LNG to Bislig and General Santos (Table 4.34).

Table 4.34. Terminal and Barge Allocation: Case 6

Primary Terminal	Subordinate Terminal
Cebu (Barge)	Tagbilaran, Tacloban, Iligan, and Surigao (Four large barges)
Zamboanga (Barge)	Bislig and General Santos (Two large barges)

Source: Author.

Rule of LNG delivery order: Same as in Case 1

Simulation result

Table 4.35 shows the results of the simulation.

Table 4.35. Results of Dynamic Simulation: Case 6

Barge Number	Idle (%)	Order (%)	Load/ Unload (%)	Transport (%)	Stoppage (%)	Block (%)	Navigation Distance	Number of Loadings
11	36.2	18.8	29.7	15.4	0.0	10.3	27,820	108
12	53.2	15.3	22.3	9.2	0.0	7.7	19,619	82
13	91.4	5.0	2.2	1.4	0.0	4.6	2,109	8
14	96.3	1.1	1.4	1.2	0.0	1.2	1,397	5
15	52.4	18.5	12.3	16.8	0.0	1.6	39,241	45
16	68.6	11.4	11.9	8.2	0.0	3.0	19,314	43

Note: Barge numbers 11–16 = large barge.

Source: Author.

Table 4.36 shows the detailed operation times of each barge.

Table 4.36. Detailed Operation Time by Barge: Case 6

Primary Terminal	Barge Number	Waiting Time for Shipment a (minute)	Loading Time b (minute)	Transport Time c (minute)	Unloading Time d (minute)	Operating Time e=a+b+c (minute)	Total Time f=a+e (minute)	Rate of Operation g=e/f (%)	Travel Times (No.)
Ceb	11	786,534	77,760	175,195	77,760	330,715	1,117,249	30	108
Ceb	12	856,268	58,320	122,595	58,320	239,235	1,095,503	22	81
Ceb	13	459,275	6,480	32,492	6,480	45,452	503,038	9	9
Ceb	14	485,789	3,600	9,101	3,600	16,301	502,090	3	5
Zam	15	307,071	33,840	188,352	33,840	256,032	563,103	45	45
Zam	16	384,513	30,960	99,876	30,960	161,796	546,309	30	43
Total		**3,279,450**	**210,240**	**635,274**	**210,240**	**1,055,754**	**3,293,913**	**32**	**291**

Ceb = Cebu, Zam = Zamboanga.

Note: Barge numbers 11–16 = large barge.

Source: Author.

Table 4.37 shows OPEX for barges in Case 6.

Table 4.37. Barge Operational Expenditure: Case 6

Item	Unit	Navigation Route (From/To)						Total
		Ceb/ Tag	Ceb/ Tac	Ceb/ Bis	Ceb/ Sur	Zam/ Ili	Zam/ San	
Number of loadings	times	58	57	44	45	45	44	**293**
Point-to-point (one way)	mile	53	190	148	214	315	220	
Total navigation distance	mile	3,074	10,830	6,512	9,630	14,175	9,680	**53,901**

(one way)								
Loading volume	kton/ times	13.5	13.5	13.5	13.5	13.5	13.5	
Total transport volume	kton	783	770	594	608	608	594	**3,956**
Travelling unit price of barge	$/ tonne/ mile	0.059	0.059	0.059	0.059	0.059	0.059	
Total	**$'000/ year**	**142**	**492**	**228**	**345**	**508**	**339**	**2,054**

Bis = Bislig, Ceb = Cebu, Ili = Iligan, kton – kilotonne, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

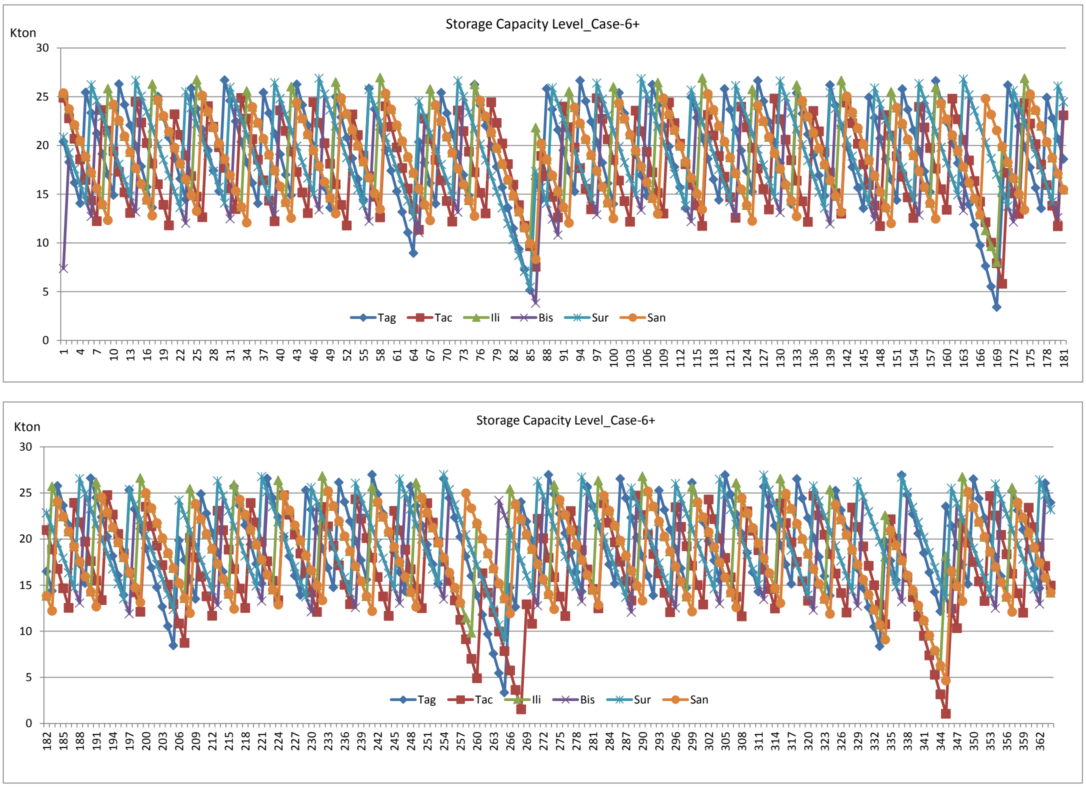
Source: Author.

Figure 4.9 shows the daily change in LNG volume remaining in the subordinate terminal storages.

By doubling the storage capacity in the subordinate terminals, the remaining LNG storage volume avoided falling to zero, although it sometimes almost dropped to this level. Delivery of LNG from Cebu to the subordinate terminals in Tagbilaran, Tacloban, Iligan, and Surigao is manageable with four large barges even in the event of a typhoon.

However, Tacloban and Tagbilaran (which consume a lot of LNG) and Bislig (which requires long-distance navigation) experienced critically low storage levels of less than 5 ktons on six occasions. Even though the result shows that the natural gas supply to GPPs will be sustained under the assumed typhoon hit, it also indicates that LNG receiving tanks in subordinate terminals could become empty if the frequency of typhoon is higher and their duration is longer.

Figure 4.9. Remaining Liquefied Natural Gas Volume in Terminal Storages: Case 6



Note: Upper graph = days 1–181; lower graph = days 182–365.

Source: Author.

4.5.8 Summary

Table 4.38 summarises the simulation results.

Because of the lower operating cost of large barges, the cases that assume the use of large barges only are cheaper than those that use small barges. Case 4 is the cheapest operation. However, the share of OPEX against annual total cost is very low – less than 3%. CAPEX and fixed costs are dominant in the total cost. Considering the total cost, Case 2 is the cheapest operation. When considering preparedness for typhoons, Case 6 is the only viable choice.

Table 4.38. Summary of Simulation Results

	Case 1 (LP Model)	Case 2	Case 3 (Typhoon)	Case 4	Case 5	Case 6 (Typhoon)
Main Features of Cases						
Storage capacity (Primary terminal)	77.4 kton	<--	<--	<--	<--	<--
Storage capacity (Subordinate terminal)	13.5 kton	<--	<--	27.0 kton	<--	<--
Number of Small barge	9	4	8			
Number of Large barge	3	3	3	5	3	6
CAPEX + Fixed cost						(Thousand USD)
(i) Primary terminal	1,248,000	1,248,000	1,248,000	1,248,000	1,248,000	1,248,000
(ii) Subordinate terminal	765,600	765,600	765,600	1,531,200	1,531,200	1,531,200
(iii) Small barge	32,400	14,400	28,800			
(iv) Large barge	18,000	18,000	18,000	30,000	18,000	36,000
(v) Total CAPEX (20 years)	2,064,000	2,046,000	2,060,400	2,809,200	2,797,200	2,815,200
(vi)=(i):(v) Total CAPEX (per year)	103,200	102,300	103,020	140,460	139,860	140,760
(vii) Fixed cost (FSRU OPEX)	47,840	47,840	47,840	47,840	47,840	47,840
(x) Fixed cost (Subordinate terminal OPEX)	18,720	18,720	18,720	28,080	28,080	28,080
(ix)=(vii)+(x) Total Fixed cost per year	66,560	66,560	66,560	75,920	75,920	75,920
(ix)=((vi)+(vii) CAPEX + Fixed cost (per year)	169,760	168,860	169,580	216,380	215,780	216,680
OPEX						(Thousand USD)
(iix) Barges	4,723	4,523	4,513	1,975	2,039	2,054
Total cost (per year)						(Thousand USD)
(iiix)=(ix)+(iix)	174,483	173,383	174,093	218,355	217,819	218,734
Evaluation						
Without Typhoon	Yes	Yes	Yes	Yes	Yes	Yes
Typhoon response	No	No	No	No	No	**Yes**

<-- = same value as the left cell, CAPEX = capital expenditure, FSRU = floating storage and regasification unit, kton = kilotonne, LP = linear programming, OPEX = operational expenditure,

Note: The operation cost of doubled storage capacity in subordinate terminal is assumed to be 1.5 times of unit cost of daily storage operation.

Source: Author.

Chapter 5

Conclusion and Policy Recommendation

An optimal small- and medium-scale LNG delivery and cost study in the Philippines was conducted in the following way.

1. The electricity demand distribution and LNG demand in 2040 were estimated and LNG terminal locations selected.
2. The optimal LNG delivery system was determined by static simulation using a linear programming model.
3. With reference to the static simulation results, the costs of various LNG delivery scenarios, including the typhoon strike scenario, were compared using dynamic simulation to model LNG barge operation.

In Chapter 2, the study first estimated the distribution of electricity demand in the Philippines by province. The results were used to identify the possible locations of GPPs in 2040. Then, the necessary amount of LNG to run the assumed number GPPs was calculated. To do this, the study identified the concentration of electricity demand, and thus, suitable places for siting GPPs and LNG receiving terminals.

In the Luzon power grid area, all the three possible LNG receiving terminals are estimated to have enough demand to become importing terminals (primary terminals). Therefore, these LNG supplies are excluded from the analysis.

In the Visayas power grid area, Cebu, Tagbilaran, and Tacloban are identified as candidate locations for bulk-breaking LNG receiving terminals. Of the three, Cebu is estimated to have the largest LNG demand.

In the Mindanao power grid area, Zanboanga, Iligan, Bislig, Surigao, and General Santos are selected as possible locations for bulk-breaking LNG receiving terminals.

In Chapter 3, the study compared several different solutions, in terms of location of LNG terminals, type and scale of facilities, and transportation models. Based on the distribution of demand, the pattern of demand near each port, and the physical conditions of the port, our mixed integer programming model indicated the most efficient (i.e. meeting the demand at minimum cost) solution for Visayas and Mindanao by 2040.

According to the results of the model and comparison of several scenarios, it is recommended that Cebu and Zamboanga are developed as the primary LNG receiving terminals, with the capacity to redistribute LNG to other demand centres in the southern districts, applying FSRU solutions. An optimal combination of large and small barges operating a hub-and-spoke transportation model is the solution with the minimum total system costs.

In Chapter 4, the dynamic simulation study identified key factors for small- and medium-scale LNG deliveries to the subordinate terminals. They include the capacity of the LNG barges and storages.

To minimise costs, it is essential to reduce the number of LNG deliveries to the subordinate terminals by using large barges. The application of large-capacity storage is crucial for mitigating disruption to LNG deliveries to the islands due to natural disasters. To avoid a shortage of LNG tanks, each subordinate terminal should have a large tank at its site, but this increases capital costs. A combination of six large-capacity LNG barges (30,000m^3) and six large-capacity LNG storages (50,000m^3) could avoid tank shortages due to typhoons. The operating cost of the LNG barges and storages is estimated at $30.1 million.

The rate of operation of the third and fourth barges allocated to Cebu is too low, however. Operating the LNG tankers more wisely could decrease the number of LNG barges needed at the Cebu primary terminal.

Appendix. Patterns of Operation in Scenarios 5 and 6

Tables A1 and A2 present the number of small barges and large barges delivery to each port from the two primary terminals chosen in Scenario 5.

Table A1. Weekly Delivery Schedule by Small Barge: Scenario 5 (number of barges)

To	From	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Tag	Ceb	2	4	2	3	3	4	1	3	4	1	3	4	2	2	3	4	2	3	2	4	2	3	4	1	4	2	2	5	2	2	4	3
Tag	Zam	1																															
Tac	Ceb	1																															
Ili	Ceb	3	3	3	3	2	3	4	2	3	3	4	1	3	3	4	1	3	2	3	3	3	4	1	4	3	2	3	2	3	3	3	2
Ili	Zam										1							2									1						
Bis	Ceb	3	2	2	2	2	2	2	3	2		2	2	2	2	2	2	2		2	2	4		2	3	2		3	2	2	2	2	3
Sur	Ceb				1																												
San	Zam										1																						

To	From	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Tag	Ceb	3	1	3	4	3	3	2	3	3	3	2	2	3	2	3	3	4	3	1	3
Tag	Zam																				
Tac	Ceb	3	4	2	3	2	4	3	2	2	4	3	2	2	3	4	2	3	2	3	3
Ili	Ceb	1											3							1	2
Ili	Zam		2	2	2	2	2	2	2	4	2		1		2	2	4	2		1	
Bis	Ceb																				
Sur	Ceb																				1
San	Zam																				

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Table A2. Weekly Delivery Schedule by Large Barge: Scenario 5 (number of barges)

To	From	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Bis	Ceb	1		1		1	1	1	1		1	1	1	1	1		1	1	1	1		1	1	1	1		1	1	1	1	1		1
Bis	Zam		1																														
Sur	Ceb	1	1	1	1	1		1	1	1	1		1	1	1	1	1		1	1	1	1		1	1	1	1	1		1	1	1	1
San	Zam	1	1	1	1	1		1	1	1		1	1	1	1		1	1	1	1		1	1	1	1		1	1	1	1	1		1

To	From	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Bis	Ceb	1	1	1		1	1	1	1	1		1	1	1	1		1	1	1	1	
Bis	Zam																				

Sur	Ceb		1	1	1	1		1	1	1	1	1		1	1	1	1		1	1	
San	Zam	1	1	1		1	1	1	1	1		1	1	1	1		1	1	1	1	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

In the case of milk-run delivery, our model optimises the amount of delivery, rather than the number of ship deliveries (since each ship does not necessarily unload equal amounts of LNG at each call to the port) that reach a port from a certain primary port or non-primary port. The benefit of such practice is for the consideration of reducing the model from a non-linear programming problem to a linear programming one, so as to save the computing resources needed which is typically beyond that of a personal computer. Tables A3 and A4 present the results of the amount of delivery by small barges and large barges to each non-primary port.

Table A3. Schedule of Delivery in Scenario 6 as Amount of Delivery Reached by Small Barges (in 52 weeks)

To	From	Via	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
g	m	g			8.4		5.6							0.1	2.15				8.95	9.25	.6	5.8		0.5
g	m	c	0.6	6.2		15	2.8	0.6	8.4	3.7	2.1	1.6	4.7	4.9	9	7.45		1.6		1.8	7	0.6	0.6	8.9
g	m		4.4	8.8	6.6	5.6			13.2	5.6	5		11.6			11.4	8.4							
c	m	g			8.4														8.95					
c	m	c	7.2	6.2		15	15	0.6	8.4	15	2.1	1.6	8.4	1.5	9	7.45	3.2	1.6		1.8	.5	0.6	0.6	8.9
c	m			6.6	6.6			11			12.9				3.85				12.65			5.2	11	2.2
	m	g					5.6							0.1	2.15					9.25	.6	5.8		0.5
	m	c	6.6				2.2			5.3			3.7	5.6			3.2				8			

Ili	Zam	Ili	4.4	15.4	13.2	6.6		11	13.2	6.6	17.9		11.6		8.85	11.4	8.4		12.65			5.2	11	2.2

To	From	Via	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
Tag	Zam	Tag	1.5	6.3	5.3	5.2	6.6	3.3	6.6	6.6	13.2		6.6	6.6	5	6.6	9.5		1.5	11	10.6			15
Tag	Zam	Tac		15.3	13.6	6.2	15	2.9	15	10.6	1.8	5.9	10.9	15	10	4.9	9	14.5		10.6		9.65	10.6	
Tag	Zam	Ili																0.5			11		10.05	
Tac	Zam	Tag																			10.6			15
Tac	Zam	Tac		15.3	13.6	6.2	15	2.9	15	15	8.4	21.6	10.9	15	10	15	10.5	19.5	15	10.6		9.65	10.6	
Tac	Zam	Ili	14.7			10.2		12.1					4.1		5							11	0.95	6.6
Ili	Zam	Tag	1.5	6.3	5.3	5.2	6.6	3.3	6.6	6.6	13.2		6.6	6.6	5	6.6	9.5		1.5	11				
Ili	Zam	Tac								4.4	6.6	15.7				10.1	1.5	5	15					
Ili	Zam	Ili	14.7			10.2		12.1					4.1		5			0.5			11	11	11	6.6

To	From	Via	45	46	47	48	49	50	51	52
Tag	Zam	Tag	15	1.9	2.7	17.2	10.6	10.6	10.6	15
Tag	Zam	Tac		13.1						

Tag	Zam	Ili					6.6	3.2		
Tac	Zam	Tag	4.35		2.7	10.6	10.6	10.6	10.6	4.5
Tac	Zam	Tac	4.75	13.1			4.4			0.5
Tac	Zam	Ili		6.6		4.4		7.8	11	
Ili	Zam	Tag	10.65	1.9		6.6				10.5
Ili	Zam	Tac	4.75				4.4			0.5
Ili	Zam	Ili		6.6		4.4	6.6	11	11	

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.

Table A4. Schedule of Delivery in Scenario 6 as Amount of Delivery Reached by Large Barges (in 52 weeks)

To	From	Via	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Bis	Ceb	Bis					6.00			6.75										4.85			5.60
Bis	Ceb	Sur	6.75	6.75	6.75	6.75		1.95								4.30	6.75			1.90	5.10		
Bis	Ceb	San													3.50			6.75				2.50	
Bis	Zam	Bis	3.35	4.25	11.30		4.30				2.50						9.90		9.60	4.25	11.90		5.60
Bis	Zam	Sur	0.90						11.90	11.00	8.40		3.40		5.00							2.50	
Bis	Zam	San						11.90		0.90		11.10	5.80		8.50								
Sur	Ceb	Bis																					
Sur	Ceb	Sur	6.75	6.75	6.75	6.75		1.95	6.75			6.75	6.75			4.30	6.75			1.90	5.10	4.25	1.15
Sur	Ceb	San						4.8						6.75	3.25	2.45					1.65		
Sur	Zam	Bis			1.80														9.60	4.25	4.25		5.60
Sur	Zam	Sur	0.90			11.90			11.90	11.00	8.40		3.40		5.00		2.00					6.75	
Sur	Zam	San	7.65	7.65	0.60		7.60				2.60	0.80	4.30					11.90	2.30	3.05			4.25
San	Ceb	Bis					6.00			6.75										4.85			5.60
San	Ceb	Sur							6.75			6.75	6.75									4.25	1.15
San	Ceb	San						4.80						6.75	6.75	2.45		6.75			1.65	2.50	
San	Zam	Bis	3.35	4.25	9.50		4.30				2.50						9.90				7.65		
San	Zam	Sur				11.90											2.00					4.25	
San	Zam	San	7.65	7.65	0.6		7.600	11.90		0.90	2.60	11.90	10.10		8.50			11.90	2.30	3.05			4.25

To	From	Via	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Bis	Ceb	Bis					6.75	6.75	2.50		6.75					6.75		5.00	3.30	4.73		6.75	
Bis	Ceb	Sur			2.75				2.50	4.20				1.25	4.63								
Bis	Ceb	San		6.75								3.40					6.75	1.75			6.75		6.75
Bis	Zam	Bis	3.15	13.50		2.50		8.55		4.20		4.25		4.25	6.38	13.50	7.65					0.90	2.58
Bis	Zam	Sur					0.90				7.65	7.65	1.20							4.73	7.18		1.68
Bis	Zam	San	7.65		5.00	2.50	7.65				0.90		1.20	5.50			0.85				0.43		
Sur	Ceb	Bis					6.75	6.75										5.00				6.75	
Sur	Ceb	Sur			6.75	6.75			4.25	4.20		3.35		1.25	4.63				3.45				
Sur	Ceb	San	6.75							2.55			6.75	5.50	2.13					2.03			
Sur	Zam	Bis	3.15	13.5		2.50		0.90						4.25		11.00	7.65					0.90	
Sur	Zam	Sur			1.75	1.75	0.9		6.75		11.00	7.65	1.20		4.25		3.40	13.50		8.98	7.18		3.35
Sur	Zam	San	1.10				3.35	3.35		4.25			3.05								3.83	11.00	
San	Ceb	Bis							2.50		6.75					6.75			3.30	4.73			

San	Ceb	Sur			4.00	6.75			1.75			3.35							3.45				
San	Ceb	San	6.75	6.75						2.55		3.40	6.75	5.50	2.13		6.75	1.75		2.03	6.75		6.75
San	Zam	Bis						7.65		4.20		4.25			6.38	2.50							2.58
San	Zam	Sur			1.75	1.75			6.75		3.35				4.25		3.40	13.50		4.25			1.68
San	Zam	San	8.75		5.00	2.50	11.00	3.35		4.25	0.90		4.25	5.50			0.85				4.25	11.00	

To	From	Via	43	44	45	46	47	48	49	50	51	52
Bis	Ceb	Bis							3.38		3.40	6.75
Bis	Ceb	Sur				6.75		6.75				
Bis	Ceb	San		6.75								
Bis	Zam	Bis			3.35	7.65	3.35	4.25	7.63		7.60	
Bis	Zam	Sur	3.38	11.90						3.40		
Bis	Zam	San	7.63				4.25			7.60		4.25
Sur	Ceb	Bis							3.38			5.50
Sur	Ceb	Sur				6.75	6.75	6.75	3.38	6.75	3.35	
Sur	Ceb	San	6.75		6.75							
Sur	Zam	Bis			1.23	0.90	3.35	0.88			7.60	
Sur	Zam	Sur	4.25	11.90		4.25				4.30		
Sur	Zam	San			2.13			7.63				5.50
San	Ceb	Bis									3.40	1.25
San	Ceb	Sur					6.75		3.38	6.75	3.35	

San	Ceb	San	6.75	6.75	6.75							
San	Zam	Bis			2.13	6.75		3.38	7.63			
San	Zam	Sur	0.88			4.25				0.90		
San	Zam	San	7.63		2.13		4.25	7.63		7.60		9.75

Bis = Bislig, Ceb = Cebu, Ili = Iligan, San = General Santos, Sur = Surigao, Tac = Tacloban, Tag = Tagbilaran, Zam = Zamboanga.

Source: Author.