Chapter 3

Economic Delivery Route:

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

3.1 Introduction

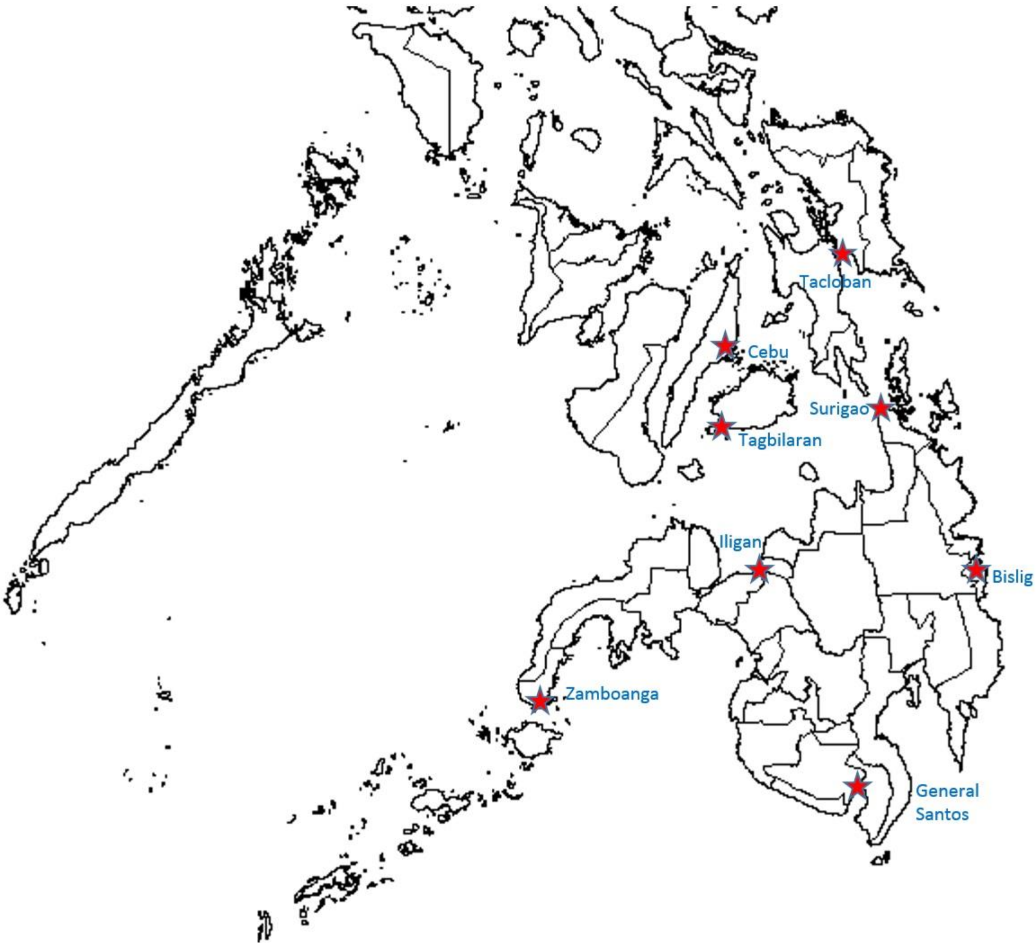
The purpose of this study is to shed light on the necessary infrastructure investment for small-scale LNG distribution in the Visayas and Mindanao regions of the Philippines.[1] Such investment needs to (i) be able to satisfy all future demand for LNG in these regions, (ii) fully consider all technical 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.

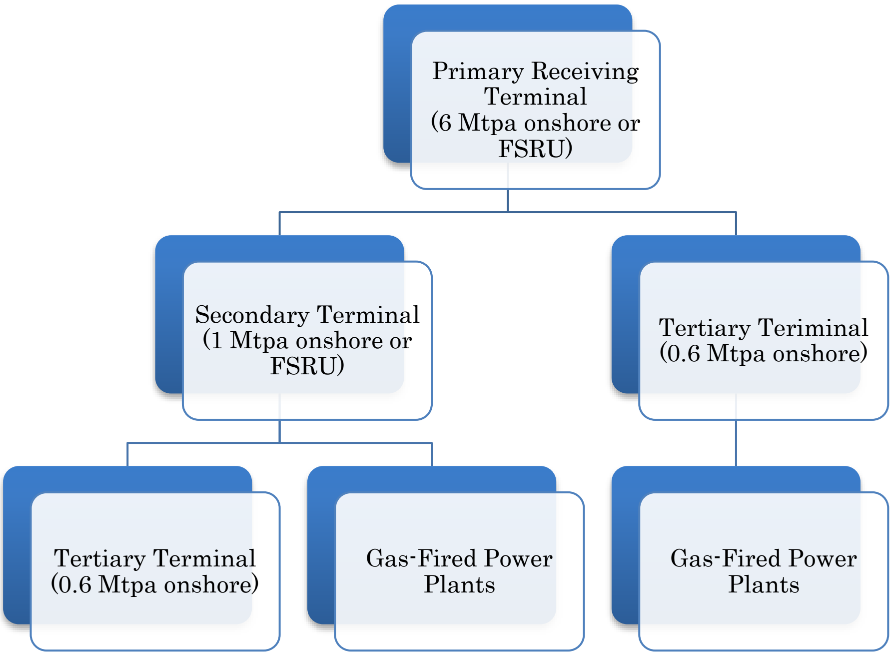
Figure 3.1. Candidate Ports as Liquefied Natural Gas Receiving Terminals in Visayas and Mindanao



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

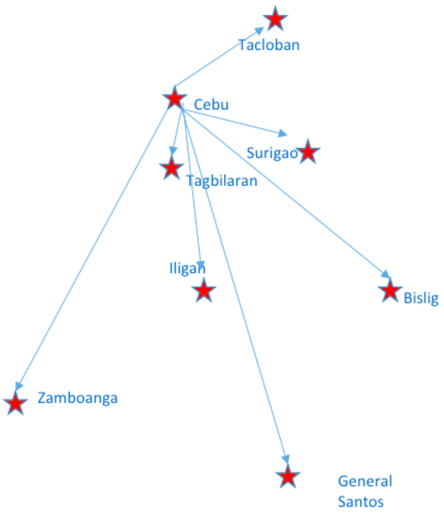
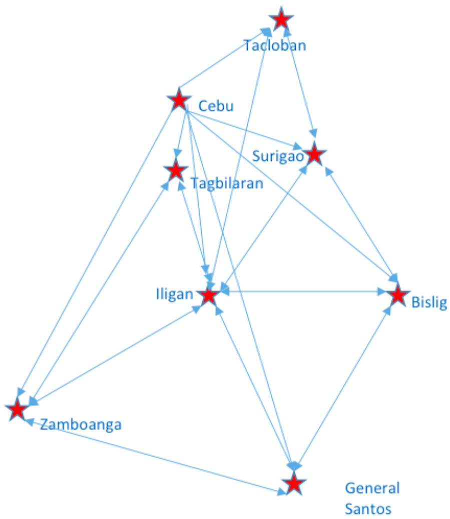


Figure 3.4. Milk-Run Model



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.