Chapter 6

Static Approach for Delivering LNG: Linear Programming

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Chapter 6
Static Approach for Delivering LNG: Linear Programming

This chapter describes the optimal solutions for delivering LNG from its production sites to its demand sites by applying the linear programming (LP) model.

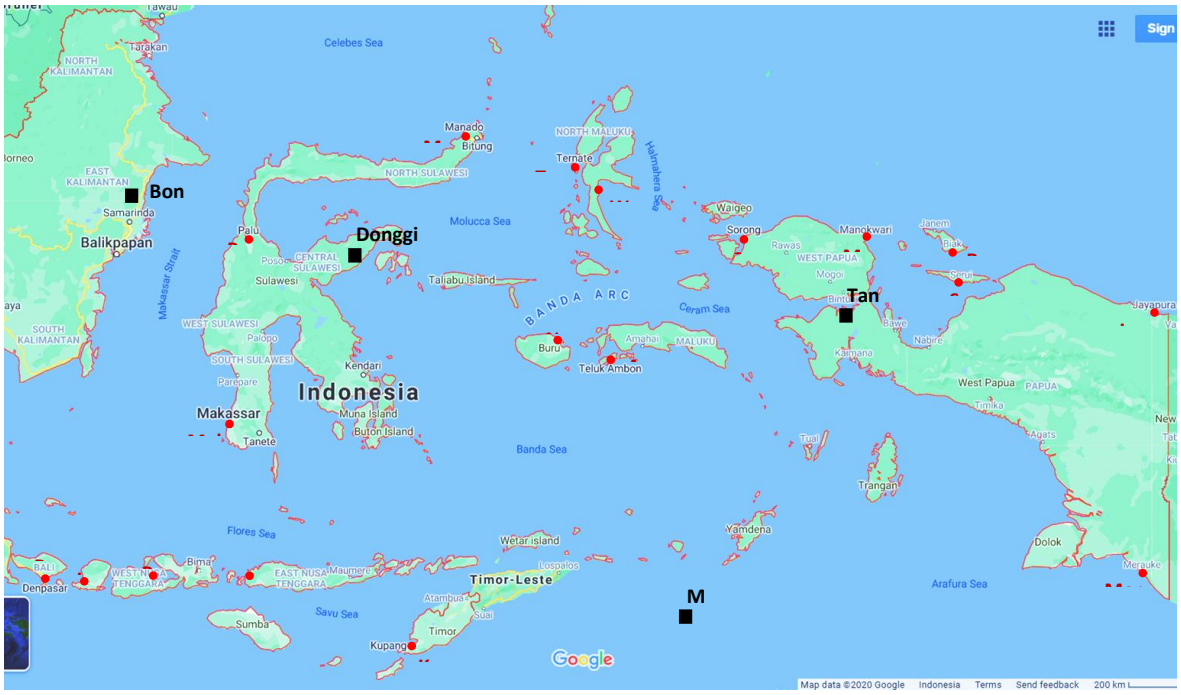
1. Prerequisites for Developing the LP Model

1.1. Assumptions

a. Target area

The target area is Eastern Indonesia (Figure 6.1). The map shows the LNG demand sites, comprising names of cities and ports. Table 6.1 shows the abbreviations of both port names of LNG production and demand sites. Hereinafter, we refer to the abbreviations.

Figure 6.1: Boundary of LNG Delivery Model

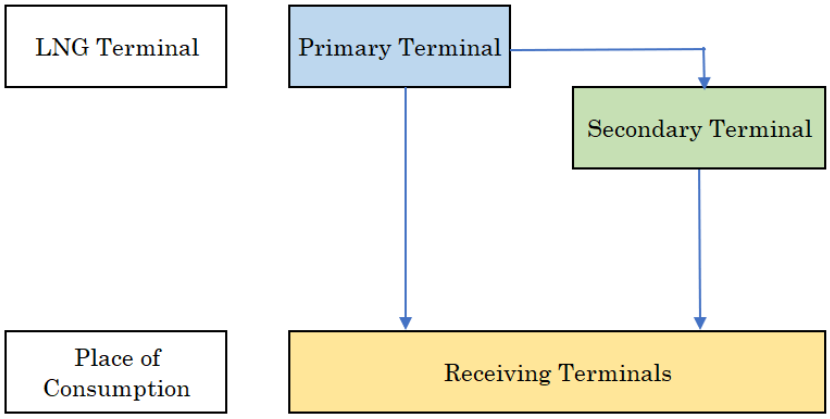


Source: Processing based on Google Maps, 2020.

b. Delivery flow of LNG in this area

LNG for domestic use in this area will be delivered from four LNG production sites – Bontang, Donggi Senoro, Masela, and Tangguh – to LNG demand sites. At the LNG receiving sites, LNG storages and its regasification units will be equipped. This study applies to two delivery routes: (i) primary terminals (LNG production sites) to the receiving terminals directly and (ii) via a secondary terminal (Figure 6.2). Basically, small and midsized LNG tankers will be engaged to deliver LNG in this area.

Figure 6.2: LNG Delivery Flow



Source: Author.

Table 6.1: LNG Production Sites and Demand Sites

Potential Location	Code No.	City Name	Port Name	Abbreviation
North Sulawesi	0	Manado	Bitung	MND
Center Sulawesi	1	Palu	Pantolan	PAL
South Sulawesi	2	Makassar	Makassar	MKS
Bali	3	Benoa	Benoa	BNO
Lombok, West Nusa Tenggara	4	Lembar	Lembar	LMB
Sumbawa, West Nusa Tenggara	5	Badas	Badas	BDS
Flores, East Nusa Tenggara	6	Labuan Bajo	Labuan Bajo	LBJ
Kupang, East Nusa Tenggara	7	Kupang	Tensu	KPG
Ambon, Maluku	8	Ambon	Ambon	AMB
Buru Island, Maluku	9	Namlea	Namlea	NLA
Halmahera (South), North Maluku	10	Weda	Weda	WED
Ternate, North Maluku	11	Ternate	Ternate	TTE
Yapen Island, Papua	12	Serui	Serui	SRU
Biak, Papua	13	Biak	Biak	BIK
Manokwari, West Papua	14	Manokwari	Manokwari	MNK
Sorong, West Papua	15	Sorong	Sorong	SON
Merauke, Papua	16	Merauke	Merauke	MRK
Jayapura, Papua	17	Jayapura	Jayapura	JAP

LNG Terminal	Abbreviation
Bontang	BON
Donggi Senoro LNG	DSL
Masela	MSL
Tangguh	TGH

Source: Badan Standardisasi Nasional (2010).

c. Future LNG demand at 18 receiving sites

Chapter 4 forecasted LNG demand at 18 sites; the forecasted results are shown in Table 6.2.

Table 6.2: Forecasted LNG Demand at 18 Receiving Sites in 2030

No	Potential Location			2030									Gas	Liquid
				Demand Electricity	Own Use & Losses T&D	Own Use & Losses T&D	Production Electricity	Production from CCGT	Capacity of CCGT	Output	Efficiency CCGT	Input	Gas Consumption (/year)	LNG Consumption (/year)
	Location	City Name	Port Name	GWh	GWh	%	GWh	GWh	GW	ktoe	%	ktoe	million m^3	kiloton
0	North Sulawesi	Manado	MND	6,719	993	12.9%	7,712	1,097	0.18	94	39%	242	269	192
1	Center Sulawesi	Palu	PAL	14,892	2,200	12.9%	17,092	1,416	0.23	122	39%	312	346	247
2	South Sulawesi	Makassar	MKS	16,799	2,482	12.9%	19,281	1,313	0.21	113	39%	290	321	230
3	Bali	Benoa	BNO	9,602	1,418	12.9%	11,020	2,968	0.48	255	39%	655	727	519
4	Lombok	Lembar	LMB	3,659	540	12.9%	4,199	2,599	0.42	224	39%	573	636	454
5	Sumbawa	Badas	BDS	1,560	230	12.9%	1,791	1,475	0.24	127	39%	325	361	258
6	Flores	Labuan Bajo	LBJ	868	128	12.9%	996	597	0.10	51	39%	132	146	104
7	Kupang	Kupang	KPG	824	122	12.9%	946	565	0.09	49	39%	125	138	99
8	Ambon	Ambon	AMB	449	66	12.9%	516	516	0.08	44	39%	114	126	90
9	Buru	Namlea	NLA	375	55	12.9%	431	431	0.07	37	39%	95	105	75
10	Halmahera (South)	Weda	WED	7,382	1,090	12.9%	8,472	2,597	0.42	223	39%	573	636	454
11	Ternate	Ternate	TTE	2,458	363	12.9%	2,821	2,541	0.41	218	39%	560	622	444
12	Yapen Island (Serui)	Serui	SRU	116	17	12.9%	134	134	0.02	11	39%	29	33	23
13	Biak	Biak	BIK	177	26	12.9%	203	203	0.03	18	39%	45	50	36

14	Manokwari	Manokwari	MNK	857	127	12.9%	983	881	0.14	76	39%	194	216	154
15	Sorong City	Sorong	SON	1,232	182	12.9%	1,414	1,414	0.23	122	39%	312	346	247
16	Merauke	Merauke	MRK	274	40	12.9%	314	293	0.05	25	39%	65	72	51
17	Jayapura City	Jayapura	JAP	360	53	12.9%	413	131	0.02	11	39%	29	32	23

Source: Author.

d. Distance from LNG production sites to demand sites (nautical miles)

Table 6.3 shows the distances between LNG production sites and demand sites, based on the existing data and author's estimations.

Table 6.3: Distance between LNG Production and Demand Sites

Miles (NM)

Production base	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	MND	PAL	MKS	BNO	LMB	BDS	LBJ	KPG	AMB	NLA	WED	TTE	SRU	BIK	MNK	SON	MRK	JAP
BON	402	144	345	578	556	532	543	941	1,092	971	890	753	1,436	1,318	1,248	1,126	2,030	1,761
DSL	363	723	564	796	774	667	564	665	568	515	572	314	900	869	766	622	1,330	1,165
MSL	765	980	695	873	868	767	621	420	350	389	558	623	906	876	772	456	678	1,201
TGH	649	1,030	945	1,165	1,143	1,042	901	777	428	467	441	558	725	694	591	383	760	992

Source: Author.

e. Distance between LNG demand sites (nautical miles)

To apply the milk-run method, distances between LNG demand sites were also prepared as Table 6.4.

Table 6.4: **Distance between LNG Demand Sites**

Nautical miles (NM)

No.	Port	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
		MND	PAL	MKS	BNO	LMB	BDS	LBJ	KPG	AMB	NLA	WED	TTE	SRU	BIK	MNK	SON	MRK	JAP
0	MND		493	714	1,051	973	843	765	791	402	376	480	221	843	791	649	532	1,142	1,116
1	PAL	493		323	572	551	511	505	903	844	932	848	714	1,397	1,279	1,209	1,087	1,991	1,723
2	MKS	714	323		324	311	298	207	441	587	597	739	779	1,673	1,647	1,544	1,375	2,011	1,985
3	BNO	1,051	572	324		59	161	351	542	837	1,178	947	987	2,005	1,414	1,817	1,105	1,626	2,331
4	LMB	973	551	311	59		146	293	513	804	1,122	895	1,399	1,949	1,381	1,761	1,072	1,570	2,275
5	BDS	843	511	298	161	146		161	439	675	688	921	934	1,271	1,219	1,155	973	1,531	1,245
6	LBJ	765	505	207	351	293	161		308	545	558	791	804	1,142	1,090	1,025	843	1,401	1,116
7	KPG	791	903	441	542	513	439	308		485	575	763	852	1,402	1,091	1,214	1,076	1,023	1,728
8	AMB	402	844	587	837	804	675	545	485		98	280	322	820	655	632	285	713	971
9	NLA	376	932	597	1,178	1,122	688	558	575	98		224	322	584	532	467	285	843	856
10	WED	480	848	739	947	895	921	791	763	280	224		210	519	493	389	221	856	830
11	TTE	221	714	779	987	1,399	934	804	852	322	322	210		584	558	454	285	908	895
12	SRU	843	1,397	1,673	2,005	1,949	1,271	1,142	1,402	820	584	519	584		114	188	392	1,168	349

13	**BIK**	791	1,279	1,647	1,414	1,381	1,219	1,090	1,091	655	532	493	558	114		127	321	1,142	314
14	**MNK**	649	1,209	1,544	1,817	1,761	1,155	1,025	1,214	632	467	389	454	188	127		236	1,090	427
15	**SON**	532	1,087	1,375	1,105	1,072	973	843	1,076	285	285	221	285	392	321	236		921	637
16	**MRK**	1,142	1,991	2,011	1,626	1,570	1,531	1,401	1,023	713	843	856	908	1,168	1,142	1,090	921		1,577
17	**JAP**	1,116	1,723	1,985	2,331	2,275	1,245	1,116	1,728	971	856	830	895	349	314	427	637	1,577	

Source: Author.

f. Annual LNG delivery amounts for domestic uses at four sites (2030)

The maximum LNG delivery amounts for domestic use in 2030 per each LNG production site are forecasted in Chapter 5 (see Table 6.5 for the summary).

Table 6.5: Annual LNG Delivery Amounts for Domestic Use at Each LNG Production Site, 2030

LNG Terminal	Gas Million CBM	LNG Kiloton
Bontang	576	265
Donggi Senoro LNG	1,087	500
Masela	10,327	4,750
Tanggu	3,391	1,560
Total	**15,380**	**7,074**

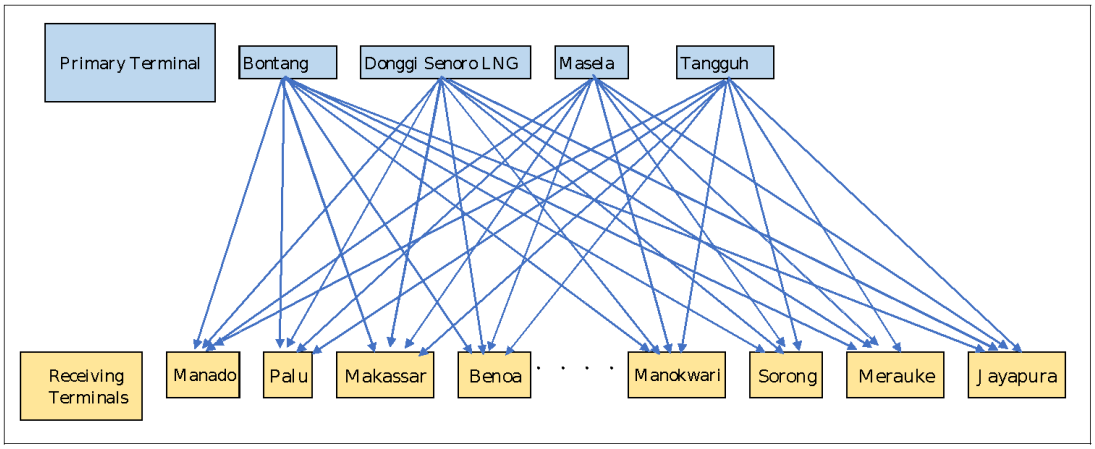
Source: Author.

The LNG production amount of Bontang and Donggi is significant so far but LNG delivery amounts for domestic use at Bontang and Donggi are not assumed significantly because these LNG production sites cater to the export market. Therefore, the role of Masela and Tangguh to deliver LNG to LNG demand sites in this area is crucial.

2. Formulas and Solutions of the LP Model

Figure 6.3 shows the formulation of the LP model for delivering LNG. Basically, the LP model applies a hub-and-spoke method, meaning, delivering LNG from the origin (LNG production sites) to the destination (LNG demand sites) directly. The LP model seeks for an optimal solution to minimise costs, represented as the summation of LNG delivery amount (i to j) x distance (i to j), where i means origin and j means destination.

Figure 6.3: LNG Delivery in the Linear Programming Model



Source: Author.

The formulas of Figure 6.3 are shown below. There are only two constraints: LNG production and LNG demand. These formulas are referred to as case 1.

$$\Sigma Xij = annual\ LNG\ production\ amount\ at\ production\ site\ i\ (Aj) \quad j$$

$$\Sigma Xij = annual\ LNG\ consumption\ amount\ at\ demand\ site\ j\ (Bj) \quad i$$

$$\Sigma\Sigma Dij * Xij \rightarrow Minimum \quad i \quad j$$

Where,

Xij = Delivering LNG amount from production site I to demand site j (tonne)

Dij = Distance between production site I to demand site j (nautical mile)

2.1. Case 1 (No constraints case)

a. Input data

Supply constraints Ai is shown in Table 6.5 and demand constrains Bj in Table 6.2. The upper limit Uij is assumed basically as same number of Bj.

Table 6.6: Input Data of the Linear Programming Model

Production base	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply
	MND	PAL	MKS	BNO	LMB	BDS	LBJ	KPG	AMB	NLA	WED	TTE	SRU	BIK	MNK	SON	MRK	JAP	
BON	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	265
DSL	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	500
MSL	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	4,750
TGH	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	1,560
Demand	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	7,074
																		Total	**3,701**

Source: Author.

b. LP solution (case 1)

Table 6.7 shows the solution of case 1 from the LP model and the following key findings:

- Bontang LNG production site will deliver LNG to Palu and Makassar of Sulawesi. On the other hand, Donggi Senoro will deliver its LNG to Manado and Ternate of north Maluku and Makassar.
- Masela will deliver its LNG to Makassar of South Sulawesi, Benoa, Lembar, Badas, Labuan Bajo, Kupang, Ambon, Namlea of Nusa Tenggara islands, and Merauke of South Papua.
- Tangguh will deliver its LNG to five cities in North Papua and Weda of North Maluku.
- Manado will receive LNG from Donggi Senoro and Palu supplied from Bontang.
- Only Makassar will receive LNG from three LNG production sites: Bontang, Donggi Senoro, and Masela.

Table 6.7: Linear Programming Solution of Case 1

Production base	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply	Supply
	MND	PAL	MKS	BNO	LMB	BDS	LBJ	KPG	AMB	NLA	WED	TTE	SRU	BIK	MNK	SON	MRK	JAP	Solution	input
BON	0	247	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	265	265
DSL	192	0	56	0	0	0	0	0	0	0	0	444	0	0	0	0	0	0	500	500
MSL	0	0	157	519	454	258	104	99	90	75	0	0	0	0	0	0	51	0	1,808	4,750
TGH	0	0	0	0	0	0	0	0	0	0	454	0	23	36	154	247	0	23	937	1,560
Demand	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	2,088,367	7,074
check	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	3,701	

Source: Author.

2.2. Case 2 to represent similar real operation of LNG delivery

a. Input *data*

Since the solution from the LP model (case 1) did not show the real operation of LNG delivery, appropriate constraints were added to case 1 to represent similar real operation. The constraints brought the following merits:

- Improved efficiency of LNG transport through the allocation of a group of neighbouring cities to an LNG production site
- Fixed LNG supply amounts by each LNG production base
- Provided overall framework of a dynamic simulation model

As a result, the following constraints were added (refer to Table 6.8):

- Bontang will deliver its LNG only to Central Sulawesi (Palu).
- Donggi will cover Manado and South Sulawesi (Makassar).
- Masela will deliver LNG to Bali, Lombok, Sumbawa, Flores, Kupang, Ambon, Buru, and Ternate (eight demand sites).
- Tangguh will deliver its LNG to Halmahera, Yapen Island, Biak, Monokwari, Sorong, Merauke, and Jayapura city (seven demand sites)

b. LP solution

Case 2 results (Table 6.9) suggest that the value of the objective function is 2,213,109 (tonne/km) and it increases by 6% from case 1. Consequently, the constraints do not affect the objective function seriously and case 2 is still the second option of case 1 to represent a more realistic LNG delivery. Case 2 also suggests LNG delivery in the following three groups: (i) Bontang–Donggi group, (ii) Masela group, and (iii) Tangguh group (Table 6.9).

Table 6.8: Constraints to LNG Delivery (Upper Limit: Uij), kiloton

Production Base	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply
	MND	PAL	MKS	BNO	LMB	BDS	LBJ	KPG	AMB	NLA	WED	TTE	SRU	BIK	MNK	SON	MRK	JAP	
BON	192	247	0	0	0	0	0	99	90	75	454	444	23	36	154	247	51	23	265
DSL	192	247	230	0	0	0	0	99	90	75	454	0	23	36	154	247	51	23	500
MSL	192	247	0	519	454	258	104	99	90	75	454	444	23	36	154	247	0	23	4,750
TGH	192	247	230	519	454	258	104	99	90	75	454	0	23	36	154	247	51	23	1,560
Demand	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	7,074
																	Total	**3,701**	

Source: Author.

Table 6.9: Linear Programming Solution

Production Base	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply Solution	Supply input
	MND	PAL	MKS	BNO	LMB	BDS	LBJ	KPG	AMB	NLA	WED	TTE	SRU	BIK	MNK	SON	MRK	JAP		
BON	0	247	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	247	265
DSL	192	0	230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	421	500
MSL	0	0	0	519	454	258	104	99	90	75	0	444	0	0	0	0	0	0	2,044	4,750
TGH	0	0	0	0	0	0	0	0	0	0	454	0	23	36	154	247	51	23	988	1,560
Demand	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	2,213,109	7,074
Check	192	247	230	519	454	258	104	99	90	75	454	444	23	36	154	247	51	23	3,701	

Note:

Bontang–Donggi Senoro group :

Masela group :

Tangguh group :

Source: Author.