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A structural and stochastic optimal model for projections of LNG imports and exports in Asia-Pacific

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Abstract

The Asia-Pacific region, the largest and fastest growing liquefied natural gas (LNG) market in the world, has been undergoing radical changes over the past few years. These changes include considerable additional supplies from North America and Australia, and a recent LNG price slump resulting from an oil-linked pricing mechanism and demand uncertainties. This paper develops an Asia-Pacific Gas Model (APGM), based on a structural, stochastic and optimising framework, providing a valuable tool for the projection of LNG trade in the Asia-Pacific region. With existing social-economic conditions, the model projects that Asia-Pacific LNG imports are expected to increase by 49.1 percent in 2020 and 95.7 percent in 2030, compared to 2013. Total LNG trade value is estimated to increase to US\$127.2 billion in 2020 and US\$199.0 billion in 2030. Future LNG trade expansion is mainly driven by emerging and large importers (i.e., China and India), and serviced, most importantly, by new supplies from Australia and the USA. The model's projected results are sensitive to changes in expected oil prices, pricing mechanisms, economic growth and energy policies, as well as unexpected geopolitical-economic events.

Keywords: Economics

1. Introduction

Given the advantages of versatile and abundant reserves and relatively low emissions, natural gas is an increasingly desirable energy source. Over the past decade, the consumption of natural gas has continued to grow, accounting for 24 percent of the global primary energy mix in 2014 ([British Petroleum \(BP\), 2015](#)). Driven by economic development, population growth and the desire for cleaner energy, it is clear that natural gas will play an even greater role in the global energy mix over the long term, with a distinct possibility of the world entering ‘a golden age of gas’ ([International Energy Agency \(IEA\), 2011](#)).

The three world gas markets for gas consumption are the European market, the North American market, and the Asia-Pacific market, accounting for 31.7, 27.8 and 19 percent of global consumption, respectively ([BP, 2015](#)). Driven by demand growth in these combined markets, global gas trade has been rapidly expanding, with liquefied natural gas (LNG) as the fastest-growing component. Over the past decade, LNG international markets have been increasing at a rate of 7.6 percent a year ([Petroleum Economist, 2015](#); [BP, 2015](#)). For the long-term outlook, the US [Energy Information Administration \(EIA\) \(2014a\)](#) has projected natural gas to be the fastest growing fossil fuel, supported by increasing supplies of shale gas, particularly in the United States. LNG trade itself is projected to expand rapidly at an annual growth rate of 3.9 percent (more than twice as fast as gas consumption), accounting for 26 percent of the total growth in global gas supplies by 2035 ([BP, 2014](#)).

Of the three world markets, the Asia-Pacific region is the world’s largest and fastest-growing international LNG market, accounting for more than 74 percent of global LNG trade in 2013, driven largely by the high demands of economic growth and constraints on domestic supply in the region. In Asia-Pacific, where economic growth is substantial throughout the region ([International Monetary Fund \(IMF\), 2015](#)), LNG is an essential energy source, accounting for 81 percent of the total gas trade in 2013 ([BP, 2015](#)). Over the past decade, LNG trade in the Asia-Pacific region grew rapidly by 8.2 percent per year ([Petroleum Economist, 2015](#)), due to increased demands from both traditional (i.e., Japan, South Korea and Taiwan) and new or emerging importers (i.e., China, India and other Asian countries).

Over the past few years, the Asia-Pacific LNG market has been undergoing radical changes, including the introduction of considerable new supplies, an LNG price slump resulting from an oil-linked pricing mechanism and demand uncertainties ([Kompas and Che, 2015a](#)). In terms of new supplies, for example, recent rapid growth in shale gas in North America and newly commencing LNG projects in Australia have fundamentally changed future LNG supply patterns. By 2035, shale gas in the USA is projected to share 68 percent of total USA gas production and 21 percent of global gas production ([EIA, 2015](#); [BP, 2014](#)). LNG supplies from the USA and

Australia alone could potentially double global LNG supply capacity over the next decade.

In terms of uncertainty over demand, there are concerns over the projected growth in the demand for LNG. Restarts of nuclear reactors in Japan and Korea will reduce LNG import demand and consumption of competing fuels such as renewables and oil have been increasing as well. China's slower economic growth (IMF, 2015) and the new pipeline gas supplies could also influence LNG consumption growth going forward (International Group of Liquefied Natural Gas Importers (GIIGNL), 2006–14).

The presence of long-term contracts, tying supplies and demands together, provides an important and guaranteed source of trade to Asia-Pacific's major exporters. However, challenges remain for maintaining import demands and the recent LNG price slump has accelerated the pressure on cost competitiveness among LNG suppliers (Kompas and Che, 2015b), shifting international LNG market dynamics (Evan, 2015). LNG spot prices for March 2015 delivery to northeast Asia, for example, posted their largest year-over-year drop on record, falling nearly 62 percent from March 2014 to average US\$7.44/million Btu. The Japan-Korea-Marker (SKM) fell by more than half from US\$ 20.2 in February 2014 to US\$6.80/million Btu in February 2015. Since October 2014, prices have been on an otherwise unusual downward trend as a result of a mild winter and ample inventories in Japan and South Korea. Cheaper competing fuels, such as thermal coal and fuel oil, are also competing with LNG in the choice of fuel mix.

These demand uncertainties and risks to LNG prices have challenged the economic feasibility of many potential LNG projects. Undoubtedly, more accurate projections of LNG trade in the market are now more important than ever, for both forecasting economic growth rates and evaluating relevant LNG strategic developments in importing and exporting nations. The Asia-Pacific Gas Model (APGM) developed in this paper, capturing the structure, interactions, dynamics and many of the uncertainties of the Asia-Pacific LNG market, is an important tool for analysing future LNG trade and market interactions in the Asia-Pacific region. The model is also valuable for estimating the market responses to geopolitical and economic events and other exogenous shocks. As such, the APGM, which is based on a non-linear stochastic optimization programming approach, allows for the modelling of relevant uncertainties and linkages to future LNG trade flows, as well as changes in supplies and demands, in the Asia-Pacific region, over the period 2015–30.

Section 2 of the paper provides background on the Asia-Pacific LNG market, while section 3 develops the theoretical framework for the APGM. Section 4 details

the supporting database and relevant calibrations. Section 5 summaries the results and section 6 concludes.

2. Background

This section provides some background and briefly reviews existing international LNG trade models, global LNG trade, and the characteristics of the Asia-Pacific LNG market.

2.1. Existing international gas trade models

To date, several modelling approaches have been developed for projections of global gas trade and LNG development, including the Deloitte World Gas Model (Deloitte, 2016), the Baker Institute World Gas Trade Model (BIWGTM) (or the Rice World Gas Trade Model) (Hartley and Medlock, 2005), the IPA World Gas Trade Model (WGTM) (IPA Energy, 2014), the World Nexant Gas Model (Nexant, 2014a and 2014b), the EIA International Natural Gas Model (INGM) (EIA, 2013; Busch, 2014) and the Global Natural Gas Model (GNGM) (NERA Economic Consultant, 2014).

While these modelling approaches are helpful, they generally focus on the North and South American and European gas markets, with limited detail on the structure and dynamics of pricing, contracting and other market conditions relevant to the Asia-Pacific LNG market. The Deloitte World Gas Model, for example, is an integrated model of world supply, transportation, shipping, liquefaction, re-gasification, infrastructure, and demand. It is based on the MarketPoint/Altos World Gas Trade Model (WGTM) extension to the NARG model. (The North American Gas Model (NARG), in particular, is designed to simulate how regional interactions of supply, transportation, and demand determine market clearing prices, volumes, storage, reserve additions, and new pipelines throughout the North America natural gas markets. The model has been used for many of the pipeline expansion decisions and resource basin profitability evaluations in North America since 1983 (Deloitte, 2016)). The model simulates local and regional interactions among resource supplies, field processing, outbound pipelining, liquefaction, shipping, re-gasification, distribution, and demand and inter-fuel competition, focusing (again) on the North and South American and European gas market. The oil-linked pricing mechanism and the use of long-term contracts, which are the important features of the Asia-Pacific LNG market, are not considered in the model structure.

The Baker Institute World Gas Trade Model (BIWGTM) employs an inter-temporal equilibrium model of the world gas market for calculating a pattern of production, transportation routes and prices to equate demands and supplies while

maximising the present value of producer rents within a competitive framework (Hartley and Medlock, 2005). The model assumes perfect mobility among international gas markets. However, the global gas market is fragmented and based on different pricing mechanisms and contractual arrangements across world and in Asia-Pacific markets in particular (Kompas and Che, 2015a).

The IPA World Gas Trade Model (WGTM) simulates regional interactions among supply, transportation, and demand interactions to determine market clearing prices, flow volumes, reserve additions and pipeline entry and exit through to 2040. The model is developed with a focus on the North American gas demand market, which is dominated by a ‘Gas-On-Gas’ pricing mechanism (IPA Energy, 2014).

The Nexant model, which is based on linear and deterministic programming algorithms for minimising total costs of gas imports, with flows of nodal gas supply as control variables, mainly focuses too on the North American and the European gas markets (Nexant, 2014a, 2014b). Asia-Pacific long-term contracting mechanisms are not considered. Also, derivations of the key variables, such as the future of Asia-Pacific pricing and contracting arrangements and LNG delivery costs, have yet to be developed here. In addition, the model’s linear and deterministic programming methodology is unable to capture uncertainties in the gas market.

The International Natural Gas Model (INGM) is the EIA gas model employed for analysing the International Energy Outlook (IEO). The model combines estimates of natural gas reserves, natural gas resources and resource extraction costs, energy demand, and transportation costs and capacity to estimate future production, consumption, and prices of natural gas (EIA, 2013). The INGM uses a linear programming formulation, which by its nature assumes a competitive market, to project global gas production, demand and trade. It also assumes that LNG contracts will only have a short-term impact, and in the long-term, LNG volume flows will be based solely on marginal prices. The model, therefore, does not include contractual flows or prices (Busch, 2014), and it fails to reflect the Asia-Pacific pricing and long-term contracting mechanisms. The Global Natural Gas Model (GNGM), finally, by NERA Economic Consultant, is used to project the macroeconomic impacts of LNG exports, but for the USA only (NERA Economic Consultant, 2014).

In this paper, the Asia-Pacific Gas Model (APGM) is developed to capture the structure, interactions, dynamics and uncertainties of the Asia-Pacific LNG market, in ways missing from all other models, by including, among other things, the particular structure and dynamics of the oil-linked pricing and long-term contracting mechanisms that are characteristic of the region. The model is based on a non-linear stochastic optimization programming approach, which also allows us to capture

Table 1. Major world LNG importers, 2013.Source: [Petroleum Economist \(2015\)](#).

Country	Import (Mt)	Share in world total (%)
Japan	85.0	37.2%
South Korea	38.8	17.0%
China	17.5	7.6%
India	12.8	5.6%
Taiwan	12.5	5.4%
Spain	9.4	4.1%
United Kingdom	6.8	3.0%
France	6.0	2.6%
Mexico	5.5	2.4%
Argentina	4.6	2.0%
World total	230.2	100.0%

uncertainties and linkages to projected future LNG trade flows, along with changes in supply and demand.

Put simply, the objective function for the APGM is to minimise the total costs of Asia-Pacific LNG imports using the control variables of trade flows among import and export nodes. At a trade equilibrium in Asia-Pacific, total LNG imports are equal to total LNG exports. The LNG trade flow in the model includes provisions for both long-term contracts and common trade, and the LNG value of imports, in particular, depends on the long-term contract price (based on the JCC oil-linked pricing formation) and the demand for gas, as well as LNG delivery cost. The delivery cost for an LNG project, in turn, depends on the cost of gas production, liquefaction, shipping, de-gasification and all other costs. All of these components are crucial to an understanding of the Asia-Pacific gas market.

2.2. Overview of global LNG trade

Global LNG trade has been expanding rapidly over the past few decades, of which the Asia-Pacific LNG market is the key driver. Most of the important global LNG importers are from the Asia-Pacific LNG market, including Japan, South Korea, China, India and Taiwan ([Table 1](#)). In 2013, the Asia-Pacific region accounted for 74.4 percent of total LNG global imports, of which Japan and South Korea alone share 37.2 percent and 17 percent of the total ([Table 1](#)). With fast growing demand, China and India are also important emerging LNG importers, accounting for roughly 13.2 percent of global LNG imports in 2013 ([Petroleum Economist, 2015](#)) (see [Table 1](#)).

Almost 90 percent of global LNG exports is dominated by ten major LNG suppliers ([Table 2](#)). In 2013, the most important LNG exporters were Qatar,

Table 2. Major world LNG exporters, 2013.Source: [Petroleum Economist \(2015\)](#).

Country	Export (Mt)	Share in world total (%)
Qatar	103.5	33.1%
Malaysia	33.05	10.6%
Australia	29.55	9.4%
Nigeria	22.12	7.1%
Indonesia	22.06	7.0%
Trinidad and Tobago	17.94	5.7%
Algeria	14.53	4.6%
Russian Federation	13.92	4.4%
Oman	11.38	3.6%
Yemen	9.29	3.0%
World total	230.2	100.0%

Malaysia, Australia, Nigeria and Indonesia. At present Qatar is the largest LNG exporter by far. However, LNG supplies have been changing significantly since 2015, with new LNG sources emerging from Australia and the USA, which soon will become the major LNG exporters in the world.

Driven by rapid economic growth and insufficient alternative domestic energy supplies, the Asia-Pacific region relies most heavily on the energy imports of oil, coal and gas. Over the past ten years, gas consumption and LNG imports in Asia-Pacific have grown rapidly at an average rate of 6.6 to 7.8 percent per year ([BP, 2015](#)). LNG provides an important source of Asia-Pacific gas consumption, and the share of LNG imports over total gas consumption have increased steadily over the past three years, from roughly 38 percent in 2010 to 40 percent in 2013 ([Petroleum Economist, 2015](#)). LNG imports in Asia-Pacific have increased since 2000, increasing further after the Fukushima disaster and the growing need for electric power in Japan, South Korea and Taiwan. [Table 3](#) summaries LNG trade flows among key importers and exporters in the Asia-Pacific region in 2013. Japan, South Korea and China were the largest LNG importers, and the largest LNG suppliers were Qatar, Malaysia and Australia ([Petroleum Economist, 2015](#)).

2.3. Characteristics of the Asia-Pacific LNG market

2.3.1. Major LNG importers

LNG demand in the Asia-Pacific region is largely driven by the traditional LNG consumers (Japan, South Korea and Taiwan) and the new or emerging consumers (China, India, Malaysia, Singapore and Thailand). Over the last ten years, LNG imports in Japan, Korea and Taiwan have increased significantly by 5.1, 6.8 and

Table 3. Major LNG trade flows in Asia-Pacific, 2013 (*Mt*). Source: [Petroleum Economist \(2015\)](#).

Importers	Exporters					Total import
	Qatar	Malaysia	Australia	Indonesia	Nigeria	
China	6.56	2.58	3.45	2.36	0.36	17.48
India	10.83	–	–	–	0.85	12.86
Japan	15.59	14.51	17.40	6.08	3.74	84.94
Malaysia	0.12	–	–	–	0.31	1.47
Singapore	0.09	–	–	–	–	0.91
South Korea	12.97	4.20	0.61	5.46	2.72	38.78
Taiwan	6.18	2.85	0.06	1.96	0.55	12.45
Thailand	0.97	–	–	–	0.23	1.37
Total export	53.33	24.13	21.51	15.86	8.75	170.26

8.0 percent per year, respectively ([Petroleum Economist, 2015](#)). LNG imports from India and China also have increased rapidly over the past few years ([EIA, 2014b](#)).

Japan is the world's largest LNG importer, accounting for 37.2 of global LNG imports ([Table 1](#)). Given the limitations of alternative energy resources (meeting less than 10 percent of total primary consumption) and without an international pipeline, the country relies on LNG imports to meet nearly all of its natural gas consumption ([EIA, 2014c](#)). Prior to the Fukushima disaster, nuclear generation was important, contributing about 26 percent of the fuel mix for electricity generation. LNG imports have been expanding significantly since 2008 and especially in the post-Fukushima period. In post-Fukushima, Japan's fuel mix for electricity generation has shifted substantially to natural gas, oil, and renewable energy. The average growth rate of LNG imports from 2008 to 2013 was 6.4 percent per year ([Petroleum Economist, 2015](#)). The recent replacement of nuclear power by LNG at relatively high prices has generated fiscal issues and contributed to ongoing budget deficits for Japan. At present, the country plans to reopen several nuclear reactors to generate electric power and rebalance the surge in LNG imports. Japan has also diversified its portfolio of LNG suppliers by increasing investment in a number of LNG projects in Australia, the USA, Indonesia, Malaysia and Canada ([EIA, 2014c](#)).

South Korea is a highly developed economy, most notably gauged by its exports of electronics and semiconductors and a world-class shipbuilding industry. Rapid economic growth and expansion of exports imply that energy consumption will increase ([EIA, 2014d](#)). Due to insufficient domestic resources, the country relies on imports to meet about 97 percent of its energy consumption. Despite the country possessing a proven reserve of 203 billion cubic feet of gas in January 2014, domestic gas production is still negligible. At present, South Korea relies on LNG imports to meet about 98 percent of its natural gas consumption, which has nearly doubled over the previous decade ([EIA, 2014d](#)). LNG imports have been expanding significantly

since 2008 and especially in post-Fukushima period at an average growth rate of 8.9 percent per year (Petroleum Economist, 2015).

Given limited domestic gas supplies and without an international pipeline, 98 percent of gas consumption in Taiwan is from LNG imports, which has more than tripled over the last decade (BP, 2015). LNG imports have been expanding significantly since 2008 at an average growth rate of 9.6 percent per year. In 2013, the country imported 12.5 Mt of LNG, ranking as the fifth largest LNG importer in the world (Petroleum Economist, 2015).

Emerging consumers, especially China and India, have accelerated LNG demand over the past few years. According to the EIA (2014b), China is the largest energy consumer in the world. Rapid growth in energy demand, especially for liquid fuels, has made China extremely influential in world energy markets. In particular, the country's gas consumption has increased nearly seven times between 2000 and 2013. Rising incomes, rapid urbanisation, concerns about air pollution and increasing oil prices has favoured the switch from oil and coal to natural gas (Chen, 2014). To meet the fast growth in gas consumption, China has increased natural gas imports rapidly from pipelines and LNG. In 2012, natural gas imports accounted for 35.2 percent of gas consumption, including 18.8 percent and 16.4 percent by pipeline and LNG imports, respectively (Petroleum Economist, 2015). China's LNG imports have also been increasing dramatically from 0.74 Mt in 2006 to 17.6 Mt in 2013. LNG imports have been expanding rapidly since 2006 at an average growth rate of 51.2 percent per year (Petroleum Economist, 2015). However, the current gas pricing system in the country, which is highly regulated and generally at prices below international market rates, with different pricing subsidies in different economic sectors, is believed to be a significant obstacle to LNG market development (EIA, 2014b; Chen, 2014).

In India, natural gas largely serves as a substitute for coal in electricity generation and fertiliser production. The country began importing LNG from Qatar in 2004 and increasingly relies on imports to meet natural gas demand (EIA, 2014e). India's LNG imports grew rapidly at a rate of about 19 percent per year from 1.9 Mt in 2004 to 12.9 Mt in 2013 (Petroleum Economist, 2015).

2.3.2. *Re-gasification capacity*

Regarding re-gasification globally, there were 100 existing re-gasification terminals in the world at the end of 2014, providing a total of 649 Mt per year in re-gasification capacity. Out of the global LNG receiving capacity, 49.4 percent is located in the Asia-Pacific region (Petroleum Economist, 2015). Table 4 represents current LNG receiving terminals by country in Asia-Pacific, of which Japan accounts

Table 4. Capacity of LNG regasification in Asia-Pacific, 2013 (*Mt/year*). Source: [Petroleum Economist \(2015\)](#).

Country	Capacity (<i>Mt</i>)	Share in world total (%)
Japan	192.0	29.6%
South Korea	45.7	7.0%
China	33.4	5.1%
India	23.5	3.6%
Taiwan	10.9	1.7%
Singapore	6.0	0.9%
Thailand	5.0	0.8%
Malaysia	3.8	0.6%
Total	320.2	49.3%

for about 60 percent of Asia-Pacific import capacity in 2013. India is the fastest growing country in LNG import capacity, increasing its capacity by more than 16 fold over the past ten years ([International Gas Union \(IGU\), 2015](#)). According to [IGU \(2015\)](#), over the long term, re-gasification capacity in Asia-Pacific is expected to double due to a number of new potential or planned terminals. Utilisation of LNG import terminals has historically been less than 50 percent due to the seasonal nature of many gas markets, as well as the variations in demand worldwide.

2.3.3. Sources of uncertainty of LNG import demand

It is important to identify the uncertainties surrounding future LNG demand in both traditional and emerging consumer groups in the Asia-Pacific region. In the traditional LNG consumer group (i.e., Japan, South Korea and Taiwan), the most important uncertain factor for future LNG demand is energy policy and the use of nuclear power for electricity generation. According to [IGU \(2015\)](#), Japan and Korea will be the major drivers of change in the near term, with a number of potential upside and downside risks. However, according to [Evan \(2015\)](#), LNG demand will be weaker in the Asia-Pacific. Slowing economic growth in Japan and the expected restart of nuclear power stations will decrease LNG demand. In South Korea, most nuclear reactors have restarted, displacing LNG, while coal-fired power plants are running at a higher capacity. In addition, other important uncertainties surrounding LNG demand in the traditional LNG consumer groups include differing rates of economic growth and changes in oil and other energy prices.

In the emerging consumer group, major uncertainties in import demand include changes in China's LNG domestic gas production, gas pipeline imports from Russia and unclear and uneven market reforms ([BP, 2014](#); [Chen, 2014](#); [Xin, 2014](#)) and emission targets ([Center for Climate an Energy Solution \(CCES\), 2015](#)). According to [BP \(2014\)](#), the most promising country for shale gas production is China, which

is projected to expand rapidly and overtake North American shale gas growth by 2027. However, based on current market conditions, [Platts \(2015a\)](#) believes China's domestic shale gas production will not achieve substantial development until or after 2020. There is also uncertainty over future gas supply from pipeline imports. Two large projects for gas pipelines from Siberia to China are currently approved, planning to supply up to 50 Mt per year of gas to China by 2025. However, given Russia's current financial crisis and the recent fall in gas prices, the progress and completion of these projects are at risk. The current gas pricing system in China, which is subsidized and highly distorted, is also another important factor influencing the country's future LNG imports. According to [Chen \(2014\)](#) and [Xin \(2014\)](#), future gas price reform is needed to support future LNG imports in China. Following the recent regulation by the National Development and Reform Commission (NDRC), and since 1 September 2014, wholesale prices for non-residential gas users are reported to have increased by 20.5 percent, moving gas prices to US\$8.12/MMBtu in China ([Jacobs, 2014](#)), and thus closer to international gas prices.

Driven by economic growth and emission reduction targets, India is projected to increase LNG imports significantly ([Balyan, 2014](#)). However, uncertainty over economic growth and fuel mix policy, targeted toward a substitution of gas for oil and coal, will also influence India's future LNG imports.

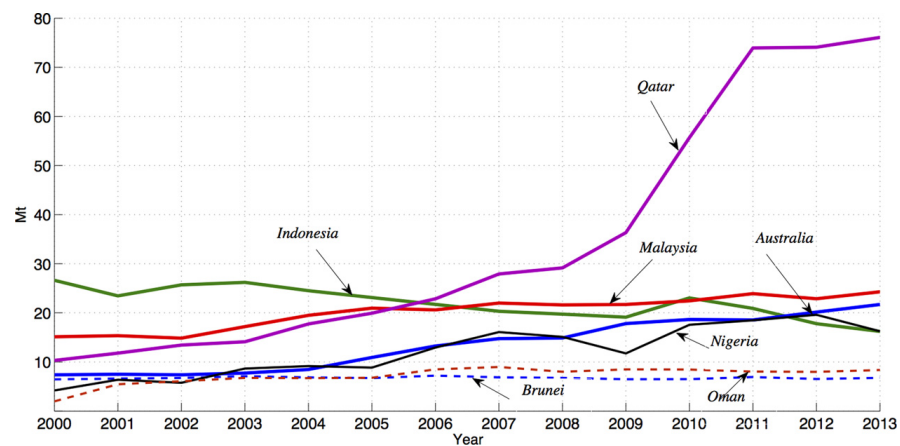
2.3.4. Major LNG exporters to Asia-Pacific

At the end of 2014, global LNG production capacity was 296 Mt per year, of which 230.2 Mt was exported by 17 countries in 2013 ([Petroleum Economist, 2015](#)). Qatar is the world largest LNP exporter with an export volume of 76.1 Mt in 2013 (accounting for 33.1 percent of global LNG exports). In the Asia-Pacific region, Qatar as an LNG exporter, is followed by Malaysia, Australia and Indonesia ([Table 5](#)). [Figure 1](#) presents historical LNG exports by major suppliers over the period 2000–13, indicating a diversified trend of LNG export development among major exporters. Qatar's LNG exports are the most striking case, increasing from 10.3 Mt in 2000 to 76.1 Mt in 2013, with a doubling of LNG capacity from 2009–11. During 2000–13, the LNG exports of Nigeria, Australia and Malaysia have increased rapidly at an average growth rate by 11.2, 10.2 and 3.9 percent, respectively. Alternatively, Indonesia's LNG exports have decreased over the past ten years at a rate of 3 percent per year ([Petroleum Economist, 2015](#)).

Natural gas is the centre of Qatar's energy sector, after many years of developing its natural gas resources, particularly in the North Field. Due to low domestic energy demand, nearly all of Qatar's gas production is exported, making the country the world-leading exporter of LNG since 2006 ([EIA, 2014f](#)). Qatar's exports increased

Table 5. Exports to Asia-Pacific in 2013.Source: [Petroleum Economist \(2015\)](#).

Country	Export (Mt)	Share in world total (%)
Qatar	53.3	31.3%
Malaysia	24.1	14.2%
Australia	21.5	12.6%
Indonesia	15.9	9.3%
Russian Federation	10.2	6.0%
Nigeria	8.8	5.1%
Oman	8.1	4.8%
Brunei	6.7	4.0%
Yemen	5.8	3.4%
United Arab Emirates	5.3	3.1%
Others	10.56	6.2%
Total	170.3	100.0%

**Figure 1.** Trend of LNG export by major suppliers, 2000–13 (Mt). Source: [Petroleum Economist \(2015\)](#).

rapidly during 2009–11 and have been relatively stable from 2011–13 ([Figure 1](#)). At present, the US\$0.4 billion Barzan Gas Project is expected to boost production in the short term ([EIA, 2014f](#)). Due to the recent Ukraine dispute between Europe and Russia, gas demands in Europe has been increasing with a switch of roughly 30 percent of Qatar's export capacity to the European market in 2013 ([Petroleum Economist, 2015](#)).

Given substantial gas resources and its advantageous location, Australia's LNG industry has been rapidly developing ([Kompas and Che, 2015c](#)), especially since 2004. As of November 2014, about 64.3 percent of global LNG projects under construction have occurred in Australia, potentially contributing new capacity for exports of about 68.7 Mt per year ([Petroleum Economist, 2015](#)). With eastern Australia's integration into the Asia-Pacific market and substantial new LNG projects, the country is expected to surpass Qatar, becoming the world's largest LNG

exporter. However, Australia's future expansion faces both opportunities and risks in the Asia-Pacific LNG market. The opportunities in the Asia-Pacific are tremendous, including high LNG demand, relatively high LNG prices, shorter shipping distances and well-established trade relationships. The challenges are considerable, including the high cost of exploitation, the need for large capital investment, often slower construction times, and the lack of experience in export-based coal seam gas. Recently falling LNG prices and increasing competition among LNG suppliers in the Asia-Pacific region have added major challenges and may threaten the economic feasibility of Australia's investment in LNG. Based on different future alternatives for Australia's LNG exports and Asia-Pacific LNG price, [Kompas and Che \(2015c\)](#) projected that Eastern Australia's export revenues will be around AU\$15–16 billion by 2020 and AU\$19–21 billion by 2030.

Regarding the effect of groundwater extraction, coal seam gas (CSG) development causes a high risk to water use for household and agriculture ([Kompas and Che, 2015d](#)) (CSG is a natural gas held in coal seams under pressure by groundwater. Coal seam gas wells release the gas by reducing the pressure through groundwater extraction ([Independent Scientific Committee on Coal Seam Gas and Large Mining Development \(IESC\), 2015](#))). Groundwater provides an important water source in Queensland ([Australian Bureau of Statistics \(ABS\), 2015](#)). CSG development in Queensland is projected to draw about 600–800 gigalitres (GL) of water out of the ground each year. By comparison, the groundwater consumption of agriculture in the major Queensland CSG area is estimated to be 550 GL ([Kompas and Che, 2015d](#)). CSG development also requires land clearing connected to roads and pipelines, pumps, generators, compressors, ponds or tanks and storage facilities. CSG fields have a big industrial footprint, requiring clearance and degradation of large areas of land ([Stop CSG, 2015](#)). As a result, future CSG development requires a relevant strategy of long-term development of agriculture and environment. Also, along with significant gains from LNG exports, the welfare of domestic gas users is apparently affected by higher gas prices, less security over long-term contracts and more uncertainty over gas supplies. The average welfare loss to domestic consumers is roughly AU\$357–AU\$455 million per year for major domestic gas consumers, including residential and commercial users, larger industries and the electricity power generation sector ([Kompas and Che, 2015e](#)).

In the USA, increases in shale gas supplies are extraordinary, bringing the country closer to energy independence and to being a major LNG exporter. According to the [Department of Energy \(DOE\) \(2015\)](#), by December 2014, total long-term applications of new gas projects received by the Department of Energy (DOE) will increase potential exports by up to 41.9 billion cubic feet per day (or up to 300 million ton (Mt) oil equivalent per year) at (currently) lower prices. LNG supplies that are contracted from North America to the Asia-Pacific region have started to

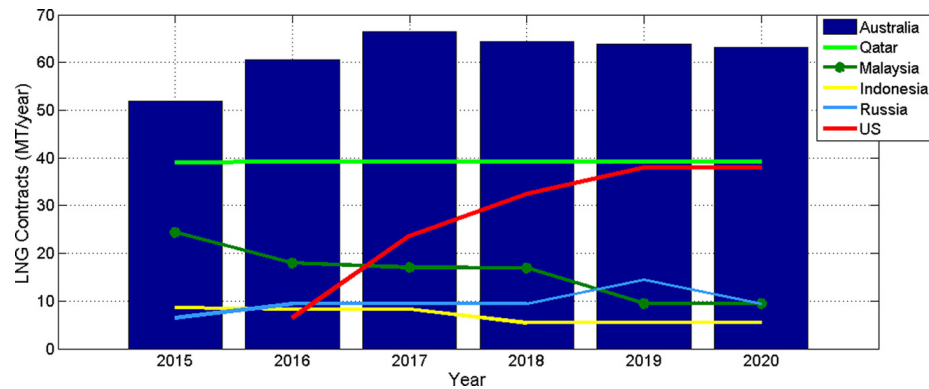


Figure 2. Emergence of Australia and the US in existing long term contracts, 2015–20 (Mt). Source: Computed from [Petroleum Economist \(2015\)](#).

grow rapidly. At present, existing contracts for LNG exports committed by the USA to Asia-Pacific have increased from 6.5 Mt in 2016 to 38.0 Mt in 2019 (see [Figure 2](#)). Cheniere Energy Inc is set to be the first company to export gas produced from the US shale boom. In addition, given the evolution of technology, the potential effects of floating LNG (FLNG), or ships that liquefy gas onboard, could have a substantial impact on the industry (if proven viable) since it removes the need to build permanent infrastructure at receiving ports ([Resutek, 2014](#)).

Uncertainties surrounding future LNG exports to Asia-Pacific are significant. First, the recent rapid falling trend in Asia-Pacific LNG prices and increasing LNG production costs are the key challenges to the economic feasibility of LNG projects and future LNG expansion ([Kompas and Che, 2015b](#)). Second, transportation costs are relatively high and uncertain from North America to the Asia-Pacific market. Despite the widening of the Panama Canal (which is expected to be a significant shipping route from the USA to Asia for LNG), which will reduce transportation costs, the overall tariffs or conditions of passage for LNG cargoes through the canal are yet to be confirmed. Third, the large investment required for LNG projects is often simply a barrier to LNG development in the North America ([Herbert Smith Freehills Energy, 2014](#)).

2.3.5. LNG pricing and contracting mechanisms

Following the annual surveys of international wholesale gas prices from 2005–13 ([IGU, 2014](#)), the major types of global LNG pricing mechanisms are Oil Price Escalation (OPE), Gas-on-Gas Competition (GOG) and Bilateral Monopoly (BIM). In the Asia-Pacific LNG market, the oil-linked pricing mechanism (OPE) and long-term contracts have historically dominated the LNG market. In 2013, oil-linked pricing formation accounted for 83 percent of total gas imports in the Asia-Pacific region ([IGU, 2014](#)).

For major LNG importers, such as Japan and South Korea, the price formula for LNG contracts is indexed to a price for a basket of crude imported to Japan, which is called the Japanese Custom Cleared price (JCC), and is based on a energy-basic equivalent between a barrel of crude oil and a million British thermal units (MBtu). By the JCC linked pricing formation, LNG prices are derived from a relationship between LNG and JCC prices (a price slope) and a base price (a constant term), which is independent with changes in oil prices ([Kompas and Che, 2015a](#)). According to [IEA \(2013\)](#), the decline in oil prices during the 1980s led to the introduction of S-curve pricing formulas in many Asian LNG contracts. The S-curve pricing formula shows a linear relationship between the price of LNG and crude oil, but it also contains price ceilings and floors to moderate the extreme impact of crude oil prices on LNG prices.

The oil-linked price mechanism has dominated LNG price formation for decades. However, this mechanism has been challenged since 2008, raising serious concerns about its use ([Agerton, 2012](#)). JCC linked LNG prices in the Asia-Pacific LNG market has experienced dramatic fluctuations due especially to uncertainties around oil prices. Recent robust world crude oil supply growth and weak global demand have caused global oil inventories to rise and crude oil prices to fall sharply since mid-2014. Brent oil prices have fallen continuously from US\$103.5/bbl in May 2014 to US\$47.35/bbl in late January 2015 ([Quandl, 2015](#)). Based on current market balances, the [EIA \(2015\)](#) projected Brent crude oil prices will reach a 2015 monthly average low of less than US\$50/bbl in January and February, and then increase through the remainder of the year to average US\$67/bbl during the fourth quarter. In 2015, Brent crude oil price is projected to be US\$58/bbl. However, several factors could generate uncertainties in future crude oil prices, including how key producers regulate output ([EIA, 2015](#)). In addition, rising oil prices since early 2008 to mid-2014 induced LNG prices to increase at a historically high level, resulting in LNG prices in the region being several times higher than the North American market. However, recent sharply falling crude oil prices (since mid-2014) have driven significant falls in LNG spot prices and future LNG long-term contract prices in the Asia-Pacific region. Based on [Platts \(2015b\)](#), LNG spot prices to the Asia-Pacific in January and February 2015 have fallen by 46.9 and 47.3 percent year to a four-year low, averaging US\$10.062 and US\$9.911 per million British thermal units (MBtu).

3. Model

This section provides the structural framework for the APGM, including LNG trade flows for imports, exports and trade linkages, and the cost function for LNG imports. The key variables of the model are indicated in [Table 6](#).

Table 6. Key variables in the Asia-Pacific Gas Model.

Variables	Denotation	Note
Number of import nodes	I	
Number of import countries	N	
Number of export nodes	J	
Number of export countries	M	
Time horizon	T	$T = 1 - T$
Representative import node	i	$i = 1 - I$
Representative import country	n	$n = 1 - N$
Representative export node	j	$j = 1 - J$
Representative export country	m	$m = 1 - M$
LNG gas demand of country n	$D_n(t)$	
Domestic gas production of country n	$Y_n(t)$	
Pipeline import of country n	$Z_n(t)$	
LNG import of country n	$X_n(t)$	
LNG export from node j to node i by long term contracts	$q_{ij}(t)$	
LNG export from node j to node i based on common trade	$x_{ij}(t)$	
Total LNG import of country n	$X_n(t)$	
Capacity of country n at time t	$\bar{X}_n(t)$	
Total LNG export of country m at time t	$X_m(t)$	
LNG supply of node j at time t	$y_j(t)$	
Gas supply to domestic consumption of node j at time t	y_{dj}	
LNG supply to other markets of node j at time t	y_{oj}	
LNG supply to the Asia-Pacific of node j at time t	$X_j(t)$	
Export capacity of node j	\bar{x}_j	
Cost of gas liquefaction per unit of LNG of node j	c_{j2}	
Cost of gas shipping per unit of LNG of node j	c_{j3}	
Cost of degasification per unit of LNG from node j to node i	c_{ij4}	
Other cost of delivery per unit of LNG of node j	c_{j5}	
Cost LNG import of from node j to node i	$e_{ij}(t)$	
Cost of LNG imports of country n	$E_n(t)$	
Total cost of Asia-Pacific LNG imports	$E(t)$	

3.1. LNG trade flows

Figure 3 represents the LNG trade flows between importers and exporters. The LNG demand side includes N import countries with I import nodes. A representative import country and node is denoted as country n ($n = 1 \dots N$) and node i ($i = 1 \dots I$), respectively. The LNG supply side includes M export countries with J export nodes. A representative export country and export node is denoted as country m ($m = 1 \dots M$) and node j ($j = 1 \dots J$), respectively.

The LNG trade flow between node i and node j at time t includes the existing long term contracts and common trade (the term common LNG trade refers to all other LNG trade that does not belong to existing long term contracts at time t , including spot and short term trade and potential future long term contracts), or

$$X_{ij}(t) = q_{ij}(t) + x_{ij}(t) \quad (1)$$

where $X_{ij}(t)$ is total LNG trade; $q_{ij}(t)$ is the trade based on existing long term contracts at time t ; and $x_{ij}(t)$ is the common LNG trade.

The cost of node i ($e_{ij}(t)$) to import $X_{ij}(t)$ from node j is given by

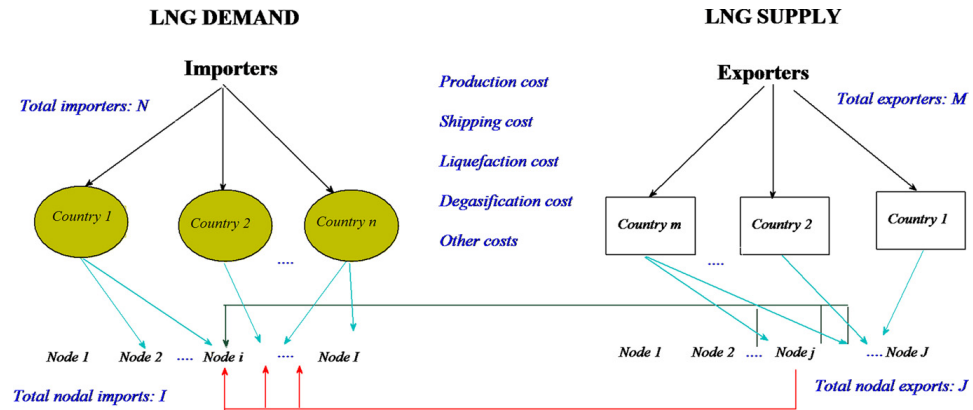


Figure 3. LNG trade flows.

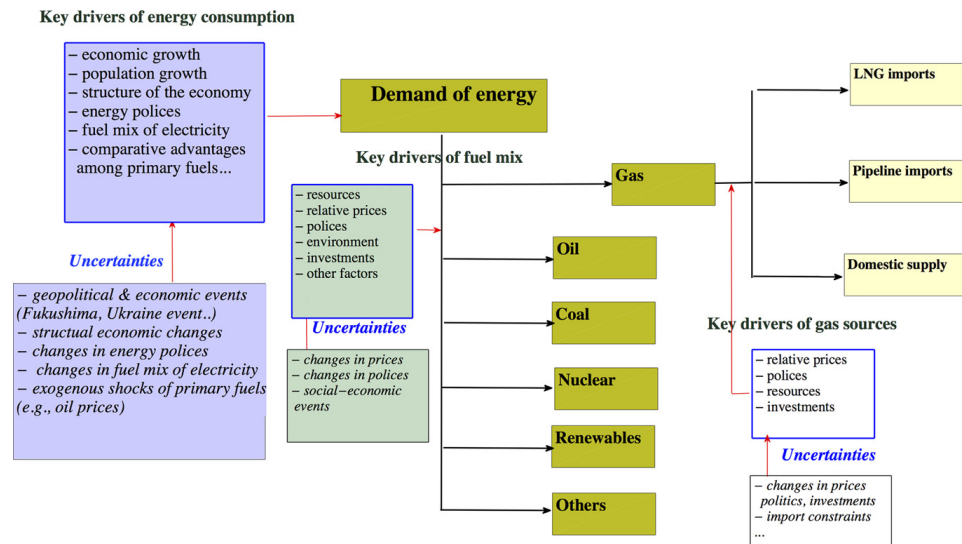


Figure 4. Demand of energy, gas and LNG in import countries.

$$e_{ij}(t) = c_{ij}(t)x_{ij}(t) + \bar{p}_{ij}(t)q_{ij}(t) \quad (2)$$

where $\bar{p}_{ij}(t)$ is the long term contract price; and $c_{ij}(t)$ is the delivery cost between the two nodes.

3.2. Representative importing country

Figure 4 represents the relationship of energy consumption, gas demand and LNG imports in a representative import country (country n). At equilibrium, energy demand is given by

$$\text{Energy demand} = \text{gas} + \text{coal} + \text{oil} + \text{nuclear} + \text{renewables} + \text{others} \quad (3)$$

The key drivers of energy demand are economic growth, population growth, the economic structure of the economy and energy policies. The sources of uncertainty in energy demand are exogenous shocks from geopolitical and economic events, and

changes in economic structure and energy policies. The key drivers of the fuel mix are differences in comparative advantage across countries, relative energy prices, environmental targets and other constraints for LNG development.

At equilibrium, gas demand is given by

$$\text{Gas demand} = \text{domestic supply} + \text{pipeline imports} + \text{LNG imports} \quad (4)$$

The key drivers for equation (4) are domestic gas resources, relative prices at gas source-points and the conditions of pipeline and LNG supplies. The sources of uncertainty include changes in relative prices among gas producers and policies and constraints surrounding domestic production and gas imports. In country n , at equilibrium, LNG import demand is given by

$$X_n(t) = D_n(t) - Y_n(t) - Z_n(t) + \xi \quad (5)$$

where $X_n(t)$ is LNG imports; $D_n(t)$ is total gas demand; $Y_n(t)$ is domestic gas production; $Z_n(t)$ is pipeline imports; and ξ is a measure of uncertainty.

Given total LNG imports of country n at time t , $X_n(t)$ includes the component of existing long term contracts in force at time t and common trade from all nodal trades in the country, or

$$X_n(t) = \sum_{i=1}^{I(n)} \sum_{j=1}^J [x_{ij}(t) + q_{ij}(t)] \quad (6)$$

where $I(n)$ is import nodes in country n and J is all export nodes in the Asia-Pacific region. Total LNG imports are constrained by the import capacity of the country, or

$$X_n(t) \leq \bar{X}_n(t) \quad (7)$$

3.3. Representative exporting country

In node j of a representative export country, total gas production of node j (y_j) supplies domestic consumption, the Asia-Pacific market and other international markets. As indicated in (1), the gas exported to Asia-Pacific by node j ($X_j(t)$) includes the exports based on existing long term contracts (q_j) and common trade (x_j). At equilibrium gas output of node j ($y_j(t)$) at time t is

$$y_j(t) = X_j(t) + y_{dj}(t) + y_{oj}(t) = x_j(t) + q_j(t) + y_{dj}(t) + y_{oj}(t) + \xi_j \quad (8)$$

where y_{dj} is domestic consumption; y_{oj} is exports to other markets; x_j is common trade to Asia-Pacific; q_j is existing long term contracted exports; $x_j(t) + q_j(t)$ is LNG exports to Asia Pacific; and ξ_j is a random component. The total LNG export of node j is constrained to be less than the export capacity, or

$$X_j(t) \leq \bar{x}_j(t) \quad (9)$$

The LNG export of country m ($X_m(t)$) is a sum of all nodal exports ($X_j(t)$) in that country, or

$$X_m(t) = \sum_{j=1}^{J(m)} \sum_{i=1}^I [x_{ij}(t) + q_{ij}(t)] \quad (10)$$

where $J(m)$ is export nodes in country m and I is all import nodes in Asia-Pacific.

3.4. LNG long term contract price

We follow the analysis of the structure and dynamics of LNG prices in Asia-Pacific as given by Kompas and Che (2015a). In this work, the econometric specification of long-term contract prices ($P_{k,J,t}^{LNG}$) is

$$P_{k,J,t}^{LNG} = \delta_{k,T} + \alpha_{k,T,t} P_{k,T,t}^{JCC} + D_{k,T,t} + \xi \quad (11)$$

where k presents different ranges of JCC prices; T presents different structural-break periods; t is time; and s represents geopolitical and economic events at t ; $\delta_{k,T}$ is the base component of LNG prices; D_t is a dummy variable for geopolitical or accidental events; and ξ is the error term of the regression.

3.5. LNG delivery cost

The delivery cost of a LNG unit traded between node j to node i includes the cost of gas production, liquefaction, shipping, de-gasification and other costs. The cost of LNG production varies from LNG project to project. According to the Massachusetts Institute of Technology (MIT) (2010), the supply-cost gas curve has a convex shape, but is a linear relationship until supply increases by more than 500 times compared to current global gas supply. In Australia, the cost of LNG production will clearly increase with additional gas output (ACIL Tasman, 2013); Core Energy Group, 2013). The cost of a unit of gas production (c_{1j}) is given by

$$c_{1j} = a_1 + a_2 y_j + \xi \quad (12)$$

where y_j is the output of gas production of node j ; a_1 and a_2 are cost and production coefficient parameters ($a_2 > 0$); and ξ is a measure of uncertainty. Based on (12), the LNG delivery cost from node j to node i ($c_{ij}(t)$) is given by

$$c_{ij}(t) = \underbrace{[a_1 + a_2 (x_j(t) + q_j(t) + y_{dj}(t) + y_{oj}(t))]}_{c_{1j}} + c_{2j} + c_{3ij} + c_{4ij} + c_{5ij} + \xi \quad (13)$$

for c_2 to c_5 , a series of preparation and delivery costs (Table 6).

3.6. Objective function of the APGM

At trade equilibrium in Asia-Pacific, total LNG imports are equal to total LNG exports, or

$$\sum_{n=1}^N X_n(t) = \sum_{m=1}^M X_m(t) \quad (14)$$

The total cost of LNG imports of country n ($E_n(t)$) is the sum of all nodal costs of LNG imports. Based on (2), the total cost of LNG imports of country n is given by

$$E_n(t) = \sum_{i=1}^{I(n)} \sum_{j=1}^J [c_{ij}(t)x_{ij}(t) + \bar{p}_{ij}(t)q_{ij}(t)] \quad (15)$$

and the total cost of LNG imports in Asia-Pacific, ($E(t)$), is the sum of LNG costs of all import countries, or

$$E(t) = \sum_{i=1}^I \sum_{j=1}^J [c_{ij}(t)x_{ij}(t) + \bar{p}_{ij}(t)q_{ij}(t)] \quad (16)$$

The objective function for the APGM is to minimise total costs of Asia-Pacific LNG imports using the control variables of trade flows among import and export nodes, or

$$\min_{x_{ij}(t)} E = \sum_{n=1}^N \sum_{i=1}^I \sum_{j=1}^J [c_{ij}(t)x_{ij}(t) + \bar{p}_{ij}(t)q_{ij}(t)] \quad (17)$$

Given the relationships and constraints of the model as discussed in Equations (1)–(16), it is assumed that importing countries are acting to minimise the costs of imports from various nodes, given relative supplies, changes in those supplies and changes in costs of supply as import proportions vary.

The model is programmed and solved using a stochastic programming process and parallel programming techniques. Solutions are obtained through an iterative procedure for all gas importers and exporters in the Asia-Pacific region. Matlab and information provided by the Geographic Information System (GIS) are also used to assist with data and other inputs, and for the analysis.

For analysing the Asia-Pacific LNG market, the APGM provides some key advantages. The model is developed (and supported by data) for the particular structure and dynamics of the oil-linked pricing and long-term contracting mechanisms, along with other market conditions in the Asia-Pacific LNG market. The model is also non-linear and stochastic allowing a full capture of the interactions or relationships between consumption, production, and trade, with uncertainty.

4. Analysis

This section describes key sources in the database and calibrations for the APGM model. The key inputs include the projection of LNG demand in Asia-Pacific, LNG long-term contracts and pricing, the ‘at capacity’ supply of major LNG exporters, LNG delivery cost of suppliers and macroeconomic indicators.

4.1. Projections of LNG demand

Projections of LNG demand by major importers in Asia-Pacific are based on studies of each country. In particular, the LNG demand outlook for Japan, China and India are based on an analysis from the [Institute of Energy Economics \(IEEJ\) \(2014\)](#), [Chen \(2014\)](#) and [Balyan \(2014\)](#), respectively. Projection of LNG demand in South Korea, Taiwan, Singapore, Malaysia, Thailand and other Asian consumers are based on the outlook for economic growth, which is based on forecasts and time trends over the medium term by [IMF \(2015\)](#). Using relationships between economic growth and LNG demand growth in the past, future LNG demand in these countries is projected.

In the traditional LNG consumer group (i.e., Japan, South Korea and Taiwan), nuclear power for electricity generation is assumed to completely resume. In the emerging consumer group, the key assumption is that gas price market reform will be take place. China’s LNG domestic gas production and outlook for gas pipeline imports from Russia is based on [Chen \(2014\)](#) and [Xin \(2014\)](#). Other sources used for future LNG demand analysis are from [BP \(2015 and 2014\)](#), [Petroleum Economist \(2015\)](#), [IGU \(2015, 2014\)](#), [EIA \(2015, 2014a–2014e\)](#), the [Ministry of Economy, Trade and Industry of Japan \(METI\) \(2015\)](#), the [Federation of Electric Power Companies of Japan \(FEPC\) 2015](#), the [International Group of Liquefied Natural Gas Importers \(GIIGNL\) \(2006–14\)](#), [IEA \(2014\)](#), [Burma and Hong \(2014\)](#), and [Xin \(2014\)](#). Data sources for import capacities is based on [Petroleum Economist \(2015\)](#) and [IGU \(2015\)](#).

4.2. Outlook of long term contract and LNG contract price

Data on existing LNG long-term contracts is based on [Petroleum Economist \(2015\)](#). The projection of the LNG long-term contract prices is based on the study of [Kompas and Che \(2015a\)](#), which is based on the oil-linked pricing mechanism with a projection of crude oil prices from the [World Bank \(2015b\)](#) and [EIA \(2013\)](#). The key references in that study include source material from the [World Bank \(2015a\)](#), [Quandl \(2015\)](#), [Platts \(2015b, 2015c\)](#), [Rogers and Stern \(2014\)](#), [Stern \(2014\)](#) and [EIA \(2014a\)](#).

4.3. Outlook of LNG production capacity

Over the period of 2015–30, the database of LNG supply capacity and long term contracts is based on existing capacity and projected new capacity from LNG projects. The new LNG projects include those already committed, economically feasibility and any announced projects. Sources of production capacity and new projects are based on company reports, [Petroleum Economist \(2015\)](#), [EIA \(2015 and 2014f, 2014g\)](#), the [Department of Energy of the US \(DOE\) \(2015\)](#), [Platts \(2015b, 2015c\)](#), [Argus \(2015, 2014\)](#) and [IGU \(2014, 2015\)](#).

It is important to identify the social-economic constraints of LNG capacity supply. For example, Russia's Yamal LNG project provides a capacity of 16.5 Mt per year produced by three LNG trains. However, the capital cost (about \$26.9 billion) could be an issue in completing the project on time. Environmental concerns over coal seam gas in Australia could also be an issue in the development of LNG projects in a number of important agricultural areas, such as in the Murray–Darling basin, Tasmania, or Queensland.

4.4. LNG delivery costs

The process of gas transmission from production to end consumer use includes three phases of upstream (exploration and production), midstream (liquefaction and shipping) and downstream (re-gasification and distribution) transmission. Following [Core Energy Group \(2013\)](#) and [Argus \(2014\)](#), LNG delivery cost is taken as the sum of production cost (capital cost, labour and other costs), transport cost, shipping, re-gasification and other costs, such as manning cost, lube, repair and maintenance. LNG capital costs are broken down further by major input sectors, including treatment, liquefaction, fractionation, utilities and offsite costs, and storage and loading costs ([Coyle et al., 1998](#) and [Kotzot et al., 2006](#)). Further details of LNG delivery cost are provided in [Kompas and Che \(2015b\)](#).

The liquefaction cost of an LNG project can be measured in terms of cost per Mt per year of supply capacity. The capital cost of an LNG project i for a unit of MBTU at 2015 prices is given by

$$c(k)_i = \frac{(\mu_i + m_i)K_i}{T(Y_i)(v_{MBtu})} cpi_i \quad (18)$$

where $c(k)_i$ is capital cost per unit of MBTU; μ_i is the depreciation rate per year; m_i is average maintenance rate per year; K_i is the investment cost; T is the lifetime of the project (with an average of about 30 years); Y_i is the supply capacity of the project, including LNG export and other gas output measured in terms of million tons of oil equivalent (Mt); v_{MBtu} is the conversion rate between Mt and MBtu

(1 Mt equals to $40.4 * 10^6$ MBtu); and cpi_i is the deflation rate at the building time of the project to 2015. As indicated in Equation (12), LNG costs are a function of additional LNG supply. Based on capital cost and additional supply, the value of a_1 and a_2 are taken as \$2 and 0.02 for price is measured in \$ per MBtu and additional supply measured in Mt.

Sources of delivery costs include [Platts \(2015b, 2015c\)](#), [McKinsey and Company \(2013\)](#), [ACIL Tasman \(2013\)](#), [Petroleum Economist \(2015\)](#), [Core Energy Group \(2013\)](#) and [GlobalInginfo \(2015\)](#). It is important to note that technological breakthroughs such as Floating LNG, or FLNG, could also reduce costs ([McKinsey and Company, 2013](#)). According to [KPMG Global Energy Institute \(2014\)](#), the key advantages of FLNG includes the ability to unlock smaller fields, have better access to remote fields, a reduction in environmental footprint and the ability to deliver projects cheaper and faster.

Calculation of shipping costs is based on distance (knots), the size of a ship, carrier utilisation, time of loading and discharge. The key parameters for shipping costs are drawn from [Platts \(2015b, 2015c\)](#) and [Argus \(2014\)](#). The key assumptions here are: one day in port for loading and two for discharge, with a boil off rate of 0.15/MMbtu/day when loaded and 15 days per year downtime ([Argus, 2014](#) and the [China–Australia Natural Gas Technology Partnership Fund, 2014](#)). Shipping distances are provided from LNG World Interactive Map ([Petroleum Economist, 2015](#)).

Other costs (including labour and other costs) are based on [Argus \(2015 and 2014\)](#), [IGU \(2014, 2015\)](#), [Platts \(2015b and 2015c\)](#), [Songhurst \(2014\)](#), [McKinsey and Company \(2013\)](#), [ACIL Tasman \(2013\)](#), [Core Energy Group \(2013\)](#), [HS CERA \(2014\)](#), and [Kotzot et al. \(2006\)](#).

4.5. Macroeconomic indicators

Macroeconomic indicators for economic growth are based on the [International Monetary Fund \(IMF\) \(2015\)](#). Exchange rates in 2015 are drawn from the [Reserve Bank of Australia \(RBA\) \(2015\)](#) and [IMF \(2015\)](#). Other social-economic indicators in import and export nations are from the [World Bank \(2015a, 2015b\)](#) and [IEA \(2014\)](#).

5. Results

This section provides the key results for projections of LNG trade in the Asia-Pacific region by the APGM over the period 2015–30. Given the uncertainties over LNG demand, delivery costs and prices, the projection of LNG trade over the study

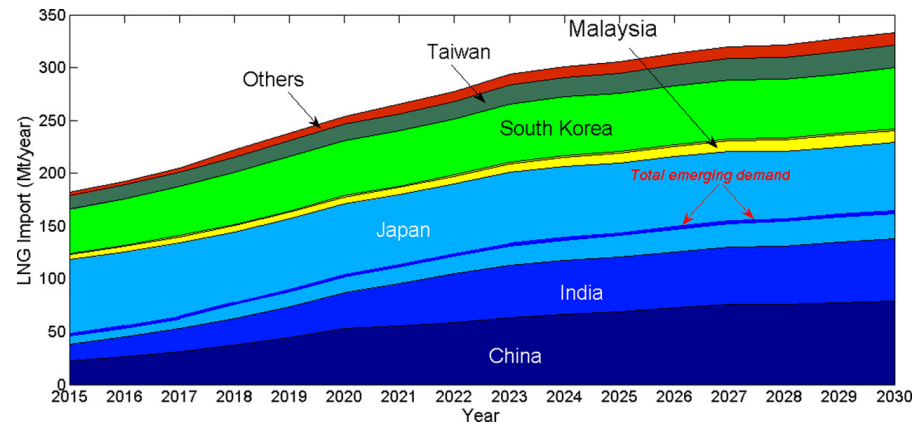


Figure 5. LNG imports by major consumers in Asia-Pacific, 2015–30 (Mt).

period is conditioned by distributions over key parameters. This section provides a summary of the projection of trade volumes in mean values (see [Figures 5–6](#)), trade values with uncertainty ([Figure 7](#)), and details trade values among major LNG consumers (as summarized in [Figure 8](#)).

5.1. Projections for LNG trade volumes

Projections for LNG imports in Asia-Pacific and major LNG consumers over the period of 2015–30 are presented in [Figure 5](#). LNG imports in Asia-Pacific are projected to increase from 181.9 million ton (Mt) in 2015 to 253.8 Mt in 2020 and 333.2 Mt in 2030. Future LNG demands from traditional LNG consumers, including Japan, South Korea and Taiwan, remain stable. Japan's LNG imports are projected to be 80.0 Mt in 2015, rising to almost 91.1 Mt in 2030. Korea's LNG consumption is projected to increase from 42.3 Mt in 2015 to 52.2 Mt in 2020 and 57.7 Mt in 2030. Over the study period, the fast growth of LNG demand is driven by emerging LNG consumers (especially China and India).

The role of emerging LNG consumers in future Asia-Pacific LNG imports is also characterised in [Figure 5](#). The share of emerging LNG importers in total LNG imports are projected to rise significantly, increasing from 20 percent in 2014 to 25.8 percent in 2015, 40.0 percent in 2020 and almost 50 percent in 2030. LNG imports from emerging consumers are expected to increase from 47.0 Mt in 2015 to almost 100.0 Mt in 2020 and 163.2 Mt in 2030. China is the most important new market for LNG imports, accounting for about half of emerging LNG demand in the region over the study period. The country is projected to import roughly 53.0 Mt in 2020 and 79.2 Mt in 2030. India's role in the emerging Asia-Pacific LNG demand is also important, increasing from 16.0 Mt in 2015 to about 34.1 Mt in 2020 and 58.6 Mt in 2030.

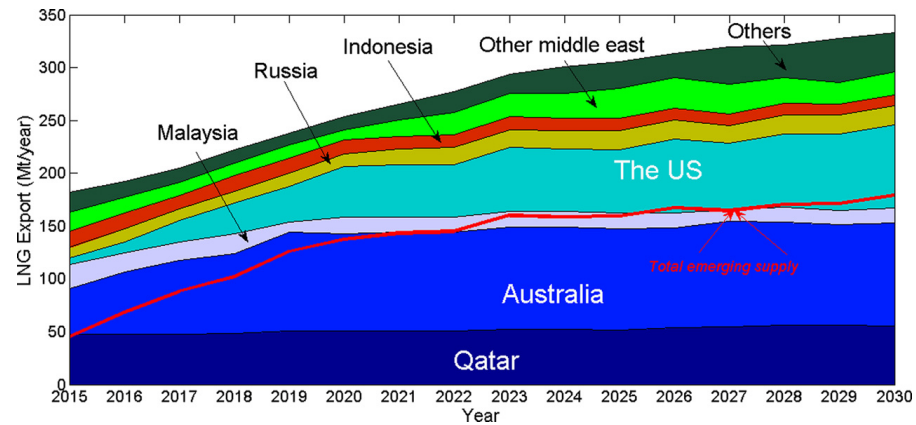


Figure 6. LNG exports by major suppliers to Asia-Pacific, 2015–30 (Mt).

Projection of LNG exports in the Asia-Pacific and major LNG suppliers over the period of 2015–30 are presented in Figure 6. Meeting LNG demands, LNG exports will increase from 181.9 Mt in 2015 to 253.8 in 2020 and 333.2 Mt in 2030. The projection of LNG exports indicates the fast growth of emerging LNG suppliers in the region, especially Australia and the USA. New LNG supplies (mainly from Australia and the USA) are projected to increase their share in Asia-Pacific LNG trade from roughly 19 percent in 2014 to 25 percent in 2015, and to surpass 50 percent in 2019 (see Figure 6). The role of traditional exporters such as Qatar, Malaysia and Indonesia are projected to diminish over the study period. While overall export capacity will not change a great deal, Qatar is expected to re-direct its LNG export capacity to the European market. Current LNG export capacity in Malaysia and Indonesia will likely switch to serve domestic demand.

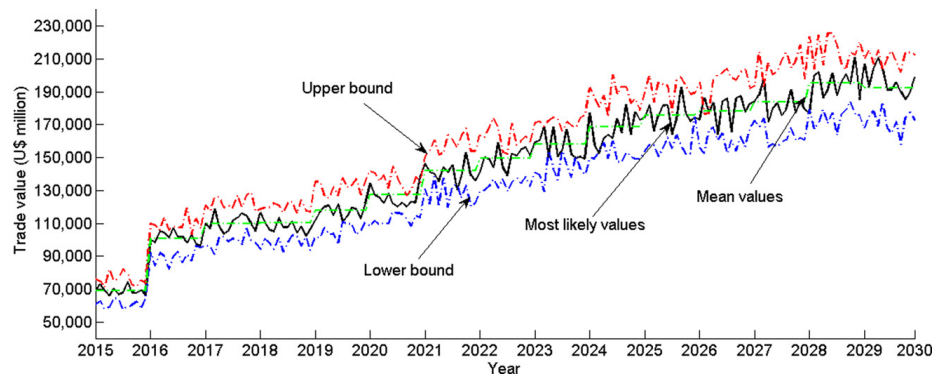
Given the current macroeconomic situation at model run (January 2015), it is projected that Australia's LNG exports will increase rapidly from 2015–20, at 43 Mt in 2015 to about 93 Mt from 2019. However, Australia's LNG future expansion is very sensitive to changes in the exchange rate, which has fluctuated significantly over the past two years, making Australia's LNG delivery costs change significantly. It is also projected that LNG exports from the USA will increase significantly from about 6.24 Mt in 2015 to 48.4 Mt in 2020 and 78.9 Mt in 2030 (see Figure 6).

The role of new LNG supplies, especially from Australia and the USA, is important to future Asia-Pacific LNG trade (see Figure 6). Combined, new LNG supplies are expected to share about half of LNG exports to the region over the next three years. Sensitivities over future LNG exports are important, especially factors such as changes in crude oil prices, exchange rates, and transport costs, along with geopolitical and economic risks.

Table 7 provides a summary of Asia-Pacific LNG trade movements in 2020. In 2020, total LNG trade among major importers and exporters is 248.7 Mt. Japan is

Table 7. LNG trade flows in 2020 among major importers and exporters (*Mt*).

Importers	Exporters							Sum import
	Australia	Indonesia	Malaysia	PNG	Qatar	Russia	the US	
Japan	34.0	1.2	10.5	3.0	7.1	7.4	14.4	77.6
Korea	18.3	7.1	1.8	–	15.2	1.4	5.2	49.1
Taiwan	2.5	3.1	–	1.5	4.9	–	3.4	15.4
China	27.9	2.4	3.3	1.8	1.9	2.8	10.9	51.1
India	7.0	–	–	–	18.1	–	9.0	34.1
Others	2.3	–	–	–	3.3	–	5.1	10.7
Sum export	92.0	13.8	15.6	6.3	50.5	11.5	48.0	237.9

**Figure 7.** LNG trade value in Asia-Pacific (*US\$ million*).

projected to be the most important LNG importer, followed by China, South Korea and India. Australia is projected to be the most important LNG exporter, following by Qatar and the USA. In 2020, Australia is projected to export 92.0 Mt, of which Japan and China will share 37 and 30 percent of total Australia's LNG exports respectively.

5.2. Projections for LNG trade values

The value of LNG trade is projected from changes in LNG demand, LNG contract prices and the delivery cost of LNG supplies under uncertainty surrounding LNG prices and costs. All values here are at 2015 prices (see Figure 7). In the Asia-Pacific, the total value of LNG trade is projected to range from US\$114.2 to US\$139.9 billion in 2020 (averaging US\$127.2 billion). In 2030, trade value is expected to increase from US\$179.1 to US\$ 218.9 billion (averaging US\$199.0 billion).

LNG trade values in Asia-Pacific in terms (in order) of minimum, mean and maximum values at a 90 percent interval are given in Figure 8. In 2020, Japan's LNG import value is projected to range from US\$45.4 to US\$ 48.4 billion in 2020 (averaging US\$46.8 billion). In 2030, trade is valued from US\$55.0 to US\$ 60.3 (averaging US\$57.7 billion). South Korea's LNG import value is expected to be from US\$27.7 to US\$ 31.4 billion in 2020 (averaging US\$29.6 billion). In 2030,

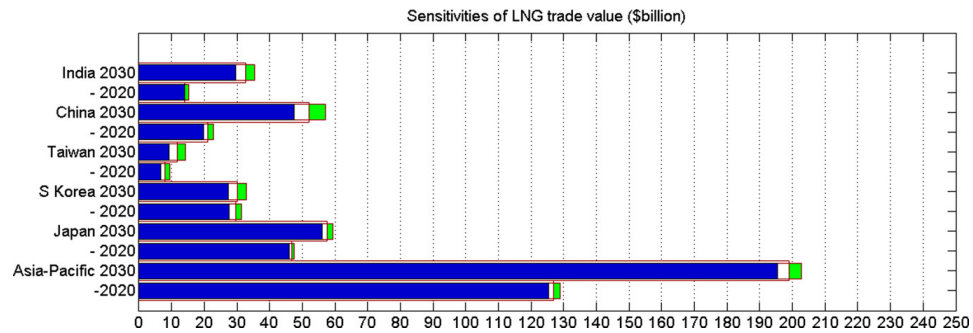


Figure 8. LNG trade value in Asia-Pacific (US\$ million).

the country's LNG import value is projected to range from US\$27.4 to US\$ 32.9 billion (averaging US\$30.0 billion). For Taiwan, LNG import values are projected to range from US\$6.6 to US\$ 9.5 billion in 2020 (averaging US\$8.0 billion). In 2030, this value is projected to range from US\$9.3 to US\$ 14.2 billion (averaging US\$11.8 billion).

In 2020, China's LNG import value is projected to range from US\$19.7 to US\$ 22.7 billion (averaging US\$21.1 billion). In 2030, this value is projected to increase from US\$47.4 to US\$ 57.0 billion (averaging US\$51.9 billion). Finally, India's LNG import value in 2020 is expected to range from US\$13.2 to US\$ 15.2 billion (averaging US\$14.1 billion). In 2030, this value is expected to increase from US\$29.7 to US\$ 35.2 billion (averaging US\$32.6 billion).

All projections, of course, are sensitive to changes in the key social-economic conditions that the model based on. These conditions include the Asia-Pacific pricing and contracting mechanism, investment in LNG supply capacity, macro-economic indicators (i.e., economic growth, exchange rate, energy policies, market reforms); and geopolitical-economic events. In particular, projections of LNG long-term contract prices are derived from the Asia-Pacific oil-linked pricing mechanism and the projection of crude oil prices (World Bank, 2015b; and EIA, 2015). Unexpected oil price shocks would cause model results to change. Investment in future LNG expansion, which depends on LNG prices and competition among primary fuels (such as oil, coal, and renewables), will also change future supply capacity, and cost competitiveness among suppliers. These are all significant risks. On the demand side, risks resulting from changes in fuel-mix policies, economic growth, energy price reforms, environmental targets, consumption of competing fuels such as nuclear power, and renewables, and new gas pipeline development will also matter. Finally, changes in the input factors for the derivation of LNG cost delivery can also clearly affect the results. A major change in liquefaction costs (resulted from changes in capital investment, project life span, etc.), for example, along with changes in labour and transport costs, can change the estimated cost competitiveness of LNG suppliers and model results.

6. Conclusions

The Asia-Pacific LNG market is currently undergoing considerable change and uncertainty, especially due to substantial new supplies emerging from Australia and North America and the falling trend in LNG prices resulting from the recent oil price slump. The Asia-Pacific Gas Model (APGM) developed in this paper, which captures the structure, interactions, dynamics and many of the uncertainties of the Asia-Pacific LNG market, provides a valuable tool for projections of LNG trade in the Asia-Pacific region from 2015–30.

LNG imports in Asia-Pacific are projected to increase from 181.9 million ton (Mt) in 2015 to 253.8 in 2020 and 333.2 Mt in 2030. The value of LNG imports in the Asia-Pacific region is projected to increase on average from US\$ 68.8 billion in 2015 to US\$127.2 billion in 2020 and US\$199.0 billion in 2030 (90 percent significance). The annual growth rate of LNG trade value is about 6 percent per year over the study period. The key sources of LNG trade expansion are driven by major emerging importers (China and India) and exporters (Australia and the US).

The share of emerging importers in total imports will increase from 20 percent in 2014 to 25.8 percent in 2015, 40.0 percent in 2020 and almost 50 percent in 2030. China is the most important new consumer, accounting for about half of emerging LNG demand in the region over the study period. The country is projected to import about 53 Mt in 2020 and 79.2 Mt in 2030. India's role in emerging Asia-Pacific LNG demand is also important, increasing from 16.0 Mt in 2015 to about 34.1 Mt in 2020 and 58.6 Mt in 2030. The traditional LNG consumers (Japan, South Korea and Taiwan) remain important in future LNG trade, contributing a value of LNG imports from US\$53.9 billion in 2015 to US\$84.4 billion in 2020 and US\$99.5 billion in 2030. However, the role of emerging importers (especially China and India) becomes especially significant. The value of LNG imports to China and India is expected to be US\$35.2 billion in 2020 and US\$84.5 billion in 2030, respectively. Much of this will be supplied by significant increases in supply from Australia and the USA. The change in the power relationships that accompany these changes in exports and imports, and the overall shift from oil to LNG, will be profound.

Declarations

Author contribution statement

Tuong Nhu Che: Conceived and designed the experiments.

Tom Kompas: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Competing interest statement

The authors declare no conflict of interest.

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