Liquefied Natural Gas as a Marine Fuel in Australia: Developing a Conceptual Framework for Strategic Decision-Making

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1 INTRODUCTION

1.1 Conventional Marine Fuel Oils and Their Emissions

When it comes to shipping large volumes of cargo over long distances, commercial shipping is the most efficient and cleanest mode of transport in terms of emissions.[1] However, the inherently low-grade, high sulphur content fuel oils used in shipping are responsible for the emission of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_X), sulphur dioxide (SO_2), volatile organic compounds (VOCs), black carbon (BC) and/or particulate organic matter (PM). According to recent studies, maritime industry accounts for approximately 2.2 percent and 2.1 percent of global CO_2 and greenhouse gas (GHG) emissions respectively.[2] Although a minor fraction of total global CO_2 emissions, international shipping was responsible for 938 tonnes of CO_2 emissions in 2012, and that figure is expected to increase by as much as 250 percent in 2050.[3]

In 2012, the World Health Organization's International Agency for Research on Cancer classified diesel exhaust as a human carcinogen.[4] The International Maritime Organization (IMO) has been under tremendous pressure to curb emissions on par with the initiatives of shore-based industries and numerous endeavors have been taken to reduce marine exhaust emissions by way of regulations, novel technologies, and alternative fuels. While there are current IMO regulations (MARPOL Annex-IV) in force to limit SO_X, NO_X, CO_2, and GHGs, more stringent regulations are expected in the near future.[5]

NO_X emissions from shipping, in the absence of abatement methods, are naturally high as most marine diesel engines operate at elevated pressures and temperatures. SO_2 emissions are high due to elevated sulphur content in marine heavy fuels in use.[6] Boyer emphasizes that NO_X emissions threaten biodiversity in ecosystems due to eutrophication.[7] Ship emissions contribute 11 percent and 4.5 percent of wet dispositions of nitrate and sulphur respectively. Dalsoren further projected that ships will be responsible for more than 50 percent of sulphur deposition by 2020.[8] Marine emissions produce more particulate matter (PM) and BC per unit of fuel consumed than other fossil fuel combustion sources due to the innate quality of fuel used. Lack affirms that BC emissions from ships contribute to increased

[1] C. Wang et al., "Improving spatial representation of global ship emissions inventories," *Environmental Science & Technology* 42, no. 1 (2008): 193–199; C. Deniz and A. Kilic, "Estimation and assessment of shipping emissions in the region of Ambarlı Port, Turkey," *Environmental Progress & Sustainable Energy* 29, no. 1 (2010): 107–115; Organisation for Economic Co-operation and Development, *Reducing Sulphur Emissions from Shipping; The impact of International Regulation* (Paris: OECD/ITF Publishing, 2016).
[2] International Maritime Organization, "Third IMO GHG Study 2014" (London: IMO, 2015).
[3] See International Maritime Organization n. 2 above.
[4] NSW Environmental Protection Agency, *Diesel and Marine Emissions Management Strategy* (Sydney: EPA, 2015).
[5] A. Dore et al., "Modelling the atmospheric transport and deposition of sulphur and nitrogen over the United Kingdom and assessment of the influence of SO_2 emissions from international shipping," *Atmospheric Environment* 41, no. 11 (2007): 2355–2367.
[6] V. Eyring et al., "Transport impacts on atmosphere and climate: Shipping," *Atmospheric Environment* 44, no. 37 (2010): 4735–4771.
[7] E.W. Boyer et al., "Current nitrogen inputs to world regions," in *Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment*, eds. A.R. Mosier et al. (Washington, D.C.: Island Press, 2004), pp. 221–230.
[8] S.B. Dalsøren et al., "Update on emissions and environmental impacts from the international fleet of ships," *Atmospheric Chemistry and Physics* 9 (2009): 2171–2194.

illness and mortality in society,[9] while Eyring found that shipping-related PM emissions caused between 20,000 and 104,000 premature mortalities annually.[10]

This article discusses the measures adopted by international organizations as well as regional and local regulatory bodies to monitor, control, and limit emissions from shipping. Emerging trends of compliance options and their pros and cons are acknowledged amid the certainty of rigorous emission regimes in the near future. The feasibility and advantages of using liquefied natural gas (LNG) as an alternative marine fuel in Australian waters are given prominence considering Australia's international standing as a leading natural gas producer. The challenges of embracing LNG as a marine fuel in general and in an Australian context are reflected in detail amid the backdrop of encouraging interests shown by the private sector and the absence of any such initiatives from the federal and state governments. This article proposes a methodology to capture the future demand profile of LNG as a marine fuel in Australia. Such a prediction tool can be utilized to demonstrate and draw attention to significant economic and ecological benefits that could be realized using the country's natural gas resources.

1.2 Efforts to Limit Emissions and Regulations by the International Maritime Organization

There are two sets of emission and fuel quality requirements defined by MARPOL Annex VI: a) worldwide directives, and b) more stringent directives applicable to ships in Emission Control Areas (ECAs) (see Figure 1). Present worldwide requirements include Tier II engine standards against NO_X emissions and a global cap on sulphur content of marine bunker fuels, which is currently set at 3.5 percent and supposed to reduce to 0.5 percent by 2020.

[INSERT FIGURE 1]

The IMO requirements for the energy efficiency design index (EEDI) and the ship energy efficiency management plan (SEEMP), which are indirect approaches to limit CO_2 emissions from ships, entered into force in January 2013. EEDI aims to achieve a 20 percent reduction of CO_2 by 2020, and 30 percent by 2025 through improvements in engine and hull-form designs. Nonetheless, studies carried out by Det Norske Veritas (DNV) and Lloyd's Register (LR) indicate that the reductions professed by these schemes are uncertain.[11] Although present IMO regulations do not address limiting PM from marine engines emissions,[12] upcoming new regulations curbing PM emissions can be expected considering its recent activities on PM and BC.

1.3 Regional, National Regulations and Guidelines

The United States Environmental Protection Agency (EPA) has rules requiring compliance with MARPOL Annex VI in U.S. waters; additionally, the EPA initiated limits on PM emissions in North American and Caribbean ECAs in 2012 and 2015.[13] Jointly, members of the European parliament have passed a resolution urging IMO to ban the use and carriage of heavy fuel oil for ships in Arctic waters.[14]

MARPOL regulations and subsequent amendments/addendums including Annex VI were integrated into EU rules by EU Directive 2005/33/EC.[15] Moreover, the EU is expected to propose

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[9] D.A. Lack et al., *Investigation of Appropriate Control Measures (Abatement Technologies) to Reduce Black Carbon Emissions from International Shipping* (Denmark: Litehauz, 2012).

[10] See Eyring et al., n. 6 above.

[11] DNV-GL, *Shipping 2020* (2012); Lloyd's Register Marine, *Global Marine Fuel Trends 2030*, (London: Lloyd's Register Group Limited & UCL Energy Institute, 2014).

[12] S. O'Malley et al., *Marine Fuel Choice for Ocean-Going Vessels within Emissions Control Areas* (Washington, D.C.: U.S. Energy Information Administration, 2015).

[13] L. Hagström and V. Koneru, "*Effship WP3: Exhaust Gas Cleaning*, Final Report" (Sweden: Effship WP3, 2013), pp. 40 at p. 12. Consultants' report on file with the authors.

[14] *IMO Urged to Ban Heavy Fuel Oil in Arctic Waters*, available online: <http://worldmaritimenews.com/archives/217140/imo-urged-to-ban-heavy-fuel-oil-in-arctic-waters//>.

[15] EU Directive 2005/33/EC, Directive of the European parliament and of the council, amending Directive 1999/32/EC as regards the sulphur content of marine fuels (Brussels: EC, 2011).

measures to reduce CO_2 emissions from shipping in its waters; the enactment of those measures is anticipated by 2017–2018.

1.4 Compliance Options and Emerging Trends

Use of marine distillates and/or ultra-low sulphur diesels is considered an immediate option to help reduce sulphur emissions, but their use is only a temporary option to reduce GHGs due to their long-term cost and availability.[16] However, initial compliance with MARPOL Annex VI will be achieved by these fuels as ship-owners have no other option until abatement techniques and fuel-switching systems are installed aboard ships.[17] Scrubber and selective catalytic reactor (SCR) technologies remove sulphur and NO_X emission from the exhaust gases. Nevertheless, these systems increase capital and operational expenditure while raising maintenance and reliability concerns.[18] Disposal of effluents from scrubbers is another issue where procedural mechanisms are not yet well-developed. While regulating ammonia slip from SCRs is an operational issue, the ineptitude of SCR during start-up and part-loads still necessitates the use of low sulphur fuel oils (LSFO) for short periods. While retrofit of scrubbers is seen as a viable option for existing vessels, new-builds are often contracted with dual-fuel capability for compliance with MARPOL Annex VI regulations.[19]

Combustion efficiency of engines has been significantly enhanced by modern fuel metering technologies, precise electronic monitoring/controls, and recirculation of exhaust gas (EGR). However, these adaptations increase weight and complexity of the engine and some techniques such as EGR require ultra-low sulphur fuel oils (ULSFO) for smooth operation.[20] Considering the composition of heavy fuel oil / marine diesel oil, and technical limits of internal combustion engines, emission gains that could be achieved by technical and operational means (such as slow-steaming) would be limited. Adopting new technologies for compliance will invariably increase operating costs of existing ships as well as the operating costs for ships that have been retrofitted or newly built. Immaturity of some compliance technologies may severely limit the confidence that can be placed on any feasibility comparisons in a conservative industry setting such as shipping.[21]

LNG, as a marine fuel, produces virtually zero sulphur dioxide emissions,[22] and has the potential to reduce CO_2 emissions by 20 to 25 percent, nitrogen oxide emissions by up to 90 percent, and particulate matter emissions by 98 to 100 percent.[23] Moreover, LNG eliminates the possibility of spills that could be catastrophic in sensitive ecosystems if conventional heavy bunker fuels were used. However, methane (CH_4) being the major constituent, natural gas has a GHG potential of 25 times compared with CO_2 if released to the atmosphere.[24] Therefore, the potential lifecycle emissions of LNG and its impact on the environment are noteworthy concerns. Nonetheless, well-to-propeller GHG emissions with the most consistent LNG chains are found to be 5.5 to 10 percent lower compared to

[16] M. Shrøder Bech, *North European LNG Infrastructure Project — Baseline report: A Feasibility Study for an LNG Filling Station Infrastructure and Test Recommendations* (SSPA, Danish Maritime Authority, 2011); N. Rehmatulla et al., "Implementation barriers to low carbon shipping" (paper presented at Low Carbon Shipping 2013, London, September 9–10, 2013).
[17] See Hagstrom n. 13 above.
[18] S. Brynolf et al., "Compliance possibilities for the future ECA regulations through the use of abatement technologies or change of fuels," *Transportation Research Part D: Transport and Environment* 28 (2014): 6–18; see O'Malley et al, n. 12 above.
[19] F. Macdonald, "Brittany Ferries orders LNG-powered newbuild," *Shipping Efficiency Review* (December 22, 2016), available online: <http://www.shipefficiencyreview.com/brittany-ferries-orders-lng-powered-newbuild/>.
[20] See Dore et al., n. 5 above and O'Malley et al, n. 12 above.
[21] See O'Malley, n. 12 above.
[22] Lloyds Register, *LNG-Fuelled Deep Sea Shipping–The Outlook for LNG Bunker And LNG-Fuelled New-Build Demand up to 2025* (London: Lloyd's Register, August 2012).
[23] J. Algell et al., *IMO Feasibility Study on LNG Fuelled Short Sea & Coastal Ships in Wider Caribbean Region* (London: IMO & SSPA, 2012).
[24] C. Chryssakis et al., "The fuel trilemma: the next generation of marine fuels," DNV-GL Strategic Research and & Innovation Position Paper no. 20 (DNV-GL, 2015).

diesel fuel chains.[25] Moreover, improved techniques have, in effect, eliminated methane slip during combustion processes of modern dual-fuel marine engines.[26]

Other compliant options are biofuels, ethanol, hydrogen, wind power, and nuclear energy. Although they achieve substantial reductions of CO_2 and other emissions, as Wang and Notteboom emphasize, their uptake is hindered by numerous practical, commercial, logistical, and safety issues.[27]

As of December 2015, there were 100 non-gas-carrying new builds to be fueled by LNG; the number of LNG-fueled vessels is predicted to be more than 1,000 by 2020.[28] The use of LNG as a marine fuel is projected to grow to 15 tonnes a year by 2020 to a possible 66 million tonnes in 2025.[29] As LNG as a marine fuel addresses emissions issues to the satisfaction of existing regulations, some suggest that LNG would be best placed to replace conventional fuel oils.[30] Therefore some shipowners have chosen to follow a far-sighted approach by building their ships LNG-ready, which incorporates flexibility to switch to LNG in the near future when market conditions are beneficial. In light of this trend, ship classification societies have already published requirements for ships that are constructed for dual-fuel or LNG propulsion at a later stage of their operating lives.[31]

1.5 Factors Affecting LNG's Future as a Marine Fuel

Compared with conventional fuels, LNG-fueled engines burn cleaner and produce fewer emissions on the combustion cycle,[32] while complying with relevant IMO regulations.[33] With proven world gas reserves,[34] the known resources of natural gas are considerably greater than those of crude oil. Algell concludes that LNG is the most appropriate alternative to crude oils in terms of long-term cost and proven reserves.[35]

LNG is projected to have a viable price development in comparison with conventional fuels.[36] Therefore, it could become an attractive marine fuel provided that a competitive pricing structure is established. Traditional price valuation structures such as Henry-Hub Pricing in the U.S. and present historically low fuel oil prices are seen as restraints against the uptake of LNG as a marine fuel.[37] Besides the market price of natural gas, a key component to be considered is the cost factor involved in supplying natural gas to LNG-fueled ships. LNG as a bunker fuel would only be attractive if the aggregate cost (Free On Board price or FOB) of delivering to the end user is economical. The early FOB price of LNG could be higher due to initial capital expenditure requirements of infrastructure. Countries such as Norway and other EU members have therefore adopted a strategy of incentivizing the first movers.

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[25] See Chryssakis et al., n. 24 above; R. Verbeek et al., *Environmental and Economic Aspects of Using LNG as a Fuel for Shipping in The Netherlands* (Delft: TNO, 2011).

[26] DNV-GL, "LNG as Ship Fuel: a focus on the current and future use of LNG as fuel in shipping," (2014), available online: <https://www.dnvgl.com/maritime/lng/index.html>.

[27] S. Wang and T. Notteboom, "The adoption of liquefied natural gas as a ship fuel: A systematic review of perspectives and challenges," *Transport Reviews* 34, no. 6 2014: 749–774.

[28] D. Holden, "Liquefied Natural Gas (LNG) Bunkering Study," Report no. PP087423-4, Rev 3 (DNV-GL, September 3, 2014).

[29] K. Kolwzan and M. Narewski, "Alternative fuels for marine applications," *Latvian Journal of Chemistry* 51, no. 4 (2012): 398–406.

[30] J. Xu et al., "The use of LNG as a marine fuel: the international regulatory framework," *Ocean Development & International Law* 46, no. 3 (2015): 225–240; J. Ashworth, "LNG Bunkers-Foggy Passage," *LNG Markets Perspective* (Singapore: Tri-Zen International, February 2016), available online: <http://www.trizeninternational.com/docs/publications.htm>.

[31] M. Claudipierre, 2016, "Getting ready to bunker," *LNG Industry* (June 2016), pp. 56–68.

[32] See DNV-GL, n. 11 and Kolwzan, n. 29 above.

[33] See Lloyd's Register Marine, n. 11 above.

[34] Geoscience Australia and BREE, *Australian Gas Resource Assessment 2012*, Department of Resources, Energy and Tourism, Geoscience Australia, Bureau of Resources and Energy Economics (Canberra, 2012).

[35] See Algell et al., n. 23 above.

[36] T. Smith et al., *Global Marine Fuel Trends 2030* (London: Lloyd's Register, 2014).

[37] M. Rozmarynowska, "LNG in Baltic seaports and the latest on the LNG market," *European LNG Outlook* 1, no. 1 (September 2015): 10–19.

Compared with conventional vessels, capital expenditure is 25 to 30 percent higher for LNG-fueled vessels. However, research indicates that additional building costs for LNG-fueled ships are recoverable in some cases within commendable payback periods for vessel types such as offshore supply vessels, short-voyage ferries, and tugs.[38]

Since the energy density of LNG is roughly 60 percent lower compared to that of fuel oils at the storage temperature,[39] 2.5 to 4 times more space is required for storage.[40] The penalty on storage[41] will reduce the steaming distance of a vessel, and limit its trading to near coastal or short sea-shipping routes. New technologies and innovations on LNG tank structures and storage layouts would be crucial factors to further improve storage efficiency and increase cargo-passenger carrying capacity in future LNG-fueled vessels.

The cryogenic state (-162° C) and low flash point (-188° C)[42] of LNG involve unfamiliar risks that must be cautiously engineered in order to preserve the safety of people, property, and the environment. The public may often react with apprehension due to a lack of knowledge and unrealistic perception of the risks associated with LNG. When the general populace is traditionally involved in the decision-making process, public consultation is an important part of the licensing process and environmental impact assessment (EIA) procedures. Thus, the public should be educated on the hazards as well as on the economic and ecological advantages of using LNG. Various public fora and media outreach may be vital in order to expedite the permit process and maintain emphasis on relevant safety concerns.[43] Moreover, identifying strategic storage locations with reference to avoiding populated areas, tourist, military, and protected areas is of paramount importance for establishing LNG bunkering infrastructure.[44] Managing risks to the public, workers, and critical infrastructure is essential to prevent catastrophic events that may affect the natural gas/LNG industry. Similar catastrophes in the magnitude of Chernobyl and/or Fukushima could create a public outcry against LNG adoption and hinder any political initiative from governments.

The international code on safety for ships using natural gas and other low-flashpoint fuels (IGF Code) was adopted in June 2015. The safety record of gas carriers in the last few decades indicates that a similar safety culture can be built upon careful training and implementing engineering and administrative safety controls on gas-fueled non-gas-carriers. While the IGF Code sets standards for LNG-fueled vessels, it does not apply to the supply side of LNG such as LNG bunker vessels. Considering the increased attention on LNG as a marine fuel and the number of gas-fueled new builds on order, the International Organization for Standardization (ISO) developed TS 1863:2015. The ISO LNG bunkering guidelines covers standardization of LNG bunkering equipment and system interfaces as well as training requirements of personnel involved in bunker operations.[45] Although the training and educational programs should be a combination of the IGF/ISO/STCW Codes and ISO guidelines to satisfy regulatory, safety, and operational requirements, there are no such combined gas-specific training standards in place for LNG bunkering systems that are approved by administrations.[46] This is a void that has to be addressed by classification societies, flag states, and relevant administrations.

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[38] IMO, *Studies on the Feasibility and Use of LNG as a Fuel for Shipping* (London: IMO, 2016); Det Norske Veritas, *Joint Industry Project, LNG Fuel Bunkering Australia: Infrastructure and Regulations* (Singapore: DNV, 2013). Consultants' report on file with the authors.
[39] See DNV-GL n. 11 above.
[40] J. Harperscheidt, "Bunkering, infrastructure, storage, and processing of LNG," *Ship & Offshore* 1, (2011): 12–15; see Directive 2005/33/EC, n. 15 above.
[41] T.E. Meyers and L.N.A. Woessner, "Recent acceptance of natural gas as fuel on U.S. flag vessels" (paper presented at Gas Fuelled Ships Conference in Rotterdam, The Netherlands, October 26–27, 2011).
[42] DNV-GL, *DNVGL Recommended practices: Development of operation of liquefied natural gas bunkering facilities 2015* (DNV-GL, October 2015), available online: <https://www.dnvgl.com/oilgas/download/dnvgl-rp-g105-development-and-operation-of-liquefied-natural-gas-bunkering-facilities.html>.
[43] J. Algell and B. Forsman, "Pilot study on the use of LNG as a fuel for a high speed passenger ship from the Port of Spain ferry terminal in Trinidad in Tobago," Report no. RE20136645-01-00-A (London: IMO & SSPA, June 23, 2013).
[44] See Algell and Forsman, n. 43 above.
[45] L. Langfeldt and H. Pewe, "Final report: European Maritime Safety Agency (EMSA) — Study on standards and rules for bunkering of gas-fuelled ships," Report no. 2012.005 (Lisbon: Germanischer Lloyd, 2013).
[46] R. Bleiberg, "Overcoming the challenge,"' *LNG Industry* (March 2016): 76–82.

Compared to conventional fuels, supply of LNG bunkers requires establishing infrastructure that warrants large capital expenditures. The projects should also ensure reliability of the supply in relation to the projected demand. Despite the interest and initiatives in some regions, reluctance, from both shipowners to adopt LNG for their new builds and bunker suppliers to develop infrastructure for LNG bunkering, is still considered the underlying problem that delays the world-wide adoption of LNG as marine fuel.[47] On the supply side, high capital requirements for the development of bunker infrastructure is deterring many stakeholders while shipowners are unwilling to invest in LNG-fueled vessels when there is no bunkering infrastructure in place to supply their vessels with LNG.

2 AUSTRALIA: (THE ABSENCE OF) A FUTURE DIRECTION FOR LNG AS A BUNKER FUEL

In light of current low fuel oil prices, Ashworth concludes that growing populaces and the ever-increasing societal expectations of oil-producing nations would not allow their per-capita income to dwindle with the unpleasant political consequences that would follow.[48] Thus, most oil exporters would not be able to put up with present low prices for the long haul. In addition, for compliance with future emission regulations and progressively higher fuel oil prices, the shipping industry will either need to use new types of fuels and/or implement abatement techniques. Bengtsson states that the maritime sector thus faces a fuel and/or technology shift within the near future.[49] Notwithstanding the present low fuel oil prices, countries like Norway and the Netherlands, and governing bodies like the EU, oil and gas majors, and even the end-users are of the opinion that LNG is prominent fuel for the future. Consequently, these regions are rolling out various schemes to develop LNG bunkering infrastructure in key port locations, in anticipation of stricter regulatory requirements on emissions that will prompt more LNG adoption in the future.[50] DMA noted that LNG bunker demand would reach 8.5 million m^3 in 2020 and 14 million m^3 in 2030 in European ECAs.[51] Considering the initial research work and investment commitments to accomplish the task of meeting the LNG demand, the EU has invested more than €60 million for various facets of the "Ten-T project,"[52] which aims to develop an LNG bunkering network in key European ports. In the U.S., the Ports of Tacoma, Jacksonville, Port Fourchon, L.A., and the Washington Ferries and Staten Island Ferries are considering conversion to LNG bunkering facilities. Singapore is set to commence a pilot scheme to supply LNG bunkers from 2017. Similar projects are underway in Korea to provide LNG bunkers by 2017.[53]

The price of oil will invariably rise again and many LNG projects, which have slowed down, are expected to get back on track by early 2020. Carnival Cruise's decision to build four LNG-fueled cruise ships, and recent decisions by prominent companies to build LNG-fueled and LNG-ready vessels confirm this sentiment.[54] While some countries and shipowners are embracing LNG-fueled shipping at these early stages, the majority of investors and countries/regions are cautiously monitoring the progress of LNG-fueled ships coming into the shipping mix and the progress on establishing marine LNG bunkering facilities. Therefore, the low number of early adopters does not mean that LNG is not

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[47] R. Hoenders, "EU initiatives regarding the use of LNG as bunker fuel and EMSA's involvement in promoting the use of LNG as alternative fuel," (EMSA, July 2013); S. Wang and T. Notteboom, "The role of port authorities in the development of LNG bunkering facilities in North European ports," *WMU Journal of Maritime Affairs* 14, no. 1 (2015): 61–92; see *DNV-GL*, n. 42 above.

[48] J. Ashworth, "LNG Bunkers – Troubled Waters" *LNG Markets Perspective March 2015*. (Singapore: Tri-Zen International, 2015), available online: <http://www.trizeninternational.com/docs/publications.html>.

[49] See Macdonald, n. 14 above.

[50] See Harperscheidt, n. 40 above.

[51] Danish Maritime Authority et al., *North European LNG Infrastructure Project: A Feasibility Study for an LNG Filling Station Infrastructure and Test of Recommendations,* (Copenhagen: Danish Maritime Authority, 2012).

[52] T. Stenhede, "Effship: A project for sustainable shipping — WP2 present and future maritime fuels," (Sweden: Effship, March 2013) Consultants' report on file with the authors. Available from project coordinators: <bjorn.allenstrom@sspa.se>; see Hoenders, n. 47 above.

[53] See Ashworth, n. 30 above.

[54] "UASC steps closer to LNG shipping," *HHP Insight* (April 21, 2016), available online: <http://www.hhpinsight.com/marine/2016/04/uasc-steps-closer-to-lng-shipping>.

progressing as a marine fuel. In fact, this is a situation where government support and intervention is required to establish the industry and reduce the risk of investments.

2.1 Key Factors Affecting Adoption of LNG Bunker Infrastructure in Australia

Natural gas was first discovered in Western Australia by Woodside in the early 1970s. What was initially a domestic market opportunity transformed into an export-driven industry in the late 1980s. The rise of coal seam gas (CSG) took place in late 1990s with the inception of the Fairview Field and Spring Gully projects.

Current major projects either in operation or in different phases of development can make Australia the world's leading natural gas exporter with ten projects worth 100 million tonnes per year of LNG production and proven gas reserves capable of supplying marine fuels by 2060 and beyond.[55] OECD/ITF 2016 estimates that the 0.5 percent global fuel sulphur cap in 2020 would have higher cost ramifications in shipping. In such a scenario, prophesying the obtainability and costing of fuels would be extremely difficult.[56] However, the onerous challenges ahead for low sulphur fuel distribution beyond 2020[57] combined with the benefits of LNG use may prove to be an attractive option in an Australian context. In view of Australia's geopolitical landscape and cultural views with regard to safety and security of the general public and the environment, embracing LNG as a marine fuel would encompass the following key factors:

- Manage public perception, safety, and security;
- Supply security of bunkering infrastructure and cost factors of LNG as a marine fuel;
- Protect coastal populations and the marine environment; and
- Address lackluster interest and lack of intervention from federal/state governments.

Each of these factors is explored in more detail below.

2.1.1 Manage Public Perception, Safety and Security

Processes, use, and handling of LNG are well understood; it has been used as ships' fuel for over thirty years on some gas carriers without serious incident.[58] Nevertheless, mitigating risks to the public, workers, and critical infrastructure is crucial to setting up LNG bunkering supplies in Australia. Moreover, the process must ensure that LNG does not cause negative environmental impacts. Following the examples set by the EU and Norway, similar public awareness campaigns could be initiated in Australia. With a world-renowned education system and a safety culture already entrenched in mining and offshore industries, setting up the safety and security regimes required for LNG bunkering should not be a problem for Australia.

2.1.2 Supply Security of Bunkering Infrastructure and Cost Factors of LNG as a Marine Fuel

The security of gas supply is determined by the following criteria: adequacy, reliability, and affordability.[59] If the supplies from terminals are insufficient to cater to the demand, as Lloyd's Register-Marine stressed,[60] the long-term concerns may be severe for LNG's future as a marine fuel. Another aspect that may affect adequacy of LNG supplies as a bunker fuel is the current regime of gas distribution policies practiced by regional governments — or rather the lack of a broad policy. There

[55] See Ashworth, n. 30 above; D. Ledesma et al., "The Future of Australian LNG exports," *The Oxford Institute for Energy Studies* (2014); N. Cassidy and M. Kosev, "Australia and the global LNG market," *Reserve Bank of Australia Bulletin* (March Qtr 2015): 33–44.
[56] OECD International Transport Forum, "Reducing sulphur emissions shipping: The impact of international regulation" (Corporate Partnership Board Report, Paris, 2016).
[57] DNV-GL, *Global Sulphur Cap 2020* (Hamburg: DNV-GL, 2016).
[58] See Verbeek, n. 25 above; A. Deal, "Liquefied natural gas as marine fuel a closer look at Tote's containership projects," Working Paper (National Energy Policy Institute, U.S., June 13, 2013).
[59] Energy Quest, *Australia's Natural Gas Markets: Connecting with the World* (2009).
[60] Lloyd's Register, *LNG Bunkering Infrastructural Survey 2014* (London: Lloyd's Register, 2014).

are three isolated geo-political LNG sectors in Australia. While the eastern market does not have any reservation quota, the Northern Territory and Western Australia utilize 1 percent and 15 percent of gas produced for their domestic use respectively. When LNG as a marine fuel gains a foothold in Australia, its supply would have to be negotiated with those of export and domestic markets.

Considering the volatile and perishable nature of LNG, the distribution network has to be reliable in terms of handling the liquid so that its composition is kept stable during the process. Technologically relevant bunkering infrastructure should be developed in strategic port locations along with a suitably trained workforce and reliable componentry.

In relation to conventional marine fuels, the infrastructure used in an LNG supply chain is more complex and costly, both in terms of capital and operational expenditure. Therefore, it is of utmost importance to maintain cost-effectiveness without compromising safety and quality. During the process, if the FOB price of LNG is found to be much higher compared to other alternatives, LNG may not be considered a viable option. However, considering the ecological impacts of fuel oils and imminent future regulatory shifts, LNG's long-term cost competitiveness is predicted to be attractive compared with marine gas oil, which is its closest rival in terms of emissions. [61]

As the capital expenditure is large for LNG bunkering facilities, it is recommended to spread the initial risk across all stakeholders.[62] Similar to those of Norway, the Netherlands, and some of the projects initiated by the EU, it may be a far-sighted tactic to provide initial incentives for the first movers to embrace LNG bunkering in Australia.[63]

2.1.3 Protect Coastal Populations and the Marine Environment

Goldsworthy established that the effect of emissions from ships in Australian waters on major coastal cities cannot be neglected.[64] The findings resonate with the fact that 66 percent of the Australian population live in coastal cities;[65] the impact of ship emissions on the health of the coastal population is significant.[66] Australia has more than fifty Commonwealth marine reserves, which cover about 36 percent of its territorial waters.[67] Although key regulatory mechanisms are in place for conservation (see Figure 2), significant oil spill incidents and their long-term effects,[68] climate change, and major coral bleaching occurrences are still pressing issues that could initiate tougher policy changes to mitigate risks regarding the uptake of LNG as a marine fuel in the future.

[INSERT FIGURE 2]

Acknowledging the effect of marine emissions in Sydney and other major ports in New South Wales (NSW),[69] the government of NSW has shown great interest in preserving local air quality. The state has

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61 See Lloyd's Register Marine, n. 11 and Ashworth, n. 30 above.

62 See Harperscheidt, n. 40 above.

63 "Rotterdam offers discount for LNG bunkering," *World Maritime News* (December 16, 2015), available online: <http://worldmaritimenews.com/archives/179002/rotterdam-offers-discount-for-lng-bunkering/>.

64 L. Goldsworthy and B. Goldsworthy, "Modelling of ship engine exhaust emissions in ports and extensive coastal waters based on terrestrial AIS data: An Australian case study," *Environmental Modelling & Software* 63 (2015): 45–60.

65 Australian Bureau of Statistics, "3222.0 - Population Projections, Australia, 2012 (base) to 2101" (2013), available online: <http://www.abs.gov.au/ausstats/abs@.nsf/mf/3222.0>.

66 J.J. Winebrake et al., "Mitigating the health impacts of pollution from oceangoing shipping: an assessment of low-sulphur fuel mandates," *Environmental Science & Technology* 43, no. 13 (2009): 4776–4782.

67 B. Beeton et al., *Commonwealth Marine Reserves Review: Report of the Expert Scientific Panel* (Canberra: Department of the Environment, 2015).

68 Australian Maritime Safety Authority, "Major historical incidents," available online: <https://www.amsa.gov.au/environment/protecting-our-environment/major-historical-incidents/>; Australian Bureau of Statistics, "1370.0 — Measures of Australia's Progress, 2010: Oceans and Estuaries — Marine pollution from oil spills" (2010), available online: <http://www.abs.gov.au/ausstats/abs@.nsf/bb8db737e2af84b8ca2571780015701e/7d81b7bd8c153460ca25779e001c4834!OpenDocument>.

69 See NSW Environmental Protection Agency, n. 4 and "Discount for LNG bunkering," n. 63 above.

urged the federal government to consider ship emissions in the National Clean Air Agreement (NCAA-2015).[70] NCAA-2015 declares the necessity of regulations, collaborations, and future directions for emission control and involvement of governments, businesses, and communities.[71] However, it does not focus on emissions from shipping in particular, nor does it mention the effects from shipping emissions on the coastal population.

2.1.4 Address Lackluster Interest and Lack of Intervention from Federal/State Governments

Considering Australia's LNG reserves and its emerging position as the world's leading LNG supplier, it is expected that Australia could gain enormous economic benefits and preserve its invaluable ecosystems by actively adopting LNG as a marine fuel. Australia's self-sufficiency in oil and liquid fuels is at sixty percent and on the decline,[72] hence the increase in oil prices is certain as fuel oil imports step up. While LNG brings forth definitive environmental and economic benefits, it could also reduce the risk posed by Australia's dependency on fuel imports. While LNG bunkering is actively promoted in other regions, an appropriate trend is yet to be seen in Australia despite its abundance of natural gas reserves. There is ample research conducted with reference to the feasibility of LNG bunker supplies in other countries.[73] However, there is a dearth of similar literature with reference to Australia. A joint industry project,[74] which was conducted on behalf of some industry partners in Australia, is the only available literature. The study stresses that large ports like Darwin, Dampier, Gladstone, Melbourne, Newcastle, and Sydney are worthy locations for LNG-fueled offshore support vessels and tug segments, and for facilitating LNG bunkering. The report recommends that financial incentives be provided to the first movers in LNG-fueled shipping, particularly in light of the introduction of increased emission regulations. However, the study falls short of providing nation-wide recommendations to overcome inertia and pursue a long-term strategy for gas-fueled shipping in Australia.

In other regions, introduction of ECAs has encouraged LNG-fueled shipping along with various state-sponsored incentive schemes for first movers. However, such initiatives are not observed in Australia as marine emissions are not perceived as an issue or addressed in policy decisions. Although Australian law-makers are committed to the IMO's emission regulations, it is evident that they do not share similar views to the IMO with reference to significance of LNG as an alternative for compliance of the very regulations to which they are committed. This shows the lack of initiative from the federal, state, and territorial policy-makers.[75] Moreover, it also indicates the negligible effect that available research has on policy-makers or the absence of adequate research in Australia on shipping emissions. For example, the NCAA 2015 discussion paper states the cost of air pollution in Australia due to mortality to be AU$11.1 to $24.3 billion annually.[76] However, the report does not acknowledge the fact that ships emit more harmful emissions per unit of fuel burnt compared with other transportation modes. Since marine emissions are not considered earnestly, the lack of interest in taking the opportunity to curtail marine emissions by using its own gas reserves for shipping is apparent. However, regardless of the lackluster interest shown by the governments, the attention of the private sector to LNG has been encouraging in Australia,[77] and one could hope that the private players may solve the LNG bunkering infrastructure issues on their own. Nevertheless, there is great need for a clear and broad regulatory framework; economic incentives will be compulsory for the ultimate success of gas-fueled shipping in Australia — two key elements that will require the involvement of all levels of government.[78]

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70 Australian Government Department of the Environment and Energy, *National Clean Air Agreement Work Plan 2015* (Canberra: Australian Government, 2015).
71 Australian Government, *National Clean Air Agreement* (Canberra: December 2015).
72 See Deal, n. 58 above.
73 See Algell, n. 23, Holden, n. 28, IMO, n. 38, Harperscheidt, n. 40, Algell and Forsman, n. 43 and Energy Quest, 59 above.
74 See IMO, n. 38 above.
75 See DNV, n. 38 above.
76 See Environment and Energy, n. 70 above.
77 "Australia embraces LNG as marine fuel," *Maritime Executive* (July 30, 2016), available online: <http://www.maritime-executive.com/article/australia-embraces-lng-as-marine-fuel>.
78 "Australia's shift to marine fuel LNG stalled in port," *Wärtsilä*, available online: <http://www.wartsila.com/resources/article/australias-shift-to-marine-fuel-lng-stalled-in-port>.

2.2 Missed Opportunities: Past, Present and Future

Historical data for delivery of bunker fuel oil in Australia shows a downward trend with reference to fuel bunkered by international ships from the 1970s to the 1980s (Figure 3). However, shipping and trade activities in Australia have increased steadily from the 1970s onwards. Ideally, bunker delivery volumes should show a positive trend in relation to positive growth in trade and shipping.

[INSERT FIGURE 3]

There may be a combination of reasons behind the downward trend of bunker delivery, including the three below; the last element appears to be the most influential.

a. Increase of oil price in OPEC nations in the early 1970s by almost 300 percent.[79]
b. Reporting of bunker delivery figures to Australian Bureau of Statistics (ABS) is not mandatory for bunker fuel suppliers.
c. Many vessels that call at Australian ports receive bunkers in cheaper regions, such as Singapore, to avoid higher costs of fuel bunkers.

Research findings (analysis of data from Goldsworthy 2015 and the authors' own data) reveal that fuel consumed by ships in Australian waters is 318 percent higher than the annual bunker demand. A similar fate would likely fall upon LNG bunkering in Australia if the required groundwork is not established in time. In such a scenario, Australia might become merely an exporter of LNG to other nations that reap the benefits of becoming pioneers of LNG bunkers in the region. Similar LNG projects involving pioneering nations in Europe paved the foundation on which countries such as Norway, the Netherlands, and Germany are currently expanding their LNG-fueled shipping and bunkering infrastructure operations.[80] The absence of such initiatives in Australia manifests the lack of strong motivation or the presence of a convincing business case for such developments. For example, although NCAA-2015 declares that $2.55 billion is allocated for an emission reduction fund,[81] it does not suggest the adoption of LNG as an emission-reduction pathway.[82]

2.3 Recent Developments: Steps in the Right Direction (Alas by Private Entities)

There are some industry initiatives in the private sector that show strong evidence of conviction in LNG as a marine fuel, such as SeaRoad's decision to build an LNG-fueled vessel for use between Devonport and Melbourne. This commitment, as well as Woodside's foray into LNG-fueled offshore support vessels and the availability of LNG in Fremantle as bunker fuel align well with the findings of DNV-GL.

Woodside's exploration of LNG-fueled offshore support vessels,[83] the findings of DNV-GL 2015,[84] SeaRoad's decision to commence an LNG-fueled ferry between Devonport and Melbourne, and the availability of LNG in Fremantle as bunker fuel are strong evidence of the private sector's

[79] P. Semolinos, "LNG as marine fuel: Challenges to be overcome,"(paper presented at 17th International Conference & Exhibition on Liquefied Natural Gas, Houston, Texas, April 17, 2013).
[80] See Bech, n. 16 above; Hoenders, n. 47 above; and OECD, n. 56 above; Danish Maritime Authority, *North European LNG Infrastructure Project: A Feasibility Study for an LNG Filling Station Infrastructure and Test of Recommendations* (Danish Maritime Authority, April 2, 2012); M-Tech, *Risk Assessment Study – Supplying Flemish ports with LNG as marine fuel: Analysis of the external human risks* (2012); Stenhede, n. 52 above
[81] See *National Clean Air Agreement*, n. 71 above.
[82] Australian Government, Department of the Environment and Energy, "About the Emission Reduction Fund," available online: <https://www.environment.gov.au/climate-change/emissions-reduction-fund/about>.
[83] Woodside Energy, "LNG-powered vessel first for Australia," (April 12, 2016), available online: <http://www.woodside.com.au/Investors-Media/announcements/Documents/12.04.2016%20Media%20Release%20-%20LNG-powered%20Vessel%20First%20For%20Australia.pdf>.
[84] See DNV, n. 38 above.

commitment to LNG as a marine fuel.[85] These decisions would certainly expedite the evolution of the LNG bunkering industry in terms of developing standards and regulatory uplift in an Australian context. While these developments are encouraging, there are still a great number of ports that are observing the market conditions and waiting in the ranks. Moreover, any initiatives from federal or state governments are yet to be seen. The adoption of LNG as a bunker fuel in Australia is a cautionary and reactive approach instead of one that is proactive. The danger of a "wait and see" approach is that major maritime hubs in the region, such as Singapore, South Korea, and Japan, are already instigating pilot LNG bunkering projects;[86] these hubs are well placed in terms of infrastructure and expertise to capture the market when LNG-fueled shipping becomes mainstream.

3 CHALLENGES AND OPPORTUNITIES: MAPPING LNG BUNKER DEMAND PROFILE IN AUSTRALIA

The aforementioned developments demonstrate that there are only a few players who embrace LNG-fueled shipping in Australia. The federal and state governments, plus the majority of investors and authorities of key ports appear to be following a wait-and-see strategy.[87] The joint industry project by DNV-GL is the only literature that provided a future potential outlook and recommendations for LNG bunkering in Australia. However, because it is an exclusive study, only an edited version is available for the public. There is a lack of research providing a sufficient business case or motivation for establishing LNG bunker infrastructures in key Australian ports.

When today's historically low fuel prices settle in their inevitable upward trend and the 0.5 percent global sulphur limit takes effect in 2020, the following questions are certain to reappear with much fervor and resolve:

a) How do we prepare for increasing fuel prices (especially marine distillates)?
b) How do we comply with stern emission regulations in the future using our own resources?
c) How do we address the moral responsibility as a society to preserve sensitive ecosystems for the next generations and invest in a greener future?

Australia is able to address these issues because of its vast natural gas reserves. Additionally, the country has all the essentials such as LNG projects capable of delivering a steady supply of gas, technical capabilities, a grid of national-regional gas pipelines, and coastal shipping routes to establish an LNG bunkering network. Yet, there is a dearth of initiatives from governments and the private sector providing a long-term vision. However, for the inception of such a vision, governments, investors, and the business community require a resolute impetus. It would be nonsensical to assume that the environmental benefits of using LNG as a marine fuel alone could urge the Australian marine industry to pursue LNG bunkering. It is assumed that systematic academic research could provide such motivation by establishing long-term financial and environmental advantages of LNG as a marine fuel in Australia. It is envisaged that a robust methodology that could establish return on investments and emission reductions will provide such impetus. The proposed LNG-demand prediction tool aims to urge the relevant stakeholders to be inspired to initiate dialogue and establish groundwork for the use of LNG as ships' fuel in Australia. Such a methodology would provide answers to the following crucial questions with highest possible accuracy:

a) What is the long-term LNG bunker demand in Australian ports as a compliant fuel for emission regulations?
b) Which strategic ports/port clusters would best fill LNG bunker demand?
c) How many LNG-powered vessels could be operating in Australian waters? What would be their LNG demands?
d) What are the emission reductions that could be achieved by LNG-fueled shipping?

[85] See "Australia's shift," n. 78 above.
[86] See Energy Quest, n. 59 above; See Ashworth, n. 30 above.
[87] See IMO, n. 38 above.

The current sentiment toward LNG as a ship fuel in Australia would invariably change when more stringent emission regulations become mainstream. In relation to fueling ships, the maritime industry will face an era of adjustment. As Porter suggested, these adjustments would demand adapting to new markets and technological changes, upgrading skills and knowledge base, and quashing complacency and the status quo to seize opportunities.[88]

Nevertheless, these adjustments cannot be addressed in haste; they require a long-term strategic vision and complex decision-making processes to deal with an evolving industry and an uncertain future. When dealing with such situations involving longer time-horizons, single-point forecasting is no longer a viable option. Wilson states that scenario forecasting prevents overly generalized processes and enables detailed planning paths concomitant with plausible scenarios.[89] Therefore, scenario forecasting facilitates more resilient strategic decisions as planning needs are specifically linked to scenarios. The proposed prediction methodology[90] involves scenario forecasting and intends to give viable snapshots of future LNG bunker demands for each region, port or clusters of ports.

3.1 Prediction Methods

Although there are numerous studies addressing the future demand of fuel for land transportation, such studies related to demand of LNG as a marine fuel are just emerging due to recent interest in LNG as a marine fuel. Most studies conducted on demand of automotive fuel incline to correlate per capita gross domestic product (GDP) with pricing and hence, fuel demand, i.e., long-run price compared to long-run income. Li forecasted automobile petrol demand in Australia based on per capita GDP forecasts.[91] Banaszak projected automotive petrol and diesel demand in Korea and Taiwan using a multi-equation demand system using per capita GDP, weighted averages of fuel prices, as well as total fuel consumption in the preceding year to predict future demand.[92] Ediger and Akar utilized auto regressive integrated moving averages and seasonal auto regressive integrated moving averages models to forecast primary energy demand in Turkey from 2005 to 2020.[93] Citing past data, they suggested causality between GDP and energy/fuel demand. Wadud adopted co-integration to map out gasoline demand in the U.S. and stressed the enduring causality between long-term revenue and consumption except during periods of recession.[94] Rao and Samimi who used co-integration techniques to predict gasoline demand in Fiji and Australia, drew similar conclusions.[95]

An LNG feasibility study in the Wider Caribbean region by Algell employed ship-type-specific trend forecasts for LNG adoption to assess the economic viability of LNG-fueled shipping as a compliance measure in ECAs.[96] The study provides a simple solution to predict potential LNG demand, which is based on present fuel oil consumption for a specific ship type and potential future LNG uptake for that ship type in the Wider Caribbean. Aronietis forecasts LNG demand in the Port of Antwerp

88 M.E. Porter, *Competitive Strategy: Techniques for Analysing Industries and Competitors* (New York: Free Press, 1980).

89 I. Wilson, "From scenario thinking to strategic action," *Technological Forecasting and Social Change* 65, no. 1 (2000): 23–29.

90 R.H. Merien-Paul et al., "Guessing to prediction: A conceptual framework to predict LNG bunker demand profile in Australia," (paper presented at IAMU AGA 17 Proceedings, Vietnam Maritime University, Haiphong, Vietnam, October 26–29, 2016), pp. 244–252.

91 Z. Li et al., "Forecasting automobile petrol demand in Australia: an evaluation of empirical models," *Transportation Research Part A: Policy and Practice* 44, no. 1 (2010): 16–38.

92 S. Banaszak et al., "Demand for ground transportation fuel and pricing policy in Asian tigers: a comparative study of Korea and Taiwan," *The Energy Journal* 20, no. 2 (1999): 145–165.

93 V.S. Ediger and S. Akar, "ARIMA forecasting of primary energy demand by fuel in Turkey," *Energy Policy* 35, no. 3 (2007): 1701–1708.

94 Z. Wadud et al., "A cointegration analysis of gasoline demand in the United States," *Applied Economics* 41, no. 26 (2009): 3327–3336.

95 B. Bhaskara Rao and G. Rao, "Cointegration and the demand for gasoline," *Energy Policy* 37, no. 10 (2008): 3978–3983.; R. Samimi, "Road transport energy demand in Australia a cointegration approach," *Energy Economics* 17, no. 4 (1995): 329–339.

96 See Holden, n. 28 above.

through 2025.[97] They combine business as usual fuel consumption as the baseline and sigmoid (S-curve) trend in technology for deducing a common denominator in LNG adoption according to Rosenberg's[98] concepts of innovation and technology. For determining the LNG adoption trend for specific ship types, Aronietis assumes S-curve of technology adoption for future predictions similar to those of Algell and DNV-GL 2015.[99] However, there is a danger in assuming past industry cycles will follow similar patterns in future. Modern technologies have enhanced faster learning curves across nations owing to real-time knowledge transfer capabilities. While the S-curves could be used to track adoption rate of a particular trend for forecasting, it would be an erroneous assumption to affirm that the timespans would follow the same historical trends. Porter noted that industry evolution may take many different paths.[100] If a firm assumes a single specific path and considers that to be the definitive direction, it may entrap an organization to an often undesirable self-fulfilling performance deadlock. Therefore, it is prudent to explore factors driving the process of industry change towards its potentially optimal configuration.

A more cautious approach therefore would be to develop scenario forecasting that encompasses a range of outcomes from a status quo level toward an optimum level. The Department of Infrastructure, Transport, Regional Development and Local Government, forecasts Australian maritime activity in 2030 using mixed linear models, along with inclusion of autoregressive covariance parameters and claims that the drivers of GDP are common to those that drive the maritime industry.[101] Since fluctuations in cargo quantities would invariably change the numbers of vessels carrying cargo in the long run, it is assumed that GDP would have a causality with marine fuel consumption. Azzara found a strong correlation between the two variables with a coefficient of determination (R^2) close to 0.8, enabling a forecast of annual growth in shipping activity and thereby fuel consumption.[102] In view of the initial data set (of bunker delivery figures, GDP, and trade volumes analyzed by the authors), the literature review, and the long timespan of the forecast horizon (thirty years), it is noted that techniques such as co-integration with error correction, exponential smoothing, partial adjustment model, and auto regressive integrated moving averages are more suited for explaining the relationship between GDP/trade volume and fuel consumption. The software package R-Studio is used for the prediction modelling as it is an open-source and flexible platform that features an array of simple and sophisticated prediction models.

3.2 Methodology

The concept of forecasting future fuel demand is not novel and has been utilized in many fields, as discussed in section 3.1. However, conceptualizing a methodology to capture LNG demand for shipping of an entire country and its strategic ports has not been attempted. Figure 4 represents the conceptual framework of the LNG demand prediction methodology for shipping activities in Australian ports through 2050. A thirty-year forecasting horizon is chosen since proven gas reserves in Australia are estimated to last toward the end of 2060.[103] Although Ashworth claims that worldwide LNG reserves would last for 200 years, the lowest and most prudent estimate is chosen for use in the Australian context.[104]

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97 R. Aronietis et al., "Forecasting port-level demand for LNG as a ship fuel: the case of the port of Antwerp," *Journal of Shipping and Trade* 1, no. 2 (2016): 2.
98 N. Rosenberg, "On technological expectations," *The Economic Journal* 86, no. 343 (1976): 523–535.
99 See Dore et al., n. 10 and Holden, n. 28 above.
100 See Porter, n. 88 above.
101 Australian Government, Department of Infrastructure, Transport, Regional Development and Local Government, *Australian maritime activity 2029–2030: Statistical Report* (Canberra: Department of Infrastructure, Transport, Regional Development and Local Government, 2010).
102 A.J. Azzara et al., "A 10-Year Projection of Maritime Activity in the U.S. Arctic" (A Report to the President. U.S. Committee on the Marine Transportation System, Integrated Action Team on the Arctic, Washington, D.C., 2015).
103 See Danish Maritime Authority, n. 51 above; P. Simshauser and T. Nelson, "Australia's coal seam gas boom and the LNG entry result," *Australian Journal of Agricultural and Resource Economics* 59, no. 4 (2015): 602–623; see Geoscience Australia, n. 34 above..
104 See Energy Quest, n. 59 above; See Ashworth, n. 30 above.

[INSERT FIGURE 4]

The conceptual framework focuses on the following forecast outcomes:

i. The first outcome path forecasts aggregate fuel oil bunker demands in both business as usual and potential optimum scenarios.
ii. The second outcome path focuses on growth trends in ship types and derives a predicted number of LNG-fueled vessels in each ship type (or vessel category).
iii. The combination of these two outcomes enables projections of LNG bunker demand by each ship type in dual scenarios.

Note: The initial bunker delivery figures from data are given in are Peta Joules (PJ) as units of measure. An energy/mass conversion factor with relation to LNG will be employed in order to calculate the predicted LNG bunker figures in tonnes.[105]

While aggregate LNG demand would assist in general calculations and overall decision-making, LNG uptake related to individual ship types would facilitate region-specific decision-making with reference to particular ship type. For example, Western Australia would invariably have a greater concentration of offshore support vessels due to significant oil and gas exploration in the region while Sydney, New South Wales would operate a great number of ferries in their waterways. A detailed description of the proposed methodology is provided below.

3.2.1 Determining Factors Affecting Growth Trends of Future Fuel Oil Bunker Demand

It is also assumed that growth in trade volume has a clear correlation with shipping activities and, hence, bunker delivery figures. Therefore, trends in growth of trade volume can be utilized to predict trends in growth of ship fuel consumption. Another influential factor that affects future fuel consumption is the trend in engine and hull form efficiency improvements. O'Malley suggests that the operating efficiency of ships is expected to increase at an average of 1 percent annually.[106] The regulatory push from the energy efficiency design index (EEDI) and the ship energy efficiency management plan (SEEMP), as well as competitive research and development efforts by engine makers are expected to improve this trend further. Therefore, efficiency improvement rates are factored into bunker demand projections.

Accordingly, bunker fuel demand can be demonstrated as:

(1) $BCN_t = f(GDPt \quad ,MF_t)$ or,

(2) $BCN_t = f(CTV_t, MF_t)$

Where BCN_t is bunker demand value at time period t, GDP_t is the gross domestic product at time period t, MF_t is other factors influencing bunker consumption at time period t, and CTV_t is the combined trade volumes (imports and exports) at time period t. Both GDP and trade volume values are inflation adjusted to 2010 as the base.

3.3 Baseline Values for Scenarios Projecting Fuel Oil Bunker Demands (Dual Scenarios of Business as Usual and Potential Optimum Bunker Demands)

Business as Usual Scenario: In this conceptual framework, given the present socio-economic setting in Australia, the present fuel oil (heavy fuel oil / marine diesel oil / marine gas oil) bunker demand and the growth that follows, is considered to be business as usual. This value represents the annual aggregate bunker quantities received by domestic ships and deep-sea-going vessels in Australia. Future projections of business as usual values are forecasted by prediction models based on data sets of past bunker delivery figures and other influential explanatory variables/factors discussed above.

[105] See Azzara et al, n. 102 above.
[106] See O'Malley et al., n. 12 above.

Potential Optimum Scenario: In anticipation of stringent air emission regulations in the near future, there is a strong possibility that all vessels will be obliged to consume ECA-compliant fuels in Australian territorial waters.[107] In addition, there is great potential that fuel burned in Australian waters will be bunkered in Australia provided that fuel pricing is attractive compared with international markets. At present, many international ships avoid receiving bunkers in Australia due to higher costs compared with other regional bunkering hubs such as Singapore. It is assumed that the amount of fuel consumed by vessels in Australian waters is greater than that of bunker deliveries in Australia. Analysis of annual ship traffic data reveals that fuels consumed by those ships in Australia are significantly higher than the business as usual demand. All vessel calls in Australian waters are analyzed using automatic identification system (AIS) data or vessel tracking data sets from the Australian Maritime Safety Authority (AMSA).

Based on the analysis of AIS data, vessel types such as tugs, offshore support vessels, container carriers, bulk carriers, ferries, and tankers are categorized and their aggregate fuel consumption in Australian waters is deduced with the following criteria as indicated in equations (3) and (4). Fuel consumption is calculated based on operating hours of main engines and diesel electrical generators. Break-up of a ship's steaming time/distance and idling time are used along with average daily consumption figures (factors) to calculate the aggregate fuel consumption. Fuel consumption calculations for each ship type are based on the length of sea passage and time spent in port/anchor, which are construed from vessel traffic data. Average daily fuel consumption figures depend on engine capacity of a particular ship and the electrical loads of particular ship type at port and/or while idling (anchorage). Similar average fuel consumption figures that depend on gross registered tonnage (GRT), engine capacities, and ship types have been employed for such calculation by different researchers.[108]

Vessels such as offshore support vessels and tugs have approximately constant average daily fuel consumption. Hence their fuel consumption is to be calculated as follows:

For the tug segment in a region;
(3) $FCon_t^{tug} = f\left[\left(stm_t^{tug}, X_{stm}^{tug}\right) + \left(Idl_t^{tug}, X_{idl}^{tug}\right)\right]$

Where, Stm_t^{tug} is the aggregate steaming time (in days) by total number of tugs in time period t, X_{stm}^{tug} is the average daily fuel consumption of a tug when steaming, Idl_t^{tug} is the aggregate idling time (in days) by total number of tugs during time period t and X_{idl}^{tug} is the average daily fuel consumption of a tug when idling.

In a similar manner, fuel consumptions can be calculated for offshore support vessels in a region and all tugs and offshore supply vessels of other regions.

However, for larger vessels such as container carriers, bulk carriers, roll-on/roll-off ferries (Ro-Ro ferries), and tankers, their daily fuel consumption rates depend on their vessel-size/engine capacity, such that, they are divided into sub categories of small, medium, and large based on their daily fuel consumption. For calculating fuel consumption of the small bulk carrier segment in a region;

(4) $FCon_t^{BC-s} = f\left[\left(stm_t^{BC-s}, X_{stm}^{BC-s}\right) + \left(Idl_t^{BC-s}, X_{idl}^{BC-s}\right)\right]$

Where, $FCon_t^{BC-s}$ is the total fuel consumption for the small bulk carrier segment of a region for time period t, Stm_t^{BC-s} is the total number of steaming time (in days) during time period t, X_{stm}^{BC-s} is the average daily fuel consumption of a small bulk carrier when steaming, Idl_t^{BC-s} is the aggregate idling

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107 See Algell and Forsman, n. 43 above; N. Saito and E. Transas, 2016, "Breaking the ice," *LNG Industry* (June 2016): 56–60; MAN Diesel & Turbo, 2012, "Cost and benefits of LNG as ship fuel for container vessels" (Denmark; MAN Diesel & Turbo, 2012) available online: <http://marine.man.eu/docs/librariesprovider6/technical-papers/costs-and-benefits-of-lng.pdf?sfvrsn=18>.

108 See IMO, n. 38 above and Algell and Forsman, n. 43 above; R.P. Sinha and W.M.N. Wan Nik, "Investigation of propulsion system for large LNG ships," *IOP Conference Series: Materials Science and Engineering* 36 (2012): 012004.

time (in days) by total number of small bulk carrier segment during time period t and X_{Idl} is the average daily fuel consumption of a small bulk carrier when idling.

In a similar manner fuel consumptions for sub-segments of each vessel type are calculated for a region and subsequently for other regions.

The aggregate quantity of fuel used in Australian waters is calculated and tabulated to each ship type in each region as required. The tabulated figures are taken as the baseline values for future predictions of potential optimum bunker quantities for each region.

Therefore, potential optimum bunker demands could be estimated by equations (5) & (6).

(5) $BCN_t^{Pot} = f(GDP_t, MF_t)$ or,

(6) $BCN_t^{Pot} = f(CTV_t, MF_t)$

3.4 Projection of Future Growth in Ship Types

Analysis of ship traffic data is carried out to identify present distribution of each ship type in Australia. It is assumed that growth rate of each ship type is generally dependent on:

- Future trends in trade-volume/GDP growth projections,
- Key trends in demand for different shipping services in Australia, such as offshore support vessels and tugs.
- Annual scrap rate for each ship type.

Hence, for growth rate in particular ship type we have;

(7) $GST_t = f(VF_t)$

Where, GST_t is the growth rate of a particular ship type at time period t and VF_t is the combined factors governing growth rate of that vessel type at time period t.

Based on the distribution of each ship type deduced from analysis of vessel traffic data and factors influencing their future growth trends, the number of ship types for each consecutive year is predicted.

3.5 Determine Factors Affecting Future LNG Adoption as Ships Fuel and Predict Number of LNG-fueled Ships in Each Vessel Type

DNV-GL 2014, found that 100 LNG-fueled (non-gas carrying) new builds were on order as of December 2015 and predicted that the figure would increase to 1,000 by 2020.[109] There are several factors that drive the adoption of LNG at the international level as well as in an Australian context, as discussed in sections 1.5 and 2.1. While the influencing factors and the overall determinant for LNG adoption mentioned above are common to shipping in general, present order books for new builds reveal that different ship types have different rates of LNG adoption.[110] Algell et al., acknowledged that offshore support vessels, tug segments, new-build cruise ships, and new-build container feeder segments are potential early adopters of LNG in the Wider Caribbean,[111] while DNV-2014[112] found that tug and offshore segments could trigger early LNG adoption in Australia. Based on the past experience in Norway and the EU, it is widely expected that initial bunkering of LNG will cater to the smaller coastal vessels followed by larger ferries and deep-sea-going cargo ships. Considering the diversity of

[109] See Kolwzan and Narewski, n. 29 above.
[110] Id.
[111] See Algell and Forsman, n. 43 above.
[112] See Recommended Practices, n. 42 above.

marine vessel operations in Australian waters and the forecasting horizon, the offshore sector and commodity export market, tugs, offshore support vessels, container feeders, bulk carriers, ferries, and tankers must be included as ship types in the prediction model.

For the growth rate in number of LNG-fueled ships for a particular vessel type we have:

(8) $LNGV_t = f(GST_t, DGG_t, DGS_t)$

Where, $LNGV_t$ is the growth rate of LNG fuelled ships for a particular ship type at time period *t*, GST_t is the growth rate of a particular ship type at time period *t*, DGG_t is the general determinant for LNG adoption at time period *t*, and DGS_t is the ship-specific determinant for LNG adoption for that particular ship type at time period *t*.

From equations (1), (2), (7) and (8) we get;

(9) $LNGD_t^{BAU} = f(LNGV_t, BCN_t^{BAU})$

Where $LNGD_t^{BAU}$ is the predicted business as usual, LNG consumption for a particular ship type at time period *t*, $LNGV_t$ is the growth rate of LNG fuelled ships for a particular ship type at time period *t*, and BCN_t^{BAU} is the bunker demand for BAU scenario for time period *t*.

From (5), (6), (7) and (8) we get;

(10) $LNGD_t^{Pot} = f(LNGV_t, BCN_t^{Pot})$

Where $LNGD_t^{Pot}$ is the predicted potential optimum, LNG consumption for a particular ship type at time period *t*, $LNGV_t$ is the growth rate of LNG fuelled ships for a particular ship type at time period *t*, and BCN_t^{Pot} is the bunker demand for potential optimum scenario for time period *t*.

4 IMPACT OF PREDICTION TOOL AND CONCLUDING REMARKS

Escalation of ships' emissions and increasing detrimental effects on the environment are grave concerns among all stakeholders involved in the maritime industry. The continued push for more stringent regulatory measures has prompted LNG's emergence as a viable and compliant marine fuel. Vessels trading in Australian waters continue to consume conventional marine fuel oils in their entirety. Sensitive ecosystems in Australia are under siege due to detrimental effects of climate change and the coastal population is exposed to harmful emissions. Endorsing and adopting LNG as a marine fuel in Australia is identified as a viable solution to address these issues.

The need for relevant research and coherent policies that could move the industry toward a common vision of establishing LNG as a marine fuel continues to grow. The proposed framework could act as a springboard for such action. The outcome of the prediction methodology would help establish the future potential of LNG bunkering and identify strategic ports for laying prerequisite groundwork in terms of soft elements; development of human resources and procedures, and hard elements; and physical assets required for LNG bunkering infrastructure development in Australia. The prediction tool encompasses all the regions, and therefore should facilitate foreseeing the whole picture and enable informed decision-making for federal and state governments, and the marine industry in order to:

a) Enable development of physical infrastructure to cater the future demand of LNG bunkers. Key ports would warrant early attention and initial development so that investment is directed where it is most needed in terms of effective financial returns and best environmental impact according to findings from section d) below.
b) Plan human resource initiatives to source and develop the skilled workforce required. Both LNG storage and distribution network facilities would require skilled human resources

specifically trained for handling LNG. These skills take time to develop and require sizeable investments in recruiting, training, and educational programs.

c) Plan public perception initiatives for acceptance of infrastructure projects. Considering the complicated and lengthy bureaucratic processes in Australia, public awareness and licensing initiatives should be planned well in advance so that they do not impede the timely adoption of LNG in key regions.

d) Quantify emission reductions that can be achieved in each region by substituting conventional marine fuels with use of LNG as marine fuel. These data could be merged with relevant studies and the external cost of emissions on mortalities/morbidities in Australia.

e) Mitigate cost of fuel oil imports by promoting LNG replacement regionally.

f) Secure uninterrupted LNG supplies through coordinated efforts of stakeholders. Prediction of LNG bunker requirements in key ports would enable policy-makers and relevant organizations to establish gas distribution policies to address estimated demands from each sector.

Regardless of holding abundant natural gas reserves, and despite the clear benefits it endows, Australia is far behind other key players with reference to promoting LNG as a marine fuel. Irrespective of the inroads made by private entities, the majority of the responsibilities sit squarely on the public sector with regard to encouraging LNG adoption in Australia for shipping. Present emission regulations and their future prognoses have established a trend toward an enduring necessity of clean, low-carbon fuels. In such a setting, Australia should not ignore the important role its natural gas resources can play as a marine fuel in its waters. Declaration of emission controls in Australian waters and promoting compliant fuels should take place concurrently with the administrative and fiscal patronage of governments. However, it is evident that environmental benefits alone would not encourage such an endeavor. The proposed LNG bunker demand prediction tool aims to shed light on future economical and societal benefits of such an initiative. It is a base on which future gains can be construed for policy-makers in terms of economic and ecological benefits of LNG as a marine fuel.

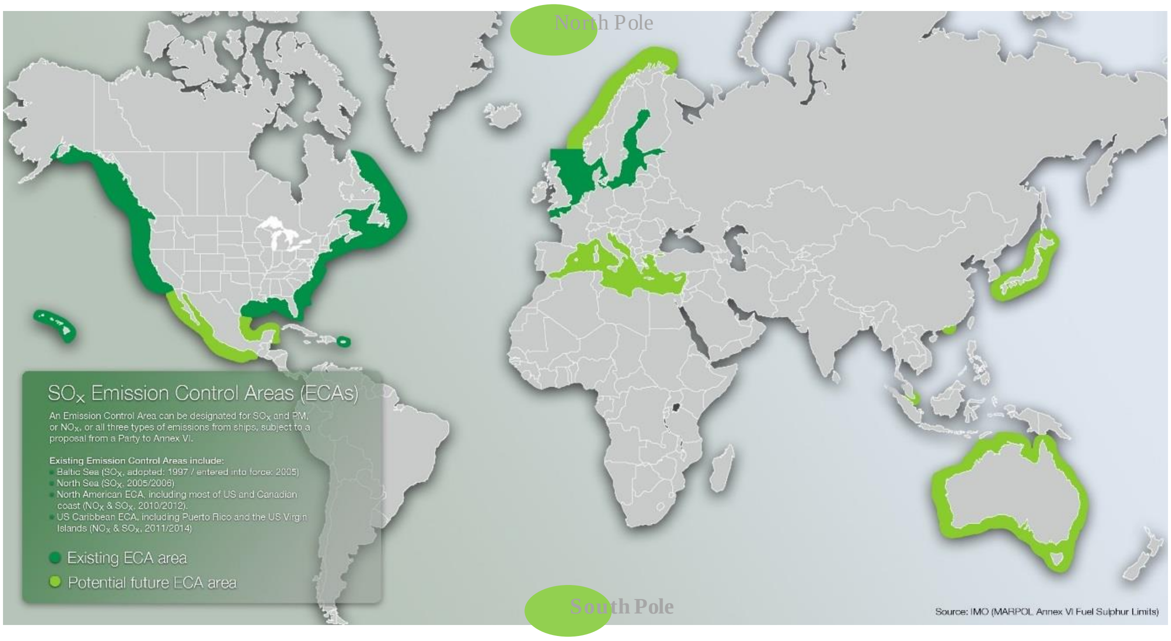

Figure 1.—Present and Potential Future ECAs
Source: Adapted from Fisher and Meech, and Maritimepropulsion.com
C. Fisher and R. Meech, *Bunkers: Analysis of the Technical and Environmental Issues*, 4th ed. (London: Petrospot Limited, 2013); Image adapted from: <http://www.maritimepropulsion.com>.

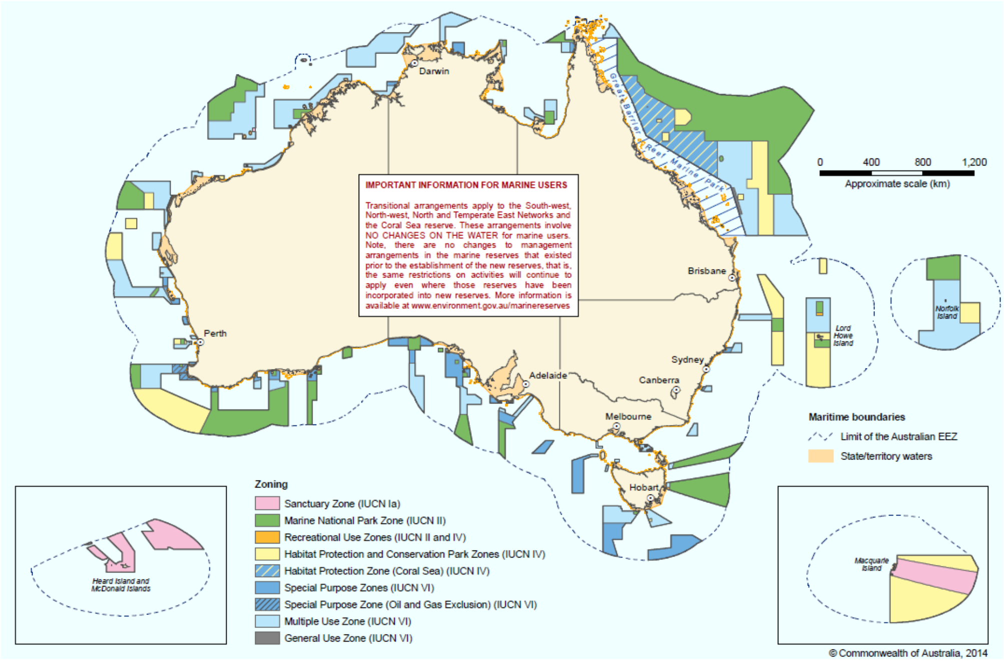

Figure 2.—Commonwealth Marine Reserves
Source: see Beeton et al., n. 67 above.

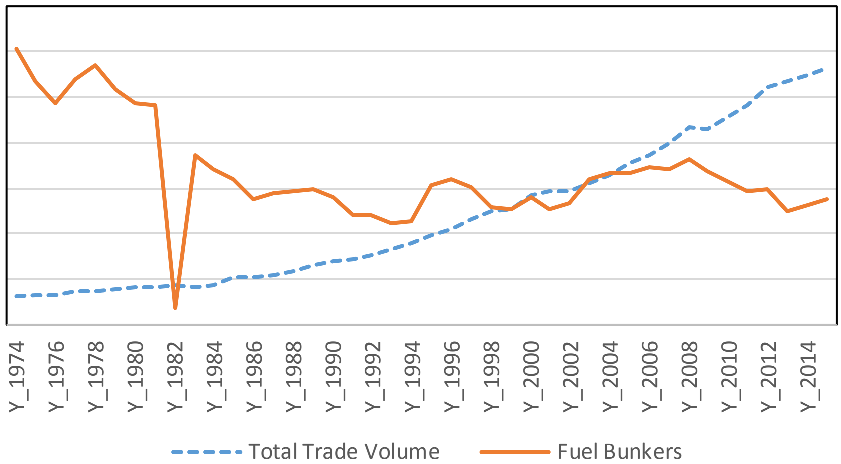

Figure 3.—Bunkers delivered to international ships in Australia versus growth in trade volume
Source: Authors with data from the Australian Bureau of Statistics and the International Monetary Fund.

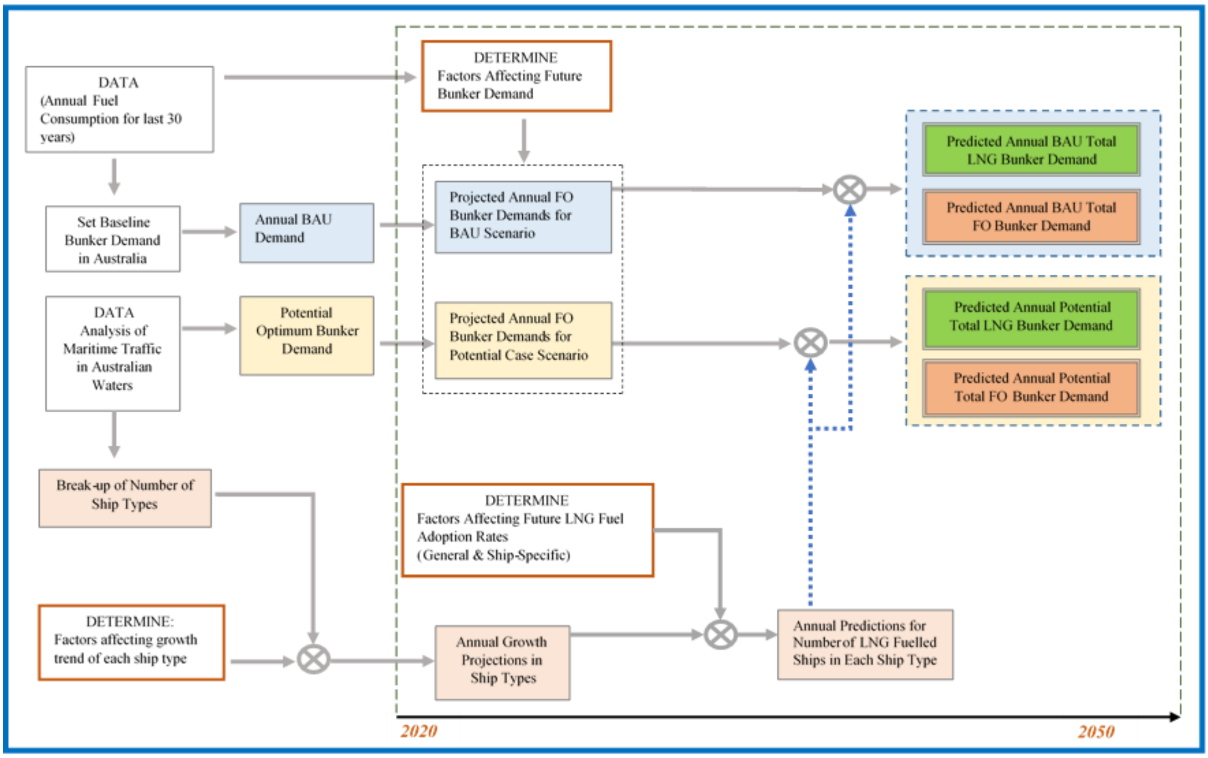

Figure 4.—Conceptual Framework
Source: Adapted from Merien-Paul et al., see n. 90 above.