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Assessing energy policy instruments: LNG imports into Saudi Arabia

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ABSTRACT

Saudi Arabia relies heavily on oil-based generation to meet its power needs within a geographically unbalanced pattern of natural demand and supply. Many initiatives are currently being assessed to reduce the high opportunity cost of burning oil for the country. This paper examines the cost and implication of a disruptive policy where Saudi Arabia imports liquefied natural gas (LNG). To determine the possible and optimal sources to procure LNG into Saudi Arabia we use and configure a partial equilibrium model, specified as a linear programming problem. Two import scenarios were tested: the first assumes an import terminal with a capacity of 5 million tonnes per annum (MTPA) and the other scenario assumes 22 MTPA. Results show that Saudi Arabia can import LNG for power generation at a discount to the opportunity cost of oil. Especially during the summer months, as Saudi Arabia's gas demand is counter-seasonal to major importing regions it leads to even more interesting market pricing conditions. It also shows a small difference in landed cost of LNG between the two scenarios which implies the global LNG market can accommodate relatively large demand from Saudi Arabia without distorting significantly the global market pricing mechanism.

1. Introduction

Natural gas consumption in Saudi Arabia represents 37% of the country's primary energy demand (BP, 2018). The power sector is the country's largest gas consuming sector, responsible for about two-thirds of the Kingdom's total gas demand, followed by the industrial and petrochemical sectors. The Kingdom's growing need for power has strained domestic natural gas supplies. As a result, local utilities are using large amounts of liquid fuels for power generation to meet rising demand for electricity and water desalination. As Fig. 1 shows, liquid fuels – crude oil, heavy fuel oil (HFO), and diesel – account for around half of all fuels used for electricity generation; their use is closely linked to the availability of natural gas. In 2017, Saudi Arabia burnt 1958 trillion British thermal units (Btu) of liquid fuels, or almost 890 thousand barrels per day (Mbbl/d), in order to generate power.

There are several initiatives put forth by the Kingdom of Saudi Arabia to reduce liquid fuel burn in power generation. This includes implementing tougher energy efficiency standards, reducing consumer subsidies on fuel and electricity tariffs and diversifying the power mix to include more natural gas and introducing renewable and nuclear energy. But natural gas in particular is poised to play a significant role in the future energy mix. Given the versatility of natural gas for its efficient uses in different sectors, it has been highlighted in official public policy documents, such as the Kingdom's Vision 2030, as a way to diversify the economy away from oil. The document specifies that the Kingdom plans to double natural gas production and expand its gas distribution network within the country (Kingdom of Saudi Arabia 2016). This has been reiterated by the CEO of Saudi Arabia's national oil and gas company, Saudi Aramco, to increase its gas production to 23 billion cubic feet per day (bcf/d) by 2030, equivalent to 238 billion cubic meters (bcm). Raw production of natural gas was recorded at 12.4 bcf/d (128 bcm) in 2017. Domestic natural gas production has seen significant growth in the past decade growing from 8 bcf/d (83 bcm) in 2007 to 12.4 bcf/d (128 bcm) in 2017 averaging 4.5% growth per annum most of which has gone toward the power sector (Saudi Aramco 2018). However, the new gas supplies in the Kingdom will not come from easy-to-produce associated gas, as has historically been the case. Rather, there has been a shift toward developing more non-associated conventional and unconventional gas fields, which together bring with them a set of challenges, including higher costs.

Given the lengthy and difficult process of developing new domestic gas resources, liquefied natural gas (LNG) imports could be a useful policy instrument for Saudi Arabia to consider. The LNG market has grown significantly over the past decade, with new LNG suppliers

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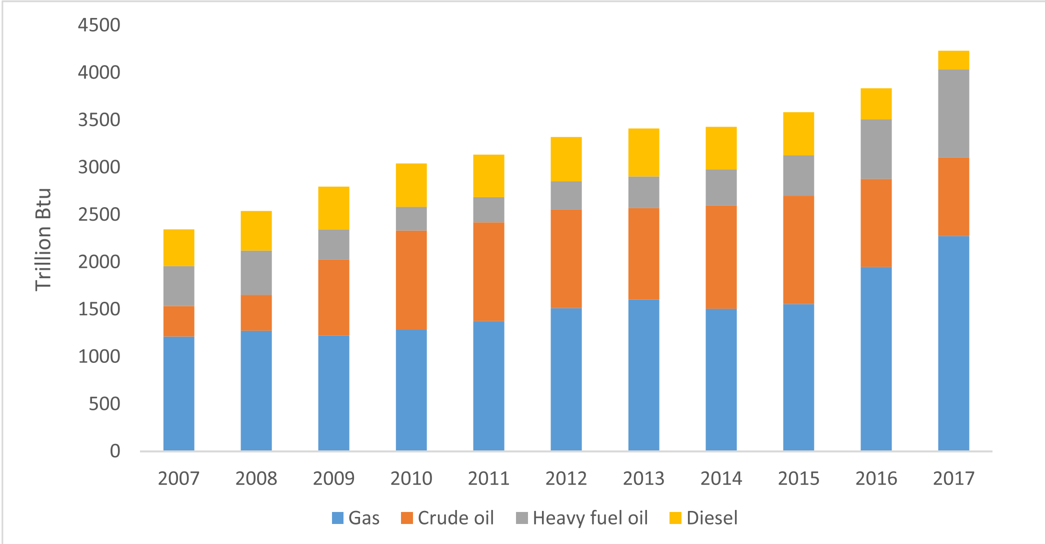

Fig. 1. Yearly fuel consumption of power and seawater desalination in Saudi Arabia.
Source: Electricity & Cogeneration Regulatory Authority (ECRA) Statistical Booklets.

emerging, such as Australia, the U.S. and Russia. Major oil and gas company, BP (formerly British Petroleum), is projecting a robust expansion in LNG supplies which is expected to account for more than 15% of total gas demand by 2040 overtaking pipeline trade in the late 2020s (BP, 2019). This growth with more LNG players is also expected to make LNG markets more competitive. Shorter term and destination-variable sales contracts are providing buyers with greater flexibility and an alternative to the traditional oil-linked long-term LNG contracts, further improving the liquidity in LNG markets. Under certain market configurations, LNG could add value to Saudi Arabia's economy by freeing more domestically produced crude oil for export (Blazquez et al., 2018). Currently, Saudi Arabia consumes all the natural gas it produces, and does not have existing infrastructure to import (nor export) natural gas. While the government of Saudi Arabia does not have concrete plans to import LNG, this paper assesses how such a policy could play out. It investigates how LNG imports could complement and support other policies and initiatives in the Kingdom, including domestic energy market development. This paper is also first of its kind to estimate LNG imports into Saudi Arabia which could allow policy-makers and stakeholders to use this information into their decision making process and to be a first step for further research on power mix optimization in the Saudi energy sector, including international trade.

While this paper specifically investigates the optionality of LNG imports for Saudi Arabia, it does raise the question whether gas imports via pipeline from nearby sources such as Qatar and Iran can be considered as a feasible and a lower cost option. Iran and Qatar also hold the world's second and third largest gas reserves, respectively. However, increasing geopolitical tensions and the different stances on certain issues in the region has put Saudi Arabia at odds with Iran and Qatar. The deteriorating relationship has resulted in cutting diplomatic and economic ties, more recently, with Iran in 2016 and Qatar in 2017 making the prospect of pipeline imports (or even LNG trade) unlikely.

A similar situation has played out in Europe where geopolitical constraints have influenced countries, such as Poland and Lithuania, to

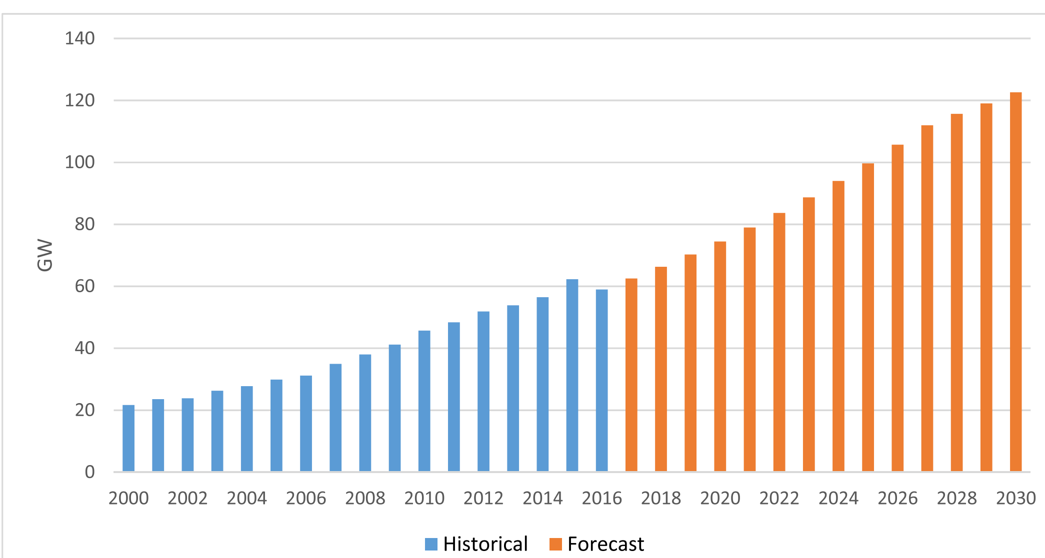

Fig. 2. Peak load demand is expected to increase.
Source: Saudi Electricity Company. http://eugcc-cleanergy.net/sites/default/files/7.%20Session%202_Eng.%20Hamed%20Al%20Saggaf_Saudi%20Electricity%20Company.pdf.

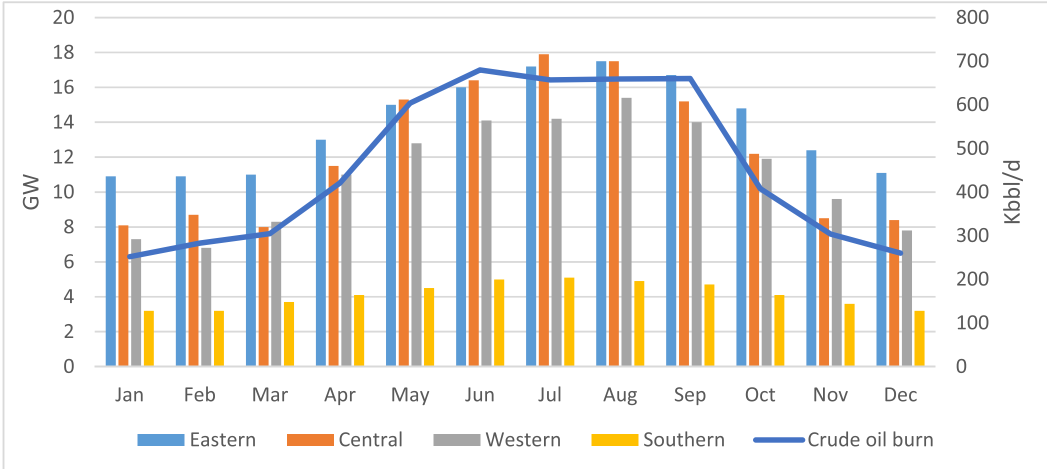

Fig. 3. Monthly average load variation in Saudi Arabia by area, 2017.
Source: ECRA, JODI (2018).

reduce their dependency on Russian-sourced pipeline gas, despite its lower cost, and opting for LNG imports as an alternative.

2. Background

2.1. Context

Despite having the sixth largest proven natural gas reserves in the world (BP, 2018), Saudi Arabia's natural gas production has yet to reach its full potential. Associated gas from crude production accounts for most of the country's gas supplies (EIA, 2017). Due to the Kingdom's rapid gas demand growth, Saudi Aramco has targeted an increase in the production of gas from non-associated gas fields in Karan, Hasbah, and Arabiyah.

Meanwhile, rapid growth in domestic power demand, driven mainly by population growth and industrial development, has increased the demand for crude oil and other liquid fuels to make up for the shortfall in the country's gas supply. Historically, low electricity tariffs – especially non-industrial tariffs – have also contributed to the residential sector's high energy consumption. Fuel and electricity price reforms and new energy efficiency standards for buildings and equipment aim to temper this power demand growth. However, the Saudi Electricity Company

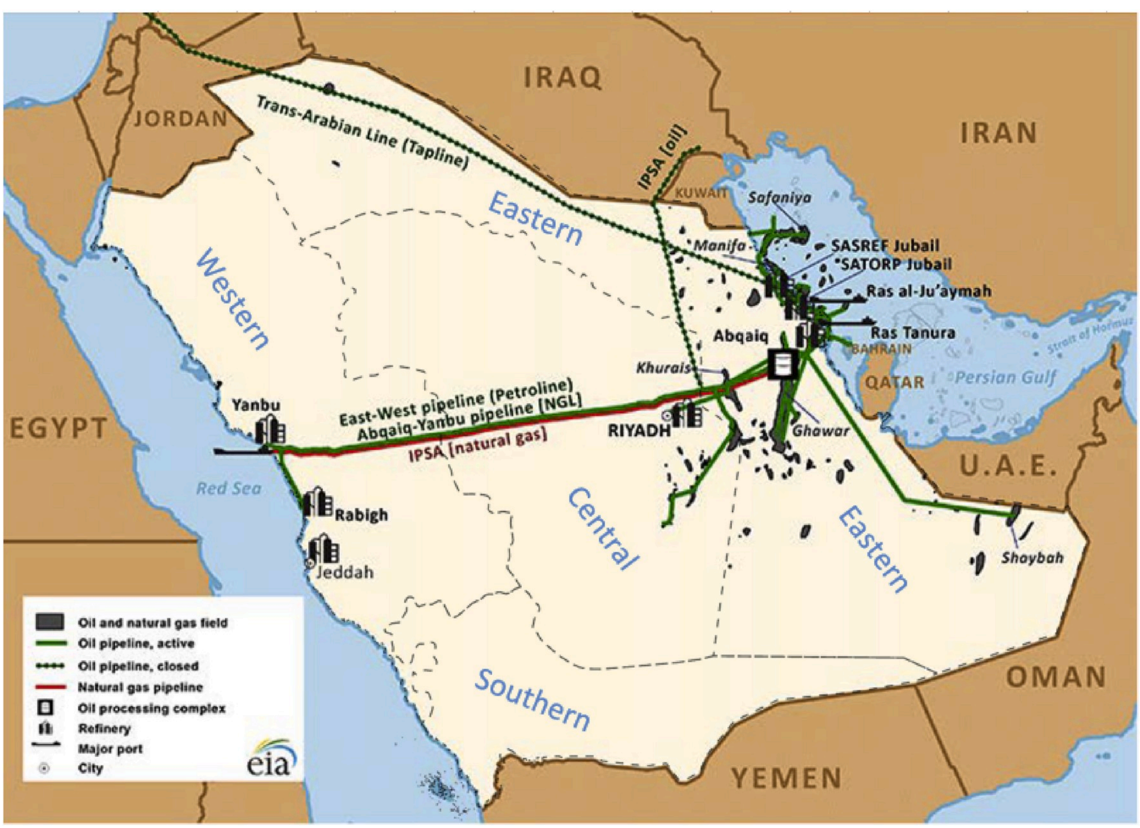

Fig. 4. Saudi Arabia oil and gas Infrastructure, by area.
Source: U.S. Energy Information Administration (EIA), SEC, KAPSARC.

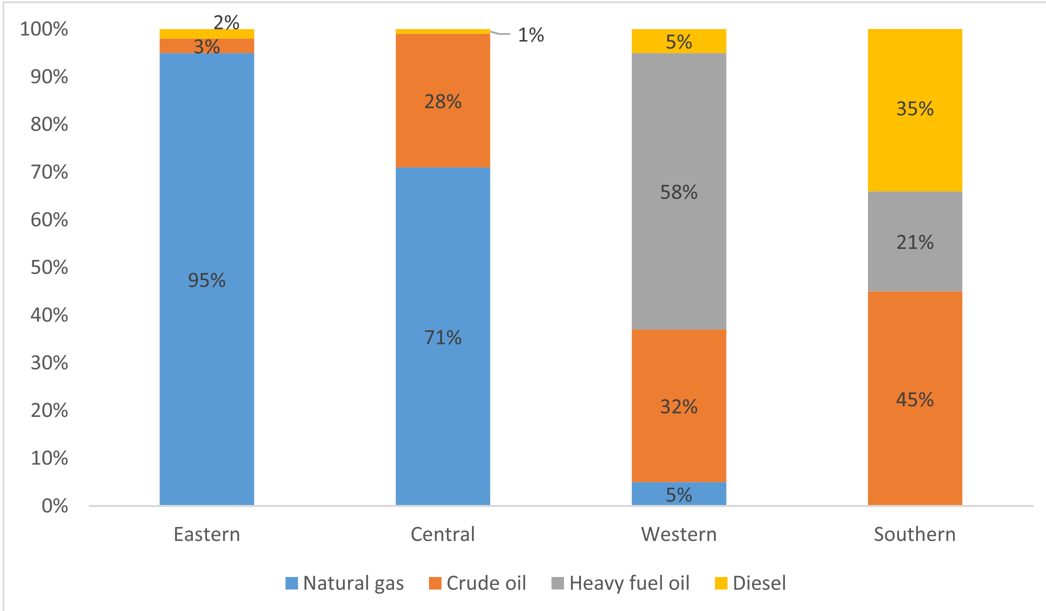

Fig. 5. Distribution of annual fuel consumption by area, 2017.
Source: ECRA.

(SEC), Saudi Arabia's largest utility, expects peak load demand to double by 2030 (AlSaggaf, 2018), as shown in Fig. 2. Given this expected growth in future power demand, maintaining the status quo in the power mix implies the increased use of crude oil and oil products as fuels for electricity generation. This would result in a large opportunity cost from the reduced quantity of domestically produced crude oil available for export.

2.2. Natural gas pricing in Saudi Arabia

Since 1984, the government of Saudi Arabia set the price of natural gas at $0.5/MMBtu. This price remained unchanged until the government raised prices in 1998 to $0.75/MMBtu. Providing low priced gas domestically to the power and industrial sector was key element in driving Saudi Arabia's industrialization policy and welfare system (OIES, 2019). The low administered gas prices added pressure on demand by various sectors, prompting the Ministry of Energy to allocate gas quantities to the different end-users. The government increased natural gas for the third time in 2016 to $1.25/MMBtu as part of their economic reform agenda, Vision 2030. Despite the reforms, natural gas prices in Saudi Arabia remain one of the lowest in the world. Going forward the government has indicated that natural gas prices would gradually transition to a "linked reference price with an applied price ceiling" by 2022 (Fiscal Balance Program 2018 update).

Plans to expand Saudi Arabia's domestic natural gas production is underway. New and proposed expansions of the Fadhili, Hawiyah and Midyan processing plants will accommodate over 3.6 bcm of additional raw gas supply from conventional gas fields. This will mostly be sourced from the Hasbah (phase 2), Khursaniyah, Midyan, Hawiyah, and Hardh gas fields over the next few years, but other new sources of supplies will be required beyond that timeframe. The development of Saudi Arabia's unconventional gas resources is ongoing in the Northern Arabian field (Turaif), at South Ghawar, and in the Jafurah Basin. International oil field services company Baker Hughes has estimated the Kingdom's technically proven shale gas reserves amount to some 645 trillion cubic feet – about double the quantity of proven shale gas reserves in the United States (U.S.) (Elass, 2018). However, in order to take full advantage of its shale gas potential, Saudi Arabia will need to address technology transfer, water scarcity, and workforce concerns.

2.3. Characteristics of Saudi Arabia's power sector

Residential electricity demand accounts for almost 50% of Saudi Arabia's annual power consumption due to the high air conditioning load during the summer months – space cooling accounts for over 70% of the power used in the residential sector (ECRA, 2011). As Fig. 3 shows, the peak load demands in the eastern, central and western areas, as defined by the Saudi Electricity Company (SEC) (see Fig. 4), are generally similar in nature because the bulk of the country's population and industrial cities are concentrated in these areas. The less populated southern area of the country consumes about 75% less power on average than each of the three other areas. However, energy demand in all four areas peaks during the summer months, i.e., roughly from April through October.

As previously mentioned, crude oil, diesel and heavy fuel oil meet the demand from the Kingdom's thermal power generation sector when natural gas is unavailable. As such, demand for crude oil peaks during the summer months in order to meet the spike in air conditioning load. However, the use of liquid fuels in power plants varies across the country's four main areas.

The western and southern areas of the country burn significant quantities of liquid fuels (Fig. 5). The Master Gas System (MGS), a country-wide gas transportation network completed in 1982, carries gas via pipelines from Saudi Arabia's eastern gas fields, where the country's gas reserves are concentrated, to other areas of the Kingdom. However, this distribution system's effectiveness is compromised by high demand in the eastern area of the country and infrastructure bottlenecks, limiting the amount of natural gas that can be transmitted via the MGS.

More liquid fuel is burnt in the west of the country than in the east. An LNG import terminal located on Saudi Arabia's Red Sea coast could therefore help meet western regional demand and mitigate infrastructure constraints in the MGS.

2.4. Literature review

There are several studies in literature investigating pathways for enhancing Saudi Arabia's power sector and improving its fuel mix. However, there is no detailed study to the best of our knowledge that allow for natural gas trade (imports or exports) for the Saudi economy

Table 1
Assumed characteristics and costs for the FSRU.

	Location	Nominal capacity (mtpa)	Nominal capacity (bcm)	Number of FSRUs	Assumed start year	Fixed cost per unit ($/MMBtu)	Variable cost per unit ($/MMBtu)
Scenario 1	Port of Jeddah	5	6.80	1	2021	0.27	0.51
Scenario 2	Port of Jeddah	22	30	5	2021	0.27	0.51

Source: Author inputs, WGM (March 2018).

when conducting analysis on optimization of the power sector. Therefore, this paper aims to establish the first steps of calculating the cost of LNG imports into Saudi Arabia under different scenarios. Most of the research in literature has focused on using domestic resources of fossil fuels and renewables to optimize the power mix under different market conditions. A study by (Matar and Anwer, 2017) explored the impact of domestic fuel price reforms and different electricity pricing schemes on the local power sector. The study utilizes KAPSARC Energy Model for Saudi Arabia (KEM-SA), a partial equilibrium model which adopts a mixed-complementarity problem formulation (KAPSARC, 2016). Under deregulated fuel prices and different electricity tariffs, the result of the study showed power producers shift generation away from oil-based plants to more natural gas (sourced domestically) and solar photovoltaic technologies. Another study by (Farnoosh, Lantz and Percebois, 2014) looked into the potential of penetrating non-fossil fuel based energy technologies into Saudi Arabia's power sector using a linear programming optimization framework. The results showed, in all scenarios, that fossil fuel based generation, especially natural gas, would still have a role to play but integrating nuclear and renewable technologies into the system lead to more cost reduction of total generation cost. The only study that explores LNG imports into Saudi Arabia was illustrated in (Blazquez et al., 2018). The study was conducted to analyze different policies to reduce domestic oil consumption in Saudi Arabia but not limited to the power sector. The study utilizes a general equilibrium model for Saudi Arabia detailed in (Blazquez et al., 2017). It shows that while introducing LNG imports into Saudi Arabia did present an increase in net public revenues being transferred to households, it did rank low compared to other policy initiatives such integrating renewable energy, increasing efficiency of power plants, and car scrapping programs.

3. Methodology

We use the World Gas Model (WGM), a partial equilibrium model, specified as a linear programming problem (Nexant, 2018) to determine the possible and optimal sources of LNG for importation to Saudi Arabia. The WGM has a dynamic nature: it considers a long time horizon (2040) further decomposed using a quarterly time resolution. The representation used in the model includes all countries that produce, consume and transit natural gas. Each country is modeled as a given node. There is an exogenously-determined demand level at each consuming node that is posited to be purely price inelastic.

The model decision variables represent the supply and trade flows of natural gas to meet the input demand figures. Overall, the model minimizes the total cost of all the components of the global gas supply chain: extraction, pipeline and LNG transportation, and underground storage. The solution is optimized subject to a set of linear constraints, including balancing the supply and demand equation at each node for each period, infrastructure capacity, and contractual restrictions. As is usual with this type of linear programming problem, the shadow variable associated with each node, at a given period, provides the marginal cost to supply gas at that node at that time. This marginal cost can be interpreted as the equilibrium price of natural gas that would prevail if the market were perfectly competitive at that time.

The model is calibrated using Nexant's proprietary database, KAPSARC data, and the authors' analysis of aspects of the Saudi Arabian and world energy system that typically determine the trajectory of future demand levels at the consuming nodes, the costs and capacities at the extraction nodes, and infrastructure characteristics. To assess the potential of LNG imports into Saudi Arabia using the WGM, we create two cases for a supply deficit building up to 2035: a 5 million tonnes per annum (mtpa) or 6.8 bcm base case and a 22 mtpa high case (30 bcm) (Table 1). The base case assumes an import terminal within the range of those in neighboring Middle Eastern countries such as Kuwait and Egypt. The high case assumes that Saudi Arabia replaces almost all of its liquid fuel usage in power plants with LNG. The high case also allows us to build a cost stack of multiple LNG supply sources to meet the highest potential demand for gas in the Kingdom.

The western coast of Saudi Arabia presents the best location for an LNG import terminal due to the proximity of power plants and water desalination facilities that now rely on liquid fuels. An import node was created in Jeddah along one of the main global shipping routes that includes the Suez Canal. The choice of a terminal in Yanbu, or any other port location along this coast, does not change the model's results. All LNG routes and distances were calculated from each existing and planned export terminal into the Saudi receiving port (Marine Traffic, 2018).

Our analysis of the receiving and regasification terminal includes a comparison of a floating storage and regasification unit (FSRU) and an onshore terminal. The former was selected for its flexibility, speed of deployment and cost competitiveness. FSRUs have lower upfront costs (typically 60% of the cost of an onshore terminal) and can accommodate short-term seasonal demand. In Kuwait, a modified vessel is deployed as an FSRU and used for nine months of the year to import LNG. In the remaining three months the same vessel can be used for short term carrier operations (King & Spalding LLP, 2015). The investment it requires is also reversible – "stranded assets" do not occur if LNG imports are only required on a short-term basis (Songhurst, 2017). We use FSRUs to build our Saudi case because they present lower upfront costs and because LNG imports may only be a transitional measure for the Kingdom.

This analysis uses the WGM's cost assumptions for Kuwait's FSRU as a benchmark. Taking into account the lead time needed to plan, construct and deliver the FSRU along with the related onshore infrastructure, the model assumes that Saudi Arabia starts importing LNG in 2021. Neither case accounts for the cost of inland infrastructure and connectivity. As such, while the increased use of FSRUs could provide economies of scale, we assume the same fixed and variable costs in both cases.

The WGM includes price forecasts for crude oil and some refined oil products, as well as coal and carbon prices for North America, Europe and Asia. The model assumes a long-term oil price of $85 per barrel (bbl) (see Fig. A1 in Appendix A) which was left unchanged.

Trade restrictions are exogenous to the WGM. As mentioned in page 4, Saudi Arabia currently does not trade with Iran and Qatar. To reflect the present circumstances, the restrictions were inserted for the forecast period for LNG trade. Saudi Arabia also has a boycott over Israel, another growing gas player in the region, which is also enforced in the model.

Other geopolitical events in the region has left liquefaction plants idle. The civil war in Yemen forced the 6.5 mtpa Yemen LNG to declare *force majeure* in April 2015, and it has remained offline since. However,

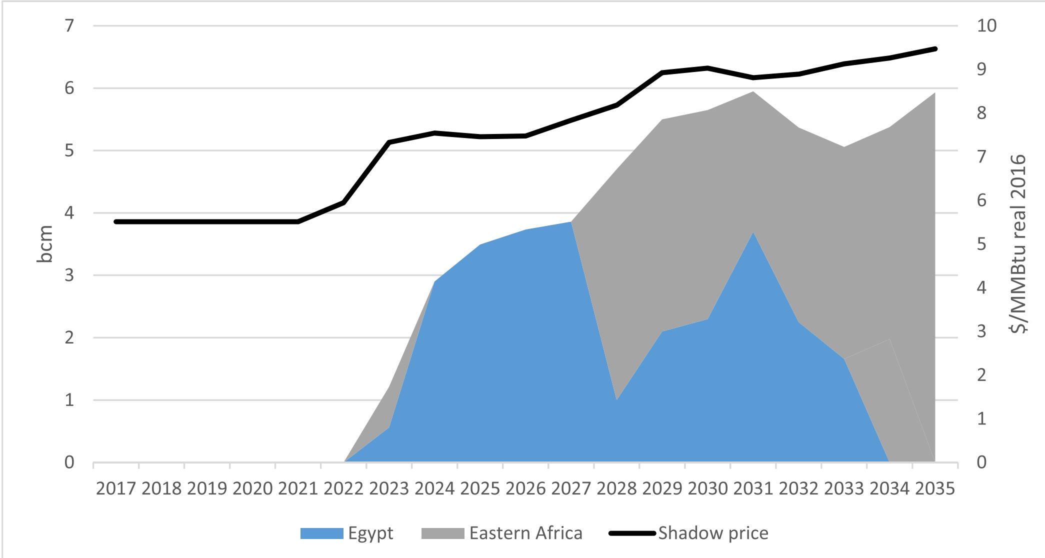

Fig. 6. Model simulation of LNG imports into Saudi Arabia under a 6.8 bcm (5 mtpa) scenario.
Source: Results based on authors' simulation of WGM (March 2018).

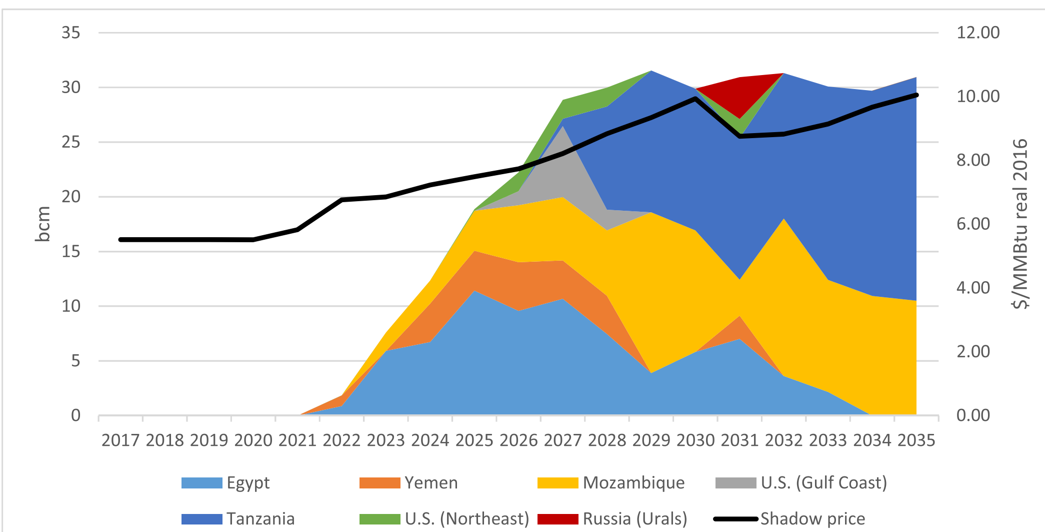

Fig. 7. Model simulation of LNG imports into Saudi Arabia under the 30 bcm (22 mtpa) scenario.
Source: Results based on authors' simulation of WGM (March 2018).

no damage has occurred to the liquefaction units and the WGM assumes exports to resume by 2022.

4. Results

4.1. Base case scenario

In the base case scenario of 6.8 bcm (5 mtpa), LNG imports into Saudi Arabia come mainly from Egypt and the Rovuma Basin in eastern Africa (Mozambique and Tanzania) (Fig. 6), due to their proximity to Saudi Arabia. The development of export infrastructure from these two areas of gas production coincides with the start of LNG imports into the Kingdom in the model. Interestingly, when running the model assuming that the current restriction of flows from Qatar to Saudi Arabia has been lifted, the model clears without any imports from Qatar. This is attributable to the high transportation cost of transporting LNG from Qatar offsetting its lower cost of supply.

The shadow price of LNG in Saudi Arabia increases from about $7.3/MMBtu in 2023 to around $9.5/MMBtu in 2035. This increase in price reflects the model's assumption that natural gas is exhaustible, with the least expensive gases tapped first. The delivered price of LNG includes the cost of gas, liquefaction, transportation and regasification.

Almost 72.5 bcm (or 53 mtpa) of LNG projects from eastern Africa are slated to come online by 2035, according to WGM assumptions. This suggests that the Rovuma Basin could be a key supplier to Saudi Arabia if the latter chose to further expand its imports after that date. Furthermore, even if LNG exports from Egypt are restricted over the long run (with priority given to growing domestic demand), other new gas projects in the Mediterranean, such as those offshore Cyprus, could potentially supply Saudi Arabia with LNG.

4.2. High case scenario

Eastern Africa continues to play a significant role in supplying LNG

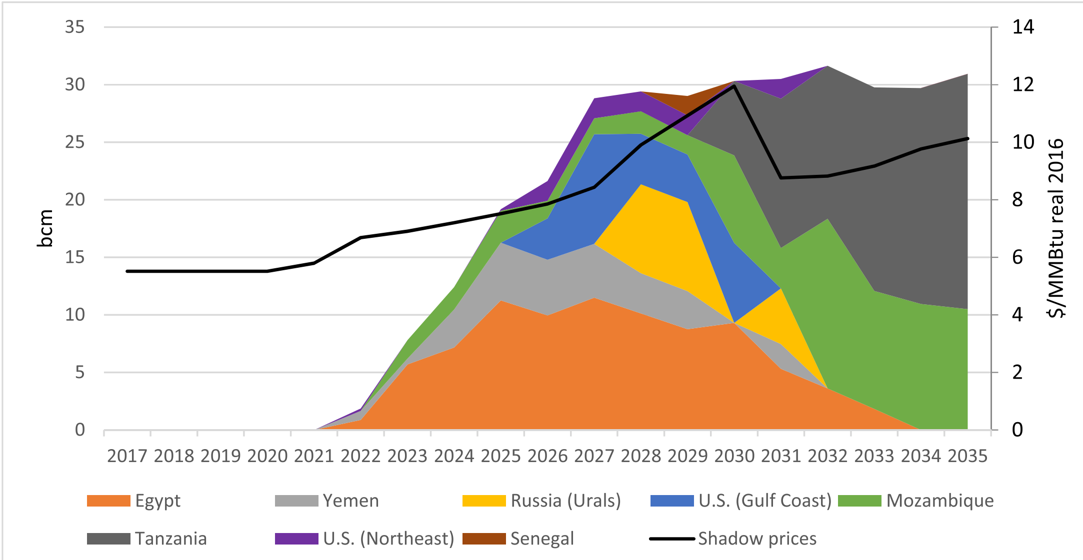

Fig. 8. Model simulation of LNG imports into Saudi Arabia under the 30 bcm scenario with risked projects from eastern Africa.
Source: Results based on authors' simulation of WGM (March 2018).

to Saudi Arabia in the 30 bcm scenario (Fig. 7), accounting for up to 76% of Saudi imports. Other suppliers in the model include Yemen, Russia, and the U.S.

Under the 30 bcm scenario, shadow prices for Saudi Arabia rise from almost $7.0/MMBtu in 2023 to $10/MMBtu in 2035. This does not show a significant difference from our base case price range which implies a relatively greater elastic supply in the LNG market beyond the 2020s. The model shows, however, a slight increase in prices in 2029 and 2030 as lower cost cargoes from Yemen and Egypt temporarily divert to accommodate new demand in South Asia and parts of the Mediterranean, respectively. Despite this, the competitive nature of the global LNG market represented in the model and the implied elastic supply curve could enable Saudi Arabia to accommodate large fluctuations in domestic natural gas demand by importing LNG, without significantly affecting the cost of supply.

4.3. Sensitivity analysis on east African production

Eastern Africa's Rovuma Basin, where gas was first discovered in 2010, contains an estimated 188 trillion cubic feet (5.3 trillion cubic meters) of proven and probable gas reserves (IHS Markit, 2017). This makes the basin one of the most promising new gas plays in the world. However, so far the only project in the prospect to have reached final investment decision status, as of writing, is Italian oil and gas company Eni's 3.3 mtpa, $8billion, Coral South floating liquefied natural gas (FLNG) facility offshore Mozambique. Other liquefaction projects in the basin remain under development and evaluation. Many eastern African project delays can be traced back to the drop in oil and gas prices in mid-2014, which threatened the economics of remotely-located greenfield projects such as Rovuma. Local institutional challenges have also created many political hurdles for development plans (Schenckery et al., 2018). We ran a scenario to understand the likely supply alternatives, in which the risks of eastern African projects were assessed and deferred until after 2030, except for Coral South FLNG.

In this scenario, the roles of the U.S. and Russia's Ural region (including Yamal and Arctic LNG 2) become more prominent, in addition to cargoes from West Africa as a consequence (Fig. 8).

Delays in eastern Africa LNG projects could cause prices to rise, as shown by the shadow price peaking at close to $12/MMBtu in 2030 before dropping back to normal levels as eastern African projects come online.

Table 2
Quarterly load profile for Saudi Arabia in 2015.

Q1 (Jan, Feb, Mar)	Q2 (Apr, May, Jun)	Q3 (Jul, Aug, Sep)	Q4 (Oct, Nov, Dec)
19%	27%	31%	23%

Source: KAPSARC based on ECRA data.

4.4. Factoring in seasonality in simulation

As Fig. 3 illustrates, Saudi Arabia's load profile is highly seasonal and counter-cyclical to the global LNG market. Peak demand for LNG globally usually occurs during the northern hemisphere winter, when demand for heating peaks.

By default, the WGM shows a flat gas demand profile throughout the year for Saudi Arabia that satisfies all residential, commercial and industrial sectors. However, as Table 2 shows, the load profile in Saudi Arabia is heavily weighted to the second and third quarters of the year, reflecting Saudi Arabia's energy demand for cooling during the summer months. We therefore adjusted the Saudi Arabian gas demand profile in WGM to reflect this seasonal profile.

Running the base case scenario (5 mtpa or 6.8 bcm) with seasonality displays a more realistic picture of the current situation in Saudi Arabia. As Fig. 9 shows, prices spike during the summer months, reflecting the higher opportunity cost of burning crude oil. However, once imports of LNG begin in 2021, shadow prices soften and drop to reflect the long-run marginal supply of LNG.

When we introduce seasonality into the model, it calls on Yemen to fill the demand gap assuming Saudi Arabia has bought all the LNG it can from Egypt and eastern Africa. This contrasts with the first scenario which shows demand without seasonality. This is due to a mismatch between supply from eastern Africa and Egypt and Saudi Arabia's demand profile. In other words, Egypt and eastern Africa's LNG capacities do not meet Saudi Arabia's total demand in the summer, forcing the model to call upon other sources of supply.

It is clear from Fig. 9 that Saudi Arabia only imports LNG during the summer months because it can meet demand from domestic gas supplies during the winter. Consequently, if Saudi Arabia did start to import LNG, it would be sensible to only contract LNG volumes seasonally, as Kuwait does, from April to October. This provides opportunities for Saudi Arabia to invest in LNG projects in nearby new gas production areas, such as

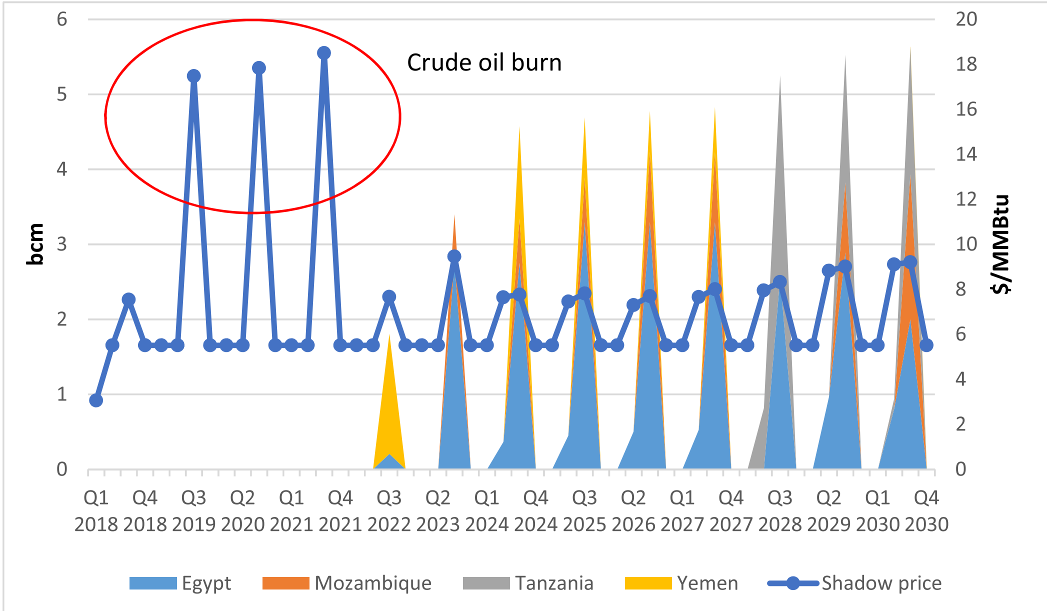

Fig. 9. LNG imports with a seasonal demand profile in Saudi Arabia.
Source: Results based on authors' simulation of WGM (March 2018).

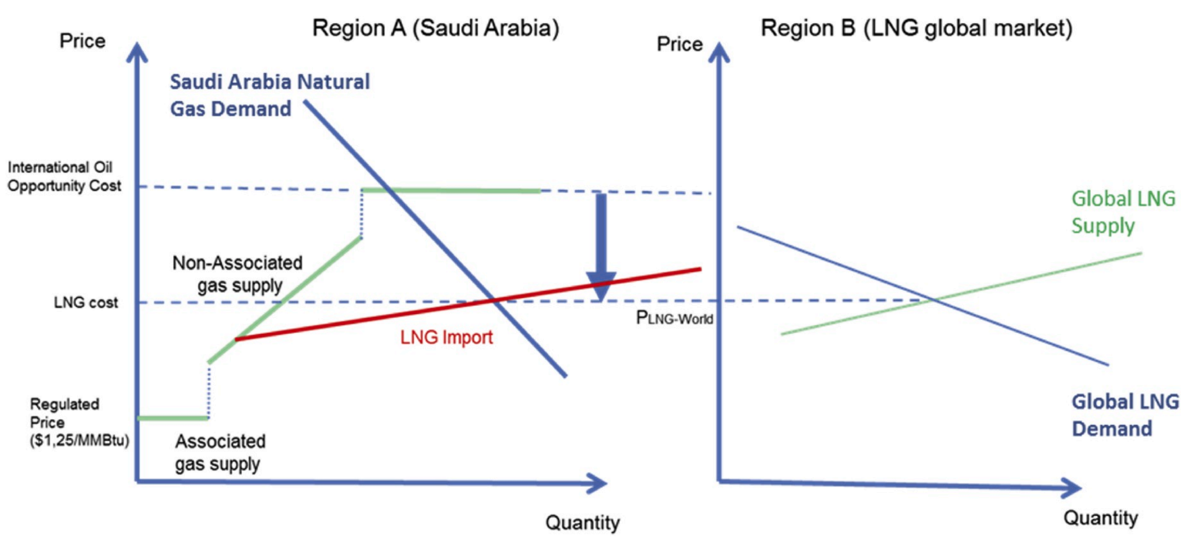

Fig. 10. Supply curve for power generation coupled with international LNG trade.
Source: Authors' illustration.

eastern Africa. This could be done jointly with winter-season importers or with trading houses. The advantage of the latter is that volumes could be shared or swapped, reducing costs.

5. Discussion

5.1. Supply curve for the power sector

The Kingdom's natural gas market in all its components through the framework illustrated in Fig. 10, with Region A representing Saudi Arabia's energy market equilibrium for power generation and Region B representing the international LNG market equilibrium. The two regions could be connected to facilitate trade, but are not now linked. Region A currently has less supply, relative to demand, than Region B. The majority of the supply is low-cost associated gas (produced as a by-product of crude oil extraction), but its quantity is limited. Shifting production toward more non-associated gas raises the cost of the gas supply. The lack of sufficient low-cost gas supply currently forces electric utilities to use crude oil and oil products, at a high opportunity cost to the country, given the international price of crude oil.

Without LNG imports (absent the ability to trade), the power market in Region A clears at the international opportunity cost of oil.

However, with LNG imports, the price clears at the total cost of imported LNG. Domestic supply quantity develops until the delivered cost equals the LNG delivered cost. A market reflecting the real price for natural gas is created, reflecting the international LNG market's supply and demand balance as well as the cost of domestic production.

Price movements in Saudi Arabia and in the global LNG market will depend on the relative elasticity (price responsiveness) of supply and demand, which will also determine the amount of trade that occurs and the infrastructure required. LNG imports could bring flexibility to Saudi Arabia's energy system while enabling domestic gas supply

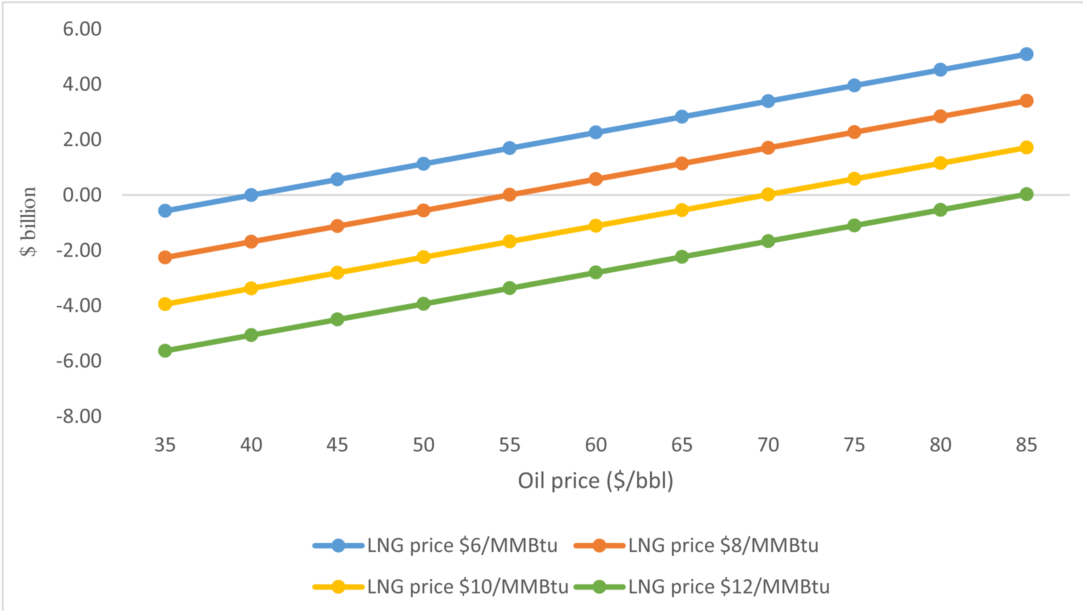

Fig. 11a. Cash netback of crude oil displacement with LNG under current domestic pricing policies (domestic price of natural gas set at $1.25/MMBtu) ($ billion).

development according to global natural gas market signals.

5.2. Market configuration requirements for an economic case for LNG imports

Saudi Arabia has always relied on their vast, low cost oil resources to meet the rise in power generation. In 2017, Saudi Arabia used 831 trillion British thermal units (or around 393 kb/d) of crude oil to generate electricity (ECRA, 2018). Using U.S. EIA efficiency estimates of petroleum-based power plants for 2017 (EIA, 2018), crude oil generated about 81,478,576 MWh to the grid. Under a government administered pricing regime, decision to import LNG may have a negative impact on the Kingdom's balance of payments. Electric utilities in Saudi Arabia purchase oil from Aramco at $6.35/bbl ($1.11/MMBtu) and natural gas at $1.25/MMBtu (APICORP, 2018). The low administered pricing of fuels to end-users in Saudi Arabia has also discouraged investments in more efficient natural gas plants, taking away the thermal efficiency advantage that gas has over oil. Around 80% of installed power plant capacity in Saudi Arabia are composed of simple cycle gas and steam turbines, while more efficient combined cycle plants comprise only 19% (ECRA, 2018). Assuming power plant efficiency is similar between oil and gas, the impact of LNG imports will depend on the cost of import, domestic prices of oil and gas, and price of oil in international markets. The lifting cost of domestic crude in Saudi Arabia also plays a factor in the accounting process. Saudi Aramco has estimated its lifting cost to be around $2.8 per barrel of oil equivalent in 2018 (Saudi Aramco 2019). The three figures below test three policy scenarios of domestic pricing against different configurations of international oil and LNG prices. It depicts the cash netback for the government of Saudi Arabia which is derived by calculating the revenue generated from crude oil displaced

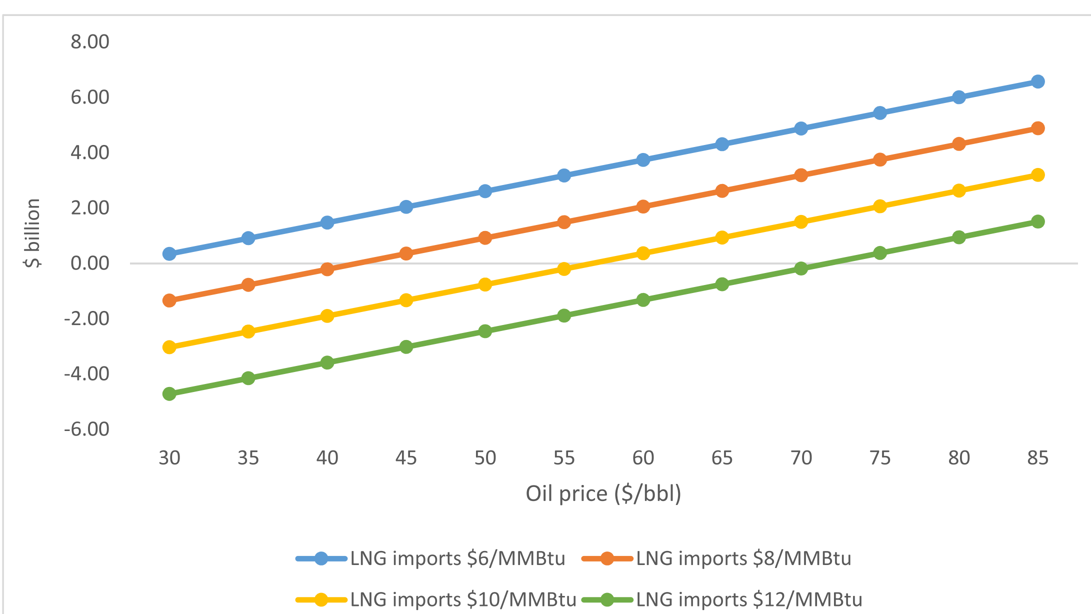

Fig. 11b. Cash netback of crude oil displacement with LNG at domestic price of gas = $3/MMBtu, ($ billion).

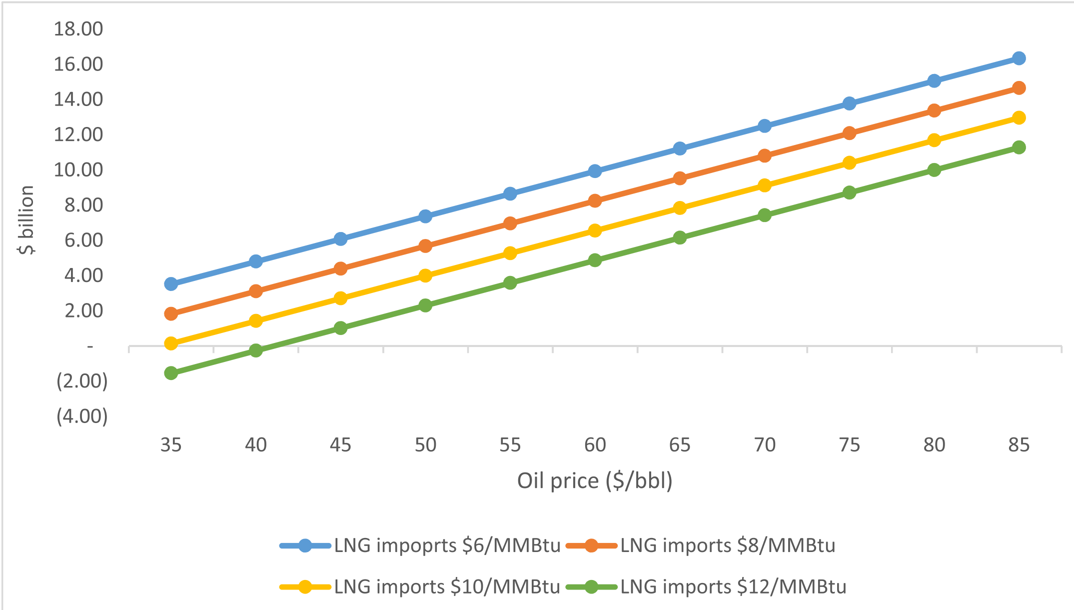

Fig. 11c. Cash netback of crude oil displacement with LNG under a deregulated domestic pricing scenario, ($ billion).

by LNG less the associated costs of substituting oil with LNG in power generation. Given Saudi Arabia's prominent role in crude oil markets, any additional exports can have an impact on international prices. Thus a price reaction function, calculated by (Blazquez et al., 2018) has been included in the operating netback calculation. The authors of the study calculated that increasing oil exports by one barrel from Saudi Arabia would generate an incremental revenue equal to 79% the international price of oil.

The following formula has been used to calculate the cash netback for Saudi Arabia:

$$\text{Cash Netback} = [\text{Generation}_{\text{Oil}} * [\text{HR}_{\text{Gas}} * (\text{DP}_{\text{Gas}} - \text{IP}_{\text{Gas}}) - \text{HR}_{\text{Oil}} * (\text{DP}_{\text{Oil}} - \text{lifting cost}_{\text{Oil}})]] - [(\text{VD}_{\text{Oil}} * \text{IP}_{\text{Oil}} * \text{PRF})]$$

where:

$\text{Generation}_{\text{Oil}}$ = Power generated by crude oil in 2017 (MWh) set at 81,478,576 MWh

HR_{Gas} = Heat rate of gas-fired generation (10.353 MMBtu/MWh).

HR_{Oil} = Heat rate of oil-fired generation (10.199 MMBtu/MWh).

DP_{Gas} = Natural gas domestic selling price ($/MMBtu).

DP_{Oil} = Crude oil domestic selling price ($/MMBtu).

VD_{Oil} = Volume of oil displaced (barrels).

IP_{Gas} = Import price of LNG ($/MMBtu).

IP_{Oil} = Export price of oil $/barrel.

$\text{Lifting cost}_{\text{oil}}$ = Average cost of oil in the kingdom estimated at $2.8/bbl.

PRF is the price reaction function estimated to be 0.79.

In the first scenario, the current administered prices of natural gas and crude oil sold to utilities is left unchanged ($1.25/MMBtu and $1.11/MMBtu respectively). Under this scenario, importing LNG into Saudi Arabia at $10/MMBtu, as determined by our simulation in WGM, would have a positive impact on the Kingdom as long as oil prices are above $70/bbl as show in Fig. 11a. If the long term price of oil is $85/bbl, LNG imports at $10/MMbtu is estimated to have a cash netback value of $1.72 billion. Alternatively, a $60/bbl long term price would generate a negative cash netback. For the government to generate a positive cash netback in a $60/bbl price environment, LNG import prices into Saudi Arabia have to be priced at around $8.5/MMBtu or less.

The second scenario (Fig. 11b) assumes the kingdom increases gas prices for utilities to $3/MMBtu while keeping the domestic price of crude unchanged at $1.11/MMBtu. In this case, a world with a $60/bbl oil price and an LNG import price of $10/MMBtu into Saudi Arabia would provide a marginal benefit for the Kingdom. At $85/bbl oil price, the power sector is estimated to provide a positive netback to the Kingdom of $3.2 billion with LNG imported at $10/MMBtu. Meanwhile with LNG at $6/MMBtu, Saudi Arabia should expect a positive cash back of $0.4 billion with an oil export price as low as $30/bbl.

If domestic prices of fuels to utilities were set by the international prices of oil and LNG, then the Kingdom are always better off importing LNG when oil prices are above $40/bbl, if LNG prices range between $6/MMBtu and $12/MMBtu as shown in Fig. 11c.

5.3. Opportunities for LNG to add value to Saudi Arabia

Integrating Saudi Arabia into the global natural gas market could provide value beyond the economic benefits that could derive from such integration. Demand-side alternatives to fixed, onshore regasification terminals, such as FSRUs, are helping to seed new markets and are offering more flexibility around LNG consumption. The scalability of LNG and flexibility in chartering FSRUs means that LNG supply can be scaled up or scaled down according to the availability of domestic energy supply, whether that be from gas or from renewable technologies. Chartering an FSRU on a short-to medium-term basis reduces the risk of stranded assets and provides greater flexibility than building costly, fixed onshore regasification terminals, as any rental commitment on an FSRU can be reversed in a matter of months.

Saudi Arabia could leverage the flexibility of LNG to help transition its energy mix away from a reliance on oil more smoothly and at a lower cost than would be the case if it were to continue relying on liquid fuels. Many importers of Saudi Arabia's crude oil and refined products are also growing LNG consumers. Hence, with more destination-free contracts, Saudi Arabia may use its trade experience to divert unwanted cargoes of LNG to such customers. Alongside the benefits outlined above, using LNG for power generation could also help Saudi Arabia meet its environmental and air quality targets.

Saudi Arabia aims to reform energy pricing mechanisms in the energy sector. Importing LNG could lead it toward more resilient energy market-based pricing in its power generation supply mix. As the Kingdom imports more LNG at international prices, the delivered cost should feed through to domestic markets and facilitate a benchmark price for Saudi gas. This price could also help create a pathway to incentivize the development of the Kingdom's domestic gas reserves as well as energy efficiency policies.

Historically, low domestic natural gas prices in Saudi Arabia resulted in demand outstripping supply. The government responded by setting limits on gas consumption for different sectors. Importing gas may put domestic gas in competition with LNG for power generation. In such a scenario, domestic natural gas volumes would be developed until their cost equals the Saudi delivered LNG price. This provides a gauge that could be used to avoid overinvesting in domestic natural gas development, especially in non-conventional gas.

6. Conclusion and policy implications

Despite its apparent disruptiveness, limited importation of LNG into western Saudi Arabia, especially during the summer months, is a worthwhile and relatively easy way to improve the energy mix in Saudi Arabia's electricity generation sector. Our modeling shows that the LNG market is elastic enough and can cater for Saudi Arabia's future demand without any significant rise in prices. Saudi Arabia plans to double natural gas production by 2030 to help reduce dependency on liquid fuels. The flexibility inherent in LNG's supply chain allows the Kingdom to use LNG in the interim as an immediate solution to switch from oil-fired generation. Its flexibility is beneficial to be used as an insurance against delays in domestic gas development, infrastructure expansions, and deployment of alternative energy. Furthermore, introducing LNG into Saudi Arabia could create a framework for gas market liberalization and a local price benchmark to help develop the country's domestic gas market.

While LNG import can displace oil -effectively, it might not be the optimal solution. Other sources of energy should also be investigated further, such as different domestic gas investment schemes, renewables (solar and wind) and nuclear power. Further modeling on power mix optimization can build on this study using estimates of imported LNG into Saudi Arabia to assess how LNG competes with other sources of energy. Another factor that would play into the mix starting in 2020 is the International Maritime Organization (IMO) plans to limit the sulfur content in marine fuels which may lead to surplus volumes of high sulfur fuel oil (HSFO) in the market, fuel that – given the right price – could compete for power generation in Saudi Arabia.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

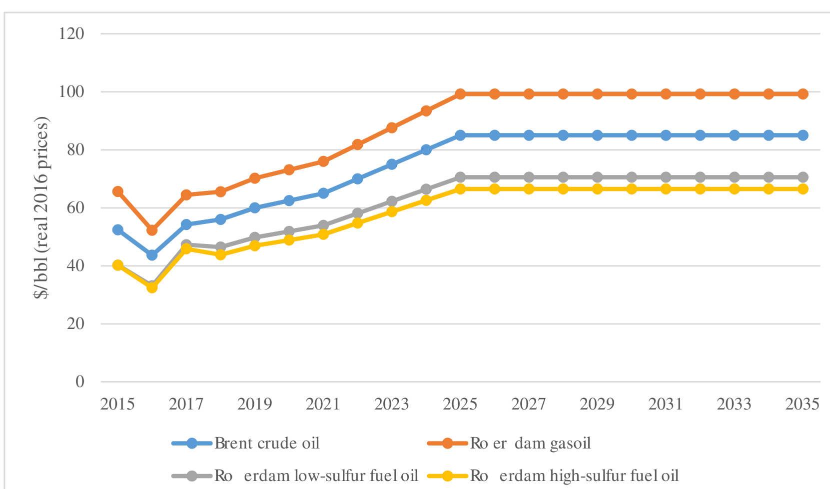

Fig. A1. WGM oil and oil products price assumptions.
Source: Nexant WGM (March 2018 edition).

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