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King Abdullah Petroleum Studies and Research Center

Commentary

The Impact of Displacing Fuel Oil on Saudi Refineries

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About KAPSARC

KAPSARC is an advisory think tank within global energy economics and sustainability providing advisory services to entities and authorities in the Saudi energy sector to advance Saudi Arabia's energy sector and inform global policies through evidence-based advice and applied research.

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Key Points

Saudi Arabia aims to displace fuel oil in its electricity system and industry. Such a move will impact the operation of its oil refineries, and this commentary explores these potential effects. An analysis using an integrated optimization model for each of the Saudi oil refineries and the coupled fuel distribution network will provide the following insights:

- If global refined fuel markets cannot accommodate higher exports by Saudi Arabia, lower fuel oil production will require local refineries to process lighter crude oils in the long run. This shift entails increasing the use of Arabian Light crude oil and reducing the use of Arabian Heavy crude oil. Additionally, overall production at PetroRabigh, SASREF, and SAMREF – refineries located in Rabigh, Jubail, and Yanbu – will decline.

- If markets can accommodate higher exports, domestic fuel oil displacement allows for higher exports of refined oil products. This can mitigate the lower utilization of PetroRabigh, SASREF, and SAMREF.

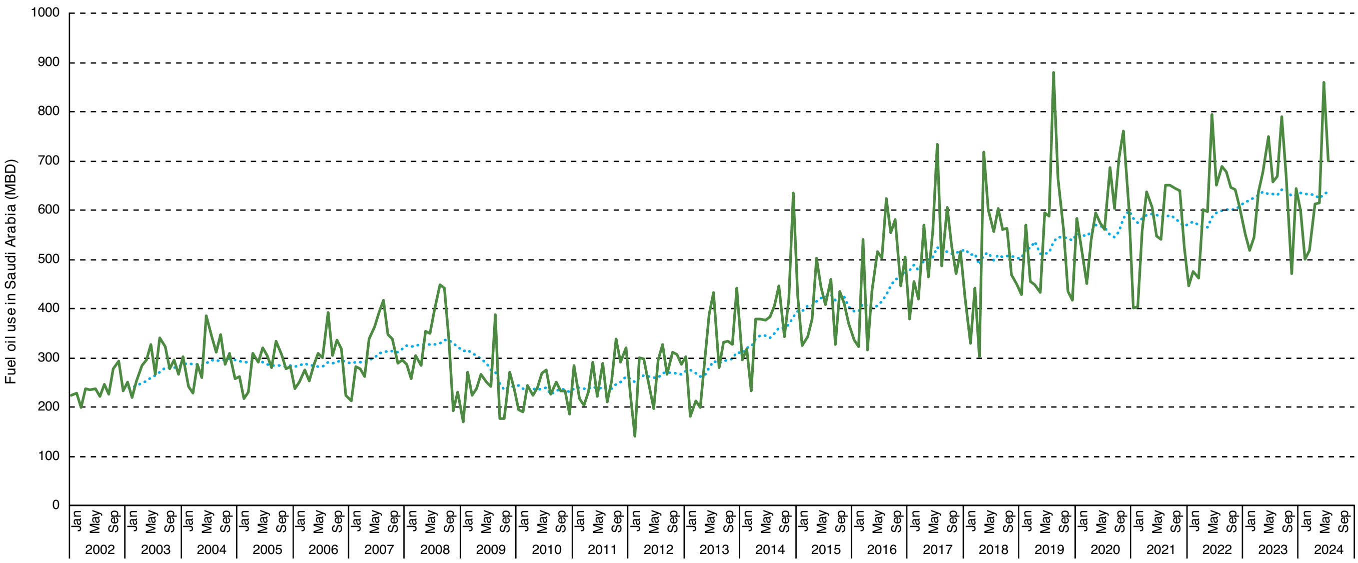
Introduction

Saudi fuel oil use has been increasing in recent years. Figure 1 highlights that the 12-month average of fuel oil use reached its highest levels in 2023 and 2024. In the first seven months of 2024, Saudi Arabia averaged 630 thousand barrels per day (MBD) of fuel oil use (JODI 2024), which is slightly higher than the 620 MBD average during the same period in 2023. The seasonal pattern in fuel oil use that is presented in Figure 1 implies that a substantial portion of the fuel is used for domestic electricity generation. As part of its Liquids Displacement Program, Saudi Arabia intends to reduce domestic consumption of fuel oil for electricity and industrial production.

Supporting this goal, Matar et al. (2015) have argued that improving resource allocation efficiency in Saudi Arabia entails reducing the use of liquid fuels in favor of natural gas and various renewable or nuclear electric power technologies. Later studies by Matar and Anwer (2017) and Matar and Shabaneh (2020) have shown that solar photovoltaics and natural gas have become the preferred substitutes for liquid fuels.

Moreover, Saudi Arabia was once a consistent net exporter of fuel oil. However, from 2018 to 2023, it became a net importer of fuel oil in all years except 2022,[1] and this trend continued in the first half of 2024. These changes are illustrated in Figure 2. Displacing fuel oil with more valuable alternatives would not only be economically advantageous but would also help Saudi Arabia to regain its status in energy security.

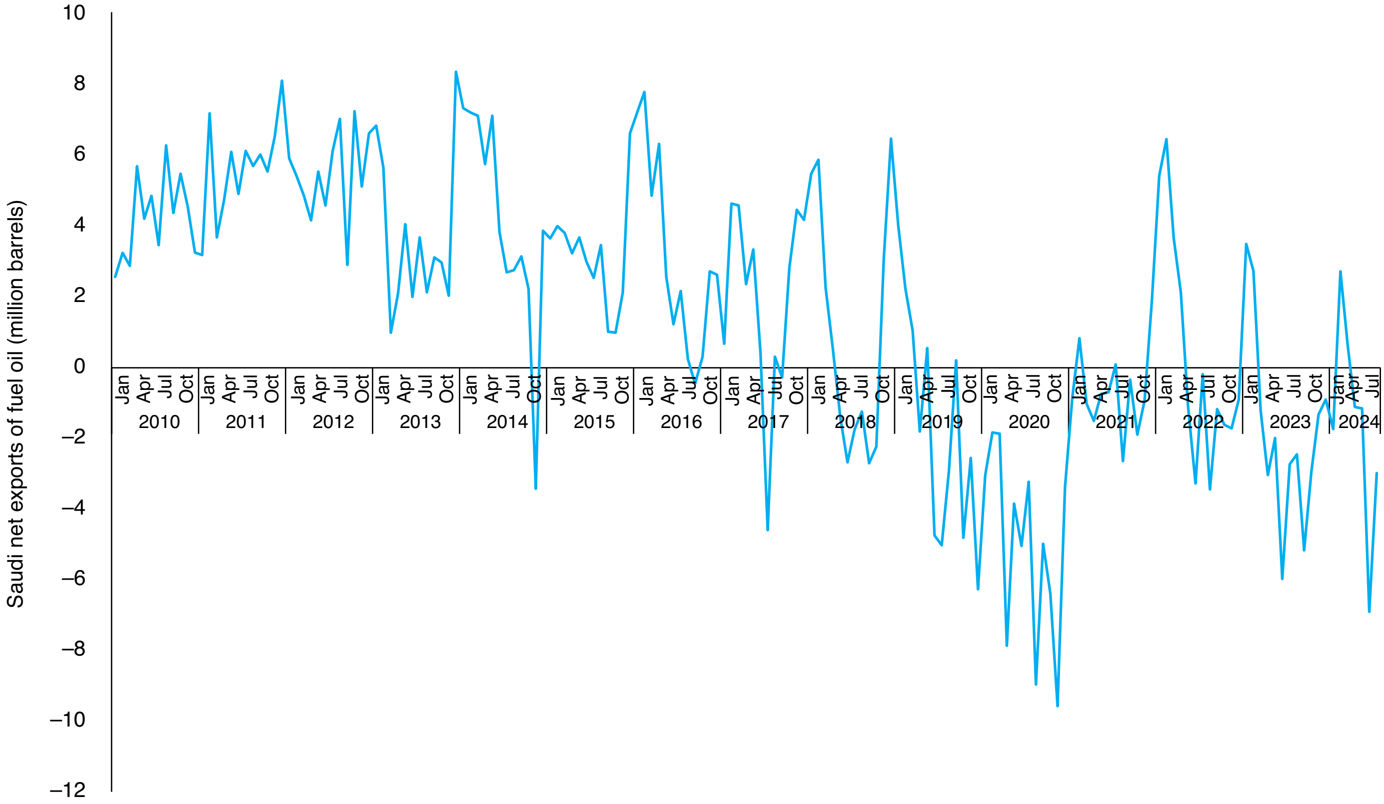
Figure 1. Fuel oil use in Saudi Arabia from 2002 to mid-2024.



Source: Jodi (2024).

[1] *Saudi Arabia produced record volumes of crude oil in 2022.*

Figure 2. Net exports of fuel oil in Saudi Arabia from 2010 to the first half of 2024.



Source: JODI (2024).

This commentary examines the potential effects of reduced domestic fuel oil use on Saudi Arabia's oil refining sector. An optimization model integrating the refining and distribution systems is employed for this analysis. I evaluate three fuel oil demand cases until 2040 and derive insights from the results.

Methods

In the current study, an optimization model that integrates two main components is utilized. The first component is an oil refinery model, which represents each of the nine operational refineries in Saudi Arabia. This refinery model is adapted from the version used in the KAPSARC Energy Model (KEM). Unlike KEM's regional aggregation, this model now includes individual refineries. The schematic guiding the model formulation is shown in Figure 3. An earlier version of the model and its input data are detailed in KAPSARC (2016), and subsequent updates to the model do not alter KAPSARC's general description. Data on unit capacities for each refinery are sourced from IHS, which is now S&P Global. If a refinery does not have a particular unit, its initial capacity is 0 million tons per year. However, the model allows for investments in any unit.

It is important to note that changes in the production of one fuel can affect the production of other fuels. Changes can include the mix of crude oil grades processed and the operation of individual units. The assays, or chemical yields, for Arabian Heavy, Arabian Medium, and Arabian Light are sourced from Cerić (2001). Data inputs for assays for gas condensate and Arabian Extra Light are estimated based on other oils that share their mass densities and sulfur contents. Although Arabian Super Light is included in the model, its yields are not incorporated. In total, the model accounts for six types of oil.

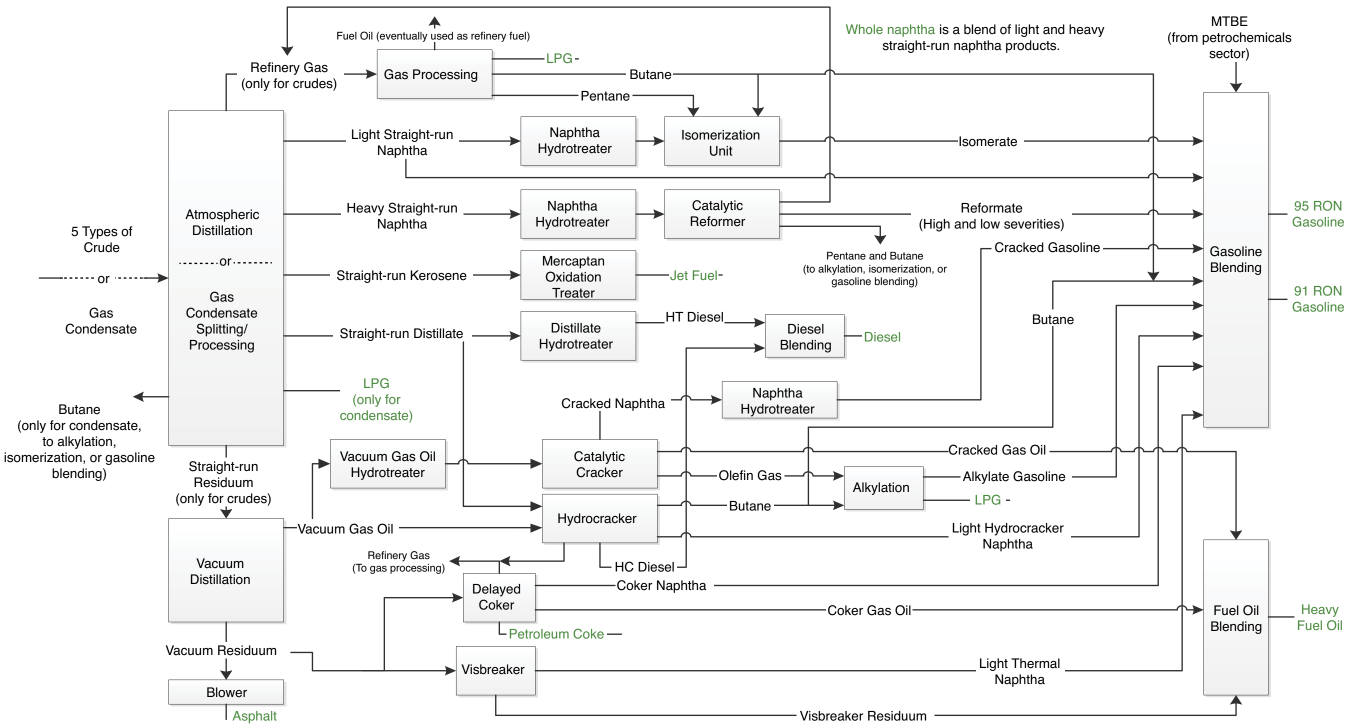
The model is calibrated to align broadly with Saudi Aramco's 2024 operational plans for each refinery. Refineries wholly owned by Saudi Aramco receive crude oils at internal transfer prices, while joint ventures pay market prices for their inputs. Although the internal transfer prices are not disclosed, it can be estimated to be US$20 per barrel for this analysis. For joint ventures, 2023 market prices for Arabian Light from OilPrice (2024) are used and these prices are fixed until 2040, applying price differentials for other grades. Additionally, it is modeled that Saudi Aramco can only claim a share of a refinery's produced volumes proportional to its equity stake in that refinery.

Unit production yields are parameterized using Hydrocarbon Processing (2004) and Gary and Handwerk (2001). The model includes 10 products: motor gasoline (91 and 95 research octane numbers), diesel, fuel oil, whole naphtha, jet fuel, kerosene, liquefied petroleum gas (LPG), petroleum coke, and asphalt. Property specifications for products are taken directly from Saudi Aramco.

The output from the nine refineries, along with any potential imports, feeds into a fuel distribution model, which constitutes the second component of the overall model. This fuel distribution model, built specifically for Saudi Arabia, details the distribution of gasoline, diesel, jet fuel, and kerosene throughout the Kingdom. This influences fuel oil operations. The constraints and data inputs associated with this model are fully described by Alhosain et al. (2024). A stylized schematic of the distribution component is shown in Figure 4.

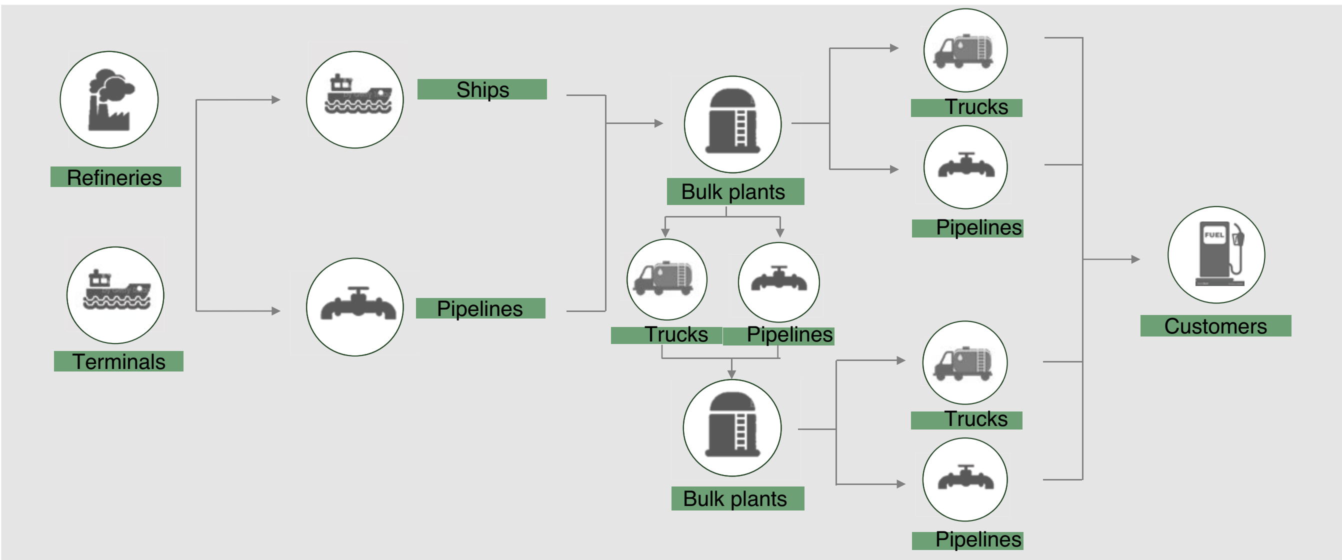
Both models have been integrated to form a unified set of constraints and a consolidated objective function. The goal of this integrated model is to maximize profits for the entire refining and distribution system. The only source of variable revenue in the model is the decision to export refined fuels, whereas the model must fulfil domestic fuel demands regardless of price.

Figure 3. Schematic on which the oil refining model is based.



Source: Author's analysis.

Figure 4. Stylized schematic for the fuel distribution component.



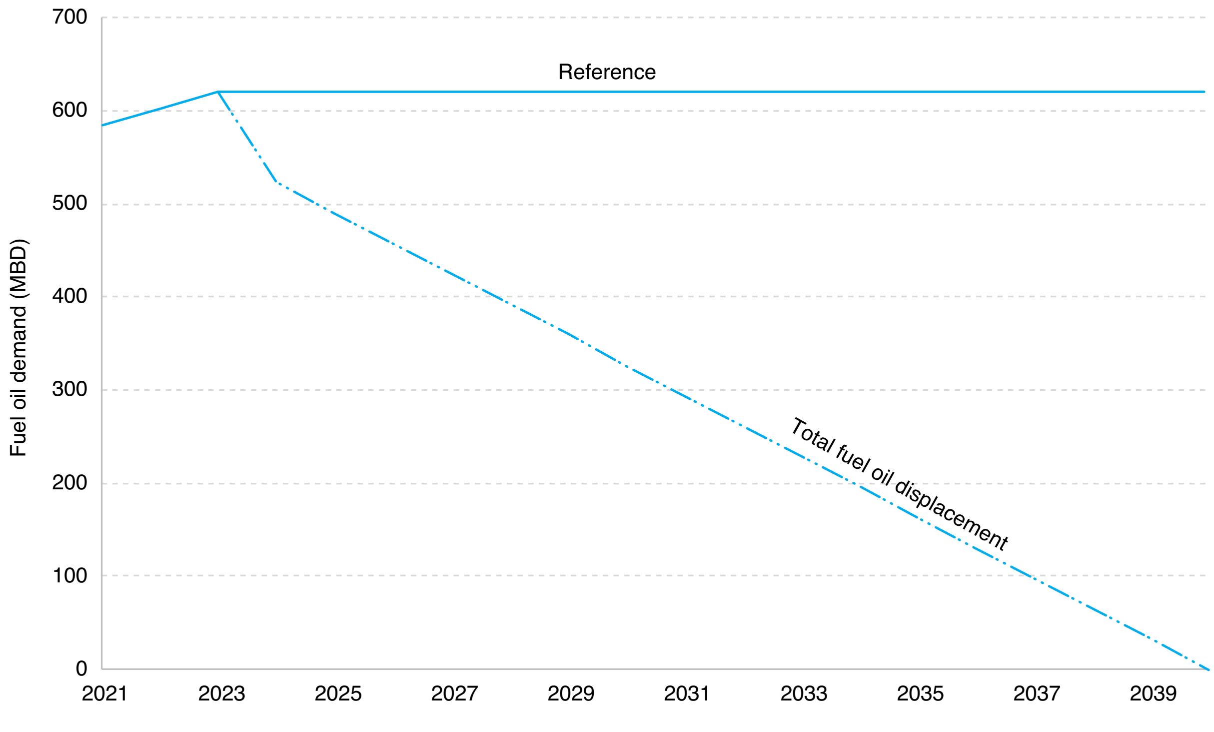
Source: Author's analysis.

Cases

A reference case projects that annual fuel oil demand remains constant from 2023 until 2040, and two additional cases explore the impact of reducing domestic fuel oil demand to zero by 2040. Figure 5 illustrates the two fuel oil demand scenarios. In one of the alternative cases, exports of each refined product are capped at the levels observed in the reference case. Global markets may not be able to accommodate higher exports by Saudi Arabia. Since the global market dynamics are outside the scope of this analysis, the second case allows for unbounded exports, assuming that the global market can absorb any additional capacity for refined fuels production.

Although the demands of other refined fuels are unchanged in all cases, they are still necessary to facilitate this analysis. Demand projections of gasoline, diesel, and jet fuel factor in the effects of expected price reforms and new infrastructure projects. Export prices for refined products are fixed at their 2023 levels.

Figure 5. Fuel oil demand assumptions in the reference and alternative cases.



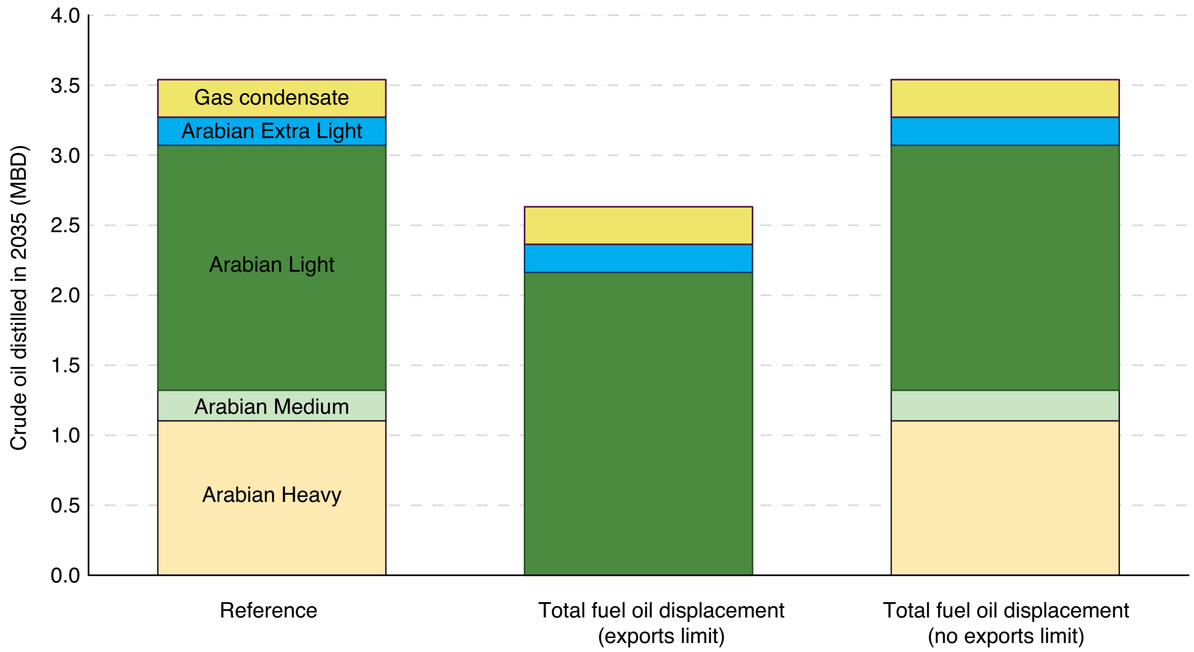
Source: Author's analysis.

Results

Figure 6 shows the amounts of oil processed at Saudi refineries in 2035. These values are aggregated for the combined set of refineries, each of which adjusts its crude oil slate in the different cases. Saudi Arabia refines just over 1 million barrels per day of Arabian Heavy crude oil in both the reference case and the total fuel oil displacement case without a limit on exports. When export volumes are capped at the levels observed in the reference case, eliminating fuel oil from local fuels shifts the profit-optimal crude oil slate to lighter grades. Specifically, domestic refineries would cease using Arabian Heavy and Arabian Medium crude oils and increase their use of Arabian Light crude oil by about 0.4 million barrels per day. They would also reduce their overall crude oil usage by nearly 1 million barrels per day in this case.

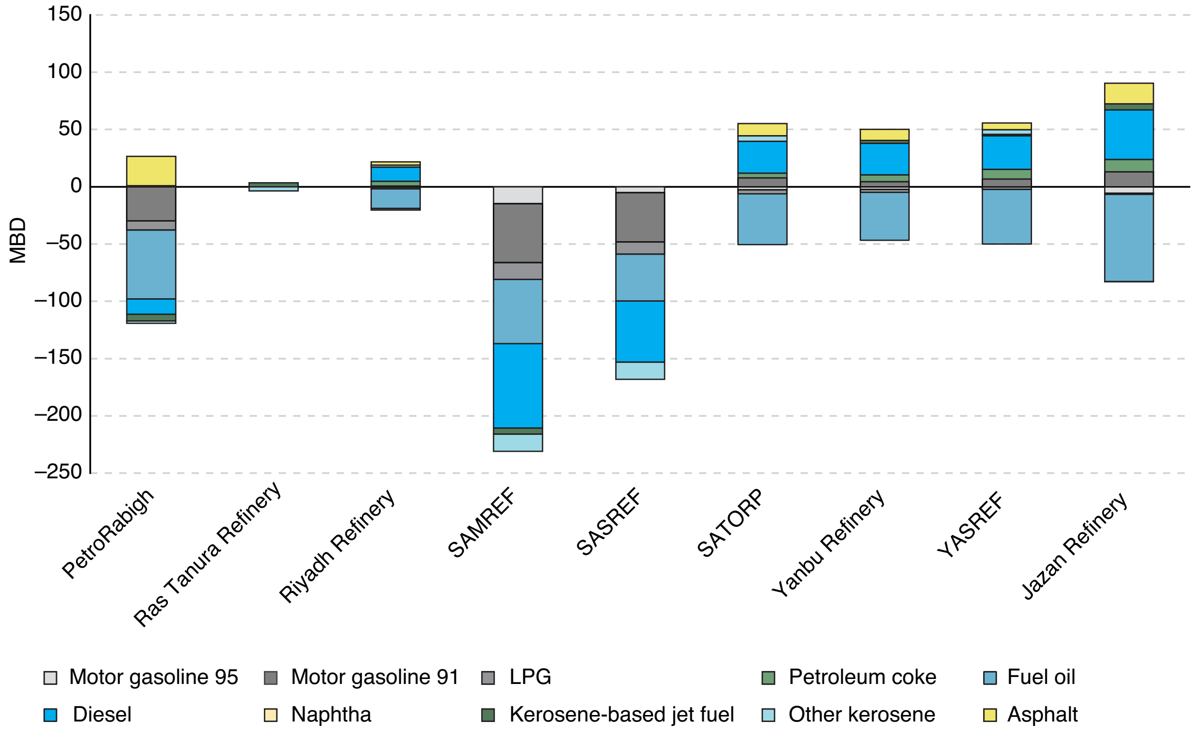
Figures 7 and 8 illustrate the changes in the production of fuels by refinery in the two alternative cases relative to the reference case. In the case where domestic fuel oil use reaches zero by 2040 and exports are capped at the

Figure 6. Volumes of crude oils processed by Saudi refineries in 2035.



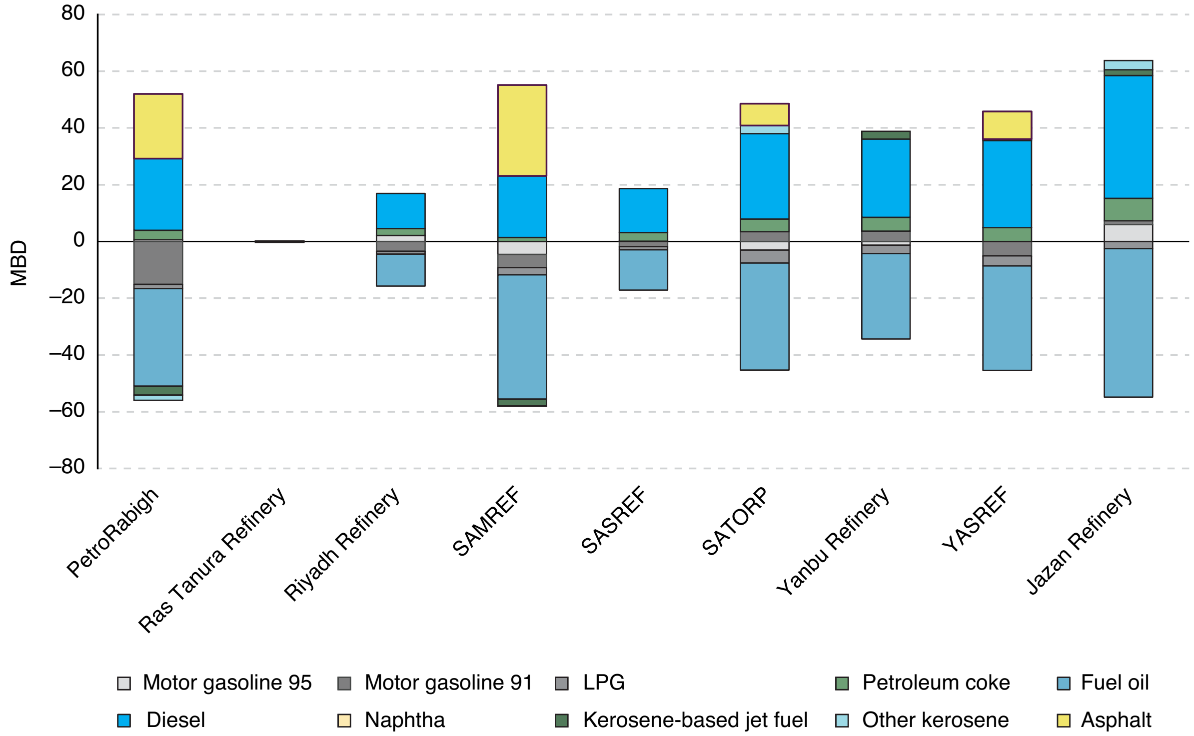
Source: Author's analysis.

Figure 7. Changes in fuel production by Saudi refineries in 2035 in the case where total fuel displacement and exports are limited.



Source: Author's analysis.

Figure 8. Changes in fuel production by Saudi refineries in 2035 in the case where total fuel displacement and the exports limits are lifted.



Source: Author's analysis.

levels observed in the reference case, production declines at PetroRabigh, SASREF, and SAMREF – three refineries in Rabigh, Jubail, and Yanbu. When limits on exports are lifted, production from these refineries increases as overall exports rise. As seen in Figure 8, fuel oil displacement without export constraints shows that the lower fuel oil production is replaced by higher production of diesel and some combination of asphalt or petroleum coke.

Concluding Remarks

Saudi Arabia aims to replace sizeable amounts of liquid fuels used in its industry and utilities with natural gas and renewable technologies. This policy direction is supported by prior research published by KAPSARC (Matar et al. 2015; Matar and Anwer 2017; Matar and Shabaneh 2020). One such liquid fuel is fuel oil, which is currently used extensively in power generation and industry in the Kingdom. As demand for fuel oil declines, the impact on Saudi refineries striving to meet the demands for other refined products could be substantial.

To analyze the implications of reduced fuel oil production, I apply an integrated optimization model of the nine oil refineries and the fuel distribution network in Saudi Arabia. A reference case is used to compare two cases that assess total fuel oil displacement by 2040. One of the two cases considers the fuel exports over time that are exhibited in the reference case, and the other considers that this limit is lifted in the event that global markets can take additional Saudi exports.

Key findings include that lower fuel oil production leads to the processing of lighter crude oils if exports are limited. In this case, local refineries could reduce their total crude oil intake by nearly 1 million barrels per day while still satisfying local fuel demands, and the use of Arabian Light crude oil rises while the Arabian Heavy and Arabian Medium crude oils are phased out. On the other hand, if global demand can accommodate higher exports, refineries could maximize their use of crude oils and thus maximize their export revenues. However, it is uncertain whether the international market can absorb these additional volumes of fuel.

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About the Project

We developed the KAPSARC Energy Model (KEM) for Saudi Arabia to understand the dynamics of the country's energy system. It is a partial equilibrium model formulated as a mixed complementarity problem to capture the administered prices that permeate the local economy. KEM has been previously used to study the impacts of various industrial fuel pricing policies, improved residential energy efficiency on the energy economy, the feasibility of deploying power plant technologies in Saudi Arabia, natural gas storage, and a way to computationally analyze residential electricity prices. The distribution network for refined products has been integrated with the oil refining sub-model of KEM. One area of current KEM development is the increased integration of oil refineries and petrochemicals.

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