Shifting Crude Oil Quality and Refining Constraints: A Data-Driven Analysis of Global Heavy Oil Dependence and Market Disruption Risk

Final Report

Prepared for: Chirality Research

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1. Executive Summary

This project aims to identify and measure potential risk related to the supply of heavy crude oil, used in the production of certain vital petroleum products such as residual fuel oil. Canada is a substantial producer of heavy crude oil, which has differing economics from light crude oil and consequently has differing demand dynamics. Having a complete picture of potential risks to the supply and demand of heavy crude oil is an important element in determining potential opportunities and threats to Canadian heavy crude oil production and export, which is a crucial piece of information in the current volatile oil market.

To accomplish our objectives, we gathered data on production and consumption of heavy crude oil and used that data to create models to forecast production and consumption into the future, which we used to create a risk index. Using our research findings and a few educated assumptions, we calculated the proportion of crude oil each of our focus countries produces and consumes that is heavy, utilizing residual fuel oil as a proxy metric when data is unavailable or of poor quality. When we created the models, we included several disruption scenarios based on actual exogenous events that occurred during our study period. Finally, when formulating our index, we included supply and demand of heavy crude oil, as well as a weight value related to Canada's exposure to each disruption scenario.

After completing the project work, we have produced a risk index, predictive models, and a dashboard to visualize our findings. Our predictive models create production and consumption projections to the year 2030 for our subject countries, either baseline or based on an included disruption event. These projections, along with the risk index for each model, are visualized using our dashboard, with easy selection of country (or overall), direction, and event scenario. These products, particularly the models of Canada's heavy crude oil production and consumption, will be useful for creating projections of trajectories for Canada's crude oil sector, which we hope will help inform strategic decisions made regarding Canada's crude oil export market and provide a framework for analysis that can be built upon.

Our key findings indicate that Canada constitutes the majority of heavy crude oil production in a world oil market that's increasingly dominated by light crude oil. Furthermore, the vast majority of Canada's crude oil exports have gone to the United States and China, even while there are countries that have structurally strong demand for heavy crude oil for their marine shipping industries. Even still, Canada's oil trade relationships with these countries are weak to non-existent, with production and shipping constraints exacerbating these issues. Canada is in a position where it could benefit strategically from a disruption in heavy crude oil production, but it needs to ensure its oil production infrastructure is up to the task.

2. Introduction & Background

The global crude oil market is differentiated not just in terms of production and price, but also in terms of quality and composition. Large amounts of Canada's crude oil deposits are heavy crude, which is more complex and costly to process than light crude, so these producers face challenges in bringing their product to market. This notwithstanding, heavy crude oil is required to produce many critical oil products, such as marine fuels, bunker oil, and heavy distillates. Additionally, other countries with large heavy crude oil deposits have been affected by geopolitical disruptions including sanctions, which create market distortions and risks for producers and consumers of heavy crude oil. Taken together, this represents high risk both for countries that produce heavy crude oil and for countries that have high demand for products of heavy crude oil.

The goals for this project were to identify trends in heavy crude oil production that could be used to measure risk to the supply of heavy crude oil, as well as identifying dependence on the products of heavy crude oil, as measured by refining capacity and demand for marine and residual fuel. These were to be used to develop predictive risk insights that could be used to assess strategic opportunities for Canada. The scope of this project was agreed to encompass the production and use of heavy crude oil, defined as crude oil with an API gravity below 26˚, and when needed identified using proxy products such as residual fuel oil consumption.

To complete our project, we used 5 key research questions to guide our inquiry, each corresponding to one of the project objectives. These included:

1. How has the global crude oil mix by API gravity changed over time (1970 – present)?
2. Which countries produce and consume heavy vs. light crude oil, and how has this changed across historical disruptions?
3. Which countries are structurally dependent on heavy crude for marine fuel production, and what are their historic sourcing patterns?
4. How concentrated is global heavy crude production, and what systemic risks arise from sanctions or production constraints?
5. What strategic role could Canada play in mitigating future heavy crude shortages?

To answer these questions, we used several different methods including time-series forecasting, literature review, index creation, and dashboard visualization, which informed us on relevant knowledge, produced metrics, and displayed metrics and data to answer our research questions.

3. Project Objectives & Deliverables

- Project Objectives
    - Analyze Global Crude Quality Trends
        - We accomplished this objective by identifying heavy crude oil production numbers in the top oil producing countries using educated assumptions when necessary.
    - Measure Heavy Oil Supply Risk
        - We accomplished this objective by identifying shifts in crude oil production and consumption for our selected countries, as visualized on our dashboard.
    - Identify Refining and Marine Fuel Dependence
        - We accomplished this objective by finding countries with outsized residual fuel needs and the uses for residual fuel oil in these countries.
    - Develop Predictive Risk Insights
        - We accomplished this objective by developing production and consumption forecast models for our selected countries and developing an index to quantify risk.
    - Assess Canada's Strategic Opportunity
        - We accomplished this objective by utilizing our index findings to identify opportunities for increased supply of heavy crude oil that Canada could fulfill given the right circumstances.

- Project Deliverables
    - Final Written Report
        - This deliverable will be submitted to the partner organization in the form of a PDF document.
    - Visualization Dashboard
        - This deliverable will be submitted to the partner organization as a Power BI dashboard file along with the Final Written Report.
    - Python Codebase
        - This deliverable will be in the form of several notebooks that will be shared with the partner organization through GitHub and Databricks.
    - Executive Summary
        - This deliverable will be included at the top of the Final Written Report seen above.

4. Review of Literature and Research

In order to construct our forecasting models, we first needed to understand what disruption in the crude oil market looks like. Consequently, we researched a handful of notable disruption events that occurred within the time range our data spans. Some events we included in our research included the 1973 OPEC oil embargo, the 1979 Iranian Revolution, the Iran-Iraq War from 1980-1988, the First Gulf War in 1990, and the sanctions-driven Venezuelan oil production collapse from 2018 onward. All these events would end up being included in our modeling as event scenarios, in addition to other localized disruption events, as well as instances of investment in pipeline construction within Canada.

1973 OPEC Embargo

The 1973 OPEC oil embargo took place in the context of the Yom Kippur War, in which Egypt and Syria led an attack on Israel. Arab OPEC members supported the Egypt-Syria coalition, while a number of western-aligned countries, including the United States and Canada, supported Israel, and in the case of the United States, that support came with significant supply contributions. The embargo was implemented by Arab OPEC members and targeted on the countries supporting Israel in October 1973, and within a month, the oil shortfall amounted to 4.4 million barrels/day, or approximately 7.5% of the world's crude oil output (Hamilton, 2011, p. 14). The results of the embargo were acute gasoline shortages, long lines at gas stations, and consequent increases in gas prices between 12-24% in December 1973. These issues were further exacerbated when, on New Years Day 1974, OPEC doubled the price of oil, resulting in gas prices 50-84% higher in March 1974 due to long lines at gas stations (Hamilton, 2011, p. 14-15). The embargo ended in March 1974, by which time the price of crude oil had risen to $11.65/barrel from a pre-embargo price of $2.90/barrel (Corbett, 2013). This scenario provides value for our modeling because, despite the effects ultimately being wide-reaching, the actual embargo was discretely targeted towards a small set of countries by another small set of countries, so it should generally be easy to model. Additionally, this type of scenario is prototypical of the types of scenarios we want to model, being a sudden and unexpected oil supply shock.

Iranian Revolution

The Iranian Revolution took place starting in October 1978, in which the monarchy, led by Shah Mohammad Reza Pahlavi, was toppled and replaced by a theocratic republic led by Ayatollah Ruhollah Khomeini. Oil production in Iran was disrupted by strike action through February 1979, which brought 4.8 million barrels/day, or approximately 7% of global supply, offline (Hamilton, 2011, p. 16). Post-revolution, oil production recovered to only 60% of pre-revolution levels (U.S. Energy Information Administration, 1980, p. 92). Hassani notes that during the 1970s, Iran had increased its production and export of oil, such that 89% of Iran's foreign exchange receipts in

1975 came from oil exports (2006, p. 152). This left the Iranian economy dependent on oil and consequently rendered it vulnerable to any sort of oil production disruption. Mazarei notes that the disruption in oil supply manifested in numerous ways, including parallel foreign exchange markets, rent seeking among the remaining oil revenues, increased budget deficits, stagnant GDP, and a more closed economy (1996). The effect of the revolution, and the consequent oil shortfall, was to cause the price of crude oil to nearly triple, from $13 in mid 1979, to $34 a year later (Gross, 2022). Furthermore, much as in the 1973 crisis, panic buying was rampant and fueled by fears of further crisis. This event is valuable for our model to show the effects of a sudden oil supply shock caused by an exogenous event contained entirely within one oil producing country, albeit with the consequences being shared across most oil consuming countries.

Iran-Iraq War

In September 1980, with the dust still settling from the revolution, Iraq launched an invasion into Iran. The cause of the invasion was complex, with territorial disputes, ideological rivalries, ethnic and religious differences, and regional power dynamics all playing a part (Burch, 2021). The war ultimately proved to be a lengthy one, lasting until August 1988. While one could not expect a protracted war between two oil powers to not have impacts on the oil sector, one component, the Tanker War, had an acute effect on oil exports from the region, with Iraqi leader Saddam Hussein hoping to draw Western powers into the war by provoking Iran to impose a blockade on shipping (Burch, 2021). At the height of the war, oil production in both Iran and Iraq was reduced by nearly half compared to pre-war production, with this shortfall accounting for around 6% of world crude oil production (Hamilton, 2011, p. 17). However, this conflict also saw the realization of two phenomena that prevented oil prices from spiking. First, demand in significant oil consuming countries shifted after years of intermittent oil crises, as industries and producers consuming oil sought to increase the efficiency of oil usage. Second, oil exploration projects in non-OPEC countries such as the United Kingdom, Mexico, and China had proven successful and production had come online. This effectively made it impossible for OPEC to keep prices set, despite even Saudi Arabia (normally a stabilizing force within OPEC) decreasing its own oil production during the war (Hamilton, 2011, p. 18). Towards the end of the war, Saudi Arabia ramped up oil production as Iraqi oil production was recovering, in an effort to regain control of the market; this brought oil prices to a low of $12/barrel in 1986 vs. $27/barrel a year earlier (Hamilton, 2011, p. 18). While this event did not result in the same type of oil shortfalls that the earlier events did, the presence of the demand shifts and production increases in non-traditional oil producing countries may make this event a salient example of creating opportunity out of uncertainty.

Gulf War

The Gulf War began in August 1990, when Iraq, having since recovered from the war with Iran, launched an attack on Kuwait. The primary cause for this attack was due to disagreements over oil production, with Iraq accusing Kuwait of overproducing oil and helping to suppress the price thereof, and of stealing oil from Iraqi territory through slant drilling. At the time Kuwait also held a significant amount of Iraqi debt from the war with Iran (Dee, 2016). Upon the invasion, economic sanctions were imposed on Iraq, although these proved ineffective, and a broad military coalition was formed to fight Iraqi forces directly, with the war ending in an Iraqi defeat in February 1991. As a result of the war, oil production in Iraq and Kuwait were shuttered, with Kuwaiti oil production taking over a year to completely recover, while economic sanctions on Iraq remained until being partially eased in 1996 with the Oil for Food Program, and Iraqi oil production only started to recover after that time (U.S. Energy Information Administration, 2011). In terms of aggregate oil production, there was only an initial supply shock around Iraq's initial invasion of Kuwait, with other OPEC countries increasing production to compensate for the lost supply. Of note, Yamani found that due to the lag between production and consumption, there was little if any actual risk of shortages, and that the price shock that did occur (with a peak price of $40/barrel) may have been based on fear (1991, p. 4). Both the war and the continued sanctions on Iraq are included as separate events in our model.

Venezuela Sanctions

Beginning with the accession of Nicolás Maduro to the Venezuelan presidency in 2013, increasing instances of institutional oppression were reported against opponents of the regime, particularly surrounding protest events, which was used as justification for the United States and aligned nations to impose sanctions on Venezuela. Sanctions imposed have touched broad segments of the Venezuelan administration and economy, with the oil sector facing particular sanctions. The first significant sanction against the Venezuelan oil sector came in 2017, when the state-owned oil company PDVSA was restricted from conducting financial transactions in the United States, as part of a sanction on financial transactions against the broader Venezuelan government (Bull & Rosales, 2020, p. 110-111). The second significant sanction came in 2018, when the assets of PDVSA within the United States were blocked, including access to the accounts of CITGO, which is majority Venezuelan-owned. The third significant sanction came in 2019, when United States companies were restricted from conducting business with the Maduro government, including PDVSA (Bull & Rosales, 2020, p. 110-111). We included the first and third sanction events in our model, since we were mainly concerned with oil export transactions from Venezuela, and the second sanction only affects money inflows from Venezuelan foreign assets. The effect of the sanctions has been to significantly decrease the amount of oil produced in Venezuela, although as Bull & Rosales note, the Maduro government also persecuted and dismissed dissenting managers within PDVSA, which combined with desertion of lower-level workers to cause an effective brain drain within the company (2020, p. 116). Per Fernandez-Villaverde et al., this period of imposed sanctions mirrors an increase in the instances of dark shipping (ie. Obfuscation of shipping vessel location data with the aim of concealing true shipment origin-destination pairs), with China being one of the primary beneficiaries of this phenomenon (2025). When Venezuelan oil production reached its low point in 2020, production that year was around 20% of production levels prior to Nicolás Maduro assuming office. While some sanctions have been lifted as of this year, the sanction events included in our model are in place through the end of our study period.

New Pipeline Construction

When dealing specifically with the Canadian oil export market, we wished to include the effect of new pipeline construction, as pipelines constitute a significant portion of Canada's oil-related infrastructure. So important are pipelines to the Canadian oil industry, that the lack of capacity within current pipelines constitutes a significant production constraint to Canadian oil. Pipelines are a significant portion of the oil supply chain, but other portions of the supply chain can also cause capacity constraints. Borenstein & Kellogg examined the increase in oil produced in the early 2010s in Alberta and North Dakota and found that while the amount of oil produced exceeded the capacity of pipelines to transport it to market, causing the WTI benchmark price at Cushing to decline substantially compared to world crude oil prices, constraints in local refining capacity meant that this excess supply of crude oil did not result in lower gasoline prices in the American Midwest (2012). In particular, they found that despite crude oil transport to the Gulf Coast being capacity constrained, the Midwest was a net importer of refined oil products (2012, p. 17). Indeed, the interaction between supply and demand and the pricing mechanism in oil markets is complicated compared to other markets. McRae noted that oil production in excess of pipeline capacity causes the price of oil to become discounted compared to benchmark prices, due to the additional transportation costs, and estimates this discount to be approximately $6-$11 per barrel in an analysis of Permian Basin oil production (2017, p. 15). Discounts due to lack of pipeline capacity are not the only factor influencing oil prices. Particularly relevant to Canadian oil production is the influence of API gravity on pipeline capacity. According to Genscape (2015, as cited in McRae, 2017, p. 13), a lowering of API gravity by 5 (from 40 to 35 as cited) causes a 3% decline in pipeline throughput. Owing to this, Canada's significant stock of heavy crude oil would require even more pipeline capacity to move the same amount of product as lighter crude oil would require. Pipelines included in our modeling include Enbridge pipelines that came online during our study period, including the Line 3, Line 6, Express, and Alberta Clipper pipelines, as well as the Keystone pipeline (including the initial segment to Cushing as well as the extension to Port Arthur), and the Trans-Mountain pipeline. In each case, the pipeline coming online is treated as a permanent shift, as opposed to the limited time period for our other event scenarios.

Miscellaneous Event Scenarios

In addition to the above geopolitical events and pipeline scenarios, we also included a number of other events to allow for a fuller picture within our modeling. Another geopolitical event included was the beginning of the Iraq War. Unlike the other geopolitical events, there was only a very limited interruption in oil production amounting to around 6 months after the initial invasion of Iraq, as restoring activities within the Iraqi oil sector was a priority. After the invasion in March 2003, oil production halted through the month of April and slowly resumed over the subsequent months, with September 2003 being the first month with production numbers exceeding March 2003 (U.S. Energy Information Administration, 2003, p. 148).

We also included a number of localized disruptions in the list of event scenarios. A key event that also impacted the Venezuelan oil sector was the Venezuelan General Strike that occurred in 2002-2003. The strike, which lasted for 63 days (Fletcher, 2003), came about on the heels of a coup attempt several months earlier, and resulted in oil production dropping to approximately 20% of pre-strike levels, with production recovering by April 2003 (U.S. Energy Information Administration, 2003, p. 148). A key localized event that occurred within Canada were the Fort McMurray wildfires that occurred in May-June 2016. It is estimated that up to 1 million barrels per day of production was shuttered during the course of the fires, which was restored during the following months (Healing, 2016). One last localized event we included was Hurricane Katrina's impact on the Louisiana coast, which impacted offshore oil production for a short period in Summer 2005. At the time, Gulf Coast offshore oil production accounted for 1.5 million barrels per day, nearly all of which was brought offline as a result of the hurricane. Furthermore, 1.9 million barrels per day of oil refining capacity was shuttered due to the hurricane (U.S. Energy Information Administration, 2005, p. 1). While the hurricane had significant general effects, oil production resumed shortly after the storm and recovered within a few months.

We also included a handful of contemporary events, one of which was the impacts of the COVID shutdowns in 2020, which we included for significant oil consumers and heavy crude producers in our model. We used a shutdown period of 6 months for each consumer country, which in all countries except China began in March 2020, and in China began in February 2020. For heavy crude producer countries, we used a shutdown period of 3 and 4 months for Canada and Venezuela respectively, with the shutdowns beginning in April 2020 in both countries. Aside from the shutdowns, we also included as a sanction event the imposition of a price cap on Russian oil by the G7 countries, which occurred in December 2022 following Russia's invasion of Ukraine. The imposition of the price cap, meant to impose penalties on Russia while mitigating negative effects on oil consumers during a time when oil prices were highly elevated, did have a corresponding decrease in oil production in Russia; however, with world oil prices also decreasing over this period, it's unclear how much of the decline can be attributed to the price cap.

5. Solution Overview

To address the research questions associated with this project, we started with a literature review to get up to date on industry concepts and terminology. Through this literature review, we gained familiarity with different oil gravities, the American Petroleum Institute (API)'s standard measure of gravity, the difference between light, medium, and heavy crude, difficulties of extracting and refining heavy crude, specifics about Canada's oil trade partners, and details about the Canadian oil industries' connection and dependence with the United States.

Following this, the first challenge was constructing a time series of heavy crude production to forecast. Heavy crude production numbers are not readily available in published literature, so assumptions were created to estimate what percentage of a country's oil production was heavy crude. Since time did not allow the examination of every country's oil industry, we selected 18 countries that represent the large majority of global oil production. Then, through reading government reports and news articles on oil production, trade, and reserves, we estimated what percent of a country’s oil production was heavy crude. This method allowed us to estimate heavy crude production for the selected 18 countries from 1973 to 2026.

Another important component of our solution was researching historical events that impacted oil production and consumption, such as regional conflicts. Research on the duration of these events allowed us to use statistical models to calculate the impact of the event on the overall oil production of the effected countries and predict the impact of such an event in the future.

Heavy oil consumption was another part of the project that required a unique solution. As consumption at different levels of API gravity is generally not published anywhere, we had to use a proxy. In the case of heavy crude, the most direct proxy is believed to be residual fuel, with the most common application being marine fuel.

To further examine the research questions posed, we utilized the statistical models ARIMAX, SARIMAX, and the machine learning forecasting model Prophet. Training and test sets were created, with the test set comprised of the final year of historical data and the rest of the historical data making up the training set. Each model was run, where appropriate, and a single model with the lowest error was selected. This model was used to predict future production and consumption of heavy crude for each country included in our research. From this forecast, we could illustrate the impact of geopolitical events on future oil production and consumption. Taking this analysis one step further, we then compared the production and consumption to determine if there would be an excess or shortage of heavy crude, depending on the event. We then compared this excess or shortage to Canada's existing trade partners to determine if this event represents a strategic opportunity or risk to Canada's oil industry.

The results of our analysis will be presented in the form of a Power BI dashboard. This dashboard will include a selection of curated interactive visualizations that answer the research questions posed.

6. Design Decisions

Throughout the project, we were required to make key decisions on the design and implementation of our solution at various points along the data pipeline. Regarding our overall data infrastructure, we decided to make use of Databricks, due to its flexibility in data warehousing and creating a data lake should it be required in the future (even though we ultimately did not need this capacity up to this point). Additionally, we used a medallion architecture, separating our data into Bronze (unprocessed), Silver (cleaned and model-ready), and Gold (business-ready) data.

For data ingestion, we primarily used APIs to allow for continued ingestion of data after our work on this project concludes. We did face an issue where one of our data sources could not be easily automated due to being behind an email sign-up wall. We did consider a web browsing automation solution but ultimately decided that since the data we were seeking to use from that source could be found from one of our other sources, we would just omit that data source completely.

For data cleaning and modeling, our data required minimal cleaning, and we performed what cleaning it did require using Python code. When creating our models, we used time series modeling, also with seasonal effects, to incorporate the fullest patterns possible for an industry that customarily has significant seasonal variation. Additionally, some input variables for our models needed manual imputation from the team, which we accomplished collaboratively using Google Sheets and linking them to our codebase in Databricks.

For data visualization, we considered using Databricks' built-in dashboard, but since we would have its functionality limited based on using the free edition, we decided to use Power BI to create our dashboard, which we were able to do easily by linking to our data sources in Databricks. Our dashboard includes the basic functionality we had intended to include (ie. Displaying projections based on models for a particular event scenario). Due to time and technical limitations, we were unable to incorporate more complex modeling, such as compounding effects for multiple event scenarios. As noted below, this functionality could potentially be implemented during future work.

7. Changes From Original Plan

Overall, the project has stayed within the scope of the project proposal. There have been some alterations to our project approach and from our initial design approach. For example, we initially envisioned a completely automated data pipeline using multiple sources. After one of our sources proved problematic to automate, after learning that particular source updates very infrequently, we considered leaving that source as a manual part of the pipeline. However, upon realizing that source includes data that is also covered by other sources, we ultimately decided to eliminate that source completely. We were able to find another source that had nearly identical data that we could access with an automated procedure to fully automate the modeling pipeline.

While the project has stayed within the scope of the project proposal, we have faced time and technical constraints in completing the entirety of the project as it was proposed. To that extent, there will be numerous areas where further work is possible to refine our model and index. Such areas include the collection of more and better data, refining key assumptions, more forecasting granularity, introducing commodities as external variables, and testing different approaches to modeling the data.

8. Summary of Key Findings

All of our key findings below have been made with the assistance of our visualization dashboard and our previous research findings. We have included images of key visualizations in the Appendix with textual references to easily illustrate our points.

1. How has the global crude oil mix by API gravity changed over time (1970 – present)?

We have found that total crude oil production has increased over time, and of that, heavy crude oil production has increased at a slower rate than total crude oil production, indicating that recent oil production has a greater proportion of light crude oil. Our forecast to 2030 indicates that this trend will continue. See Figure 1 for our relevant visualization.

2. Which countries produce and consume heavy vs. light crude oil, and how has this changed across historical disruptions?

On the production side, we find that Canada is the single largest producer of heavy crude oil, accounting for a majority of heavy crude oil production that has been increasing over time, as seen in Figure 2. We also find that Iraq is the second largest producer of heavy crude oil, while Venezuela is only the third largest producer of heavy crude oil, and its production numbers decreased substantially from 2016 to 2020, with only a small rebound in the years after.

On the consumption side, we find that the three largest consumers of heavy crude oil are the United States, Singapore, and China, and those countries have swapped positions over time, as seen in Figure 3. Generally, the United States has been the largest consumer of heavy crude oil during most years, with China being the largest consumer during 2020 and second largest in 2019 and from 2021 to 2023, and Singapore being the second largest consumer prior to 2019 and since 2024. Rounding out the top 5 are Saudi Arabia and Japan, with Japan holding the number 4 spot until 2024.

3. How concentrated is global heavy crude production, and what systemic risks arise from sanctions or production constraints?

Following up from our previous question, we recall that heavy crude oil production is disproportionately concentrated in Canada, with Iraq producing a smaller proportion, and Venezuela producing an even smaller but historically higher proportion, as can be seen in Figure 2. In total, those three countries produce over 85% of the world's heavy crude oil. Given that our previous research has established that Canada has constraints on shipping that limit potential oil production, and that Venezuela has been under a sanction regime for the last decade that has contributed to unprecedented drops in production, we can conclude that sanctions and production constraints present substantial risk to heavy crude oil production.

4. Which countries are structurally dependent on heavy crude for marine fuel production, and what are their historic sourcing patterns?

This question can be answered by looking at the net balance between production and consumption for our focus countries, as seen in Figure 4. We find that 5 of our focus countries have a negative net balance, indicating they consume more heavy crude oil than they produce. Of these, 3 countries have significantly negative net balances, those being Singapore, Japan, and the United Arab Emirates. Through our research, we have found that Singapore and Japan especially have significant marine shipping industries and thus have comparatively high demand for marine fuel. This is compounded by Singapore's use as a bunkering hub and is likely the reason why Singapore's heavy oil consumption is so high given its relatively low population. Singapore's oil is sourced largely from the Middle East, but also from other countries including Russia and Brazil (Dingwall, 2026), while Japan's oil is sourced almost entirely from the Middle East (Golubkova, 2026).

5. What strategic role could Canada play in mitigating future heavy crude shortages?

To answer this final question, we can look at Canada's existing heavy crude trade relationships, as seen in Figure 5. We can see that Canada exports heavy crude oil to most countries and only imports a negligible amount primarily from Ecuador. Of the countries to which Canada exports heavy crude oil, the vast majority of exports, 88%, go to the United States, with the next highest proportion, 9%, going to China. In total, only 3% of Canada's heavy crude oil goes to countries other than the United States or China. Given that there are other countries that have demonstrated demand for heavy crude oil, such as the above-mentioned Japan and Singapore, it would be a strategic opportunity for Canada to strengthen its trade relationships with these countries and other countries and develop its oil production infrastructure to allow for increased heavy crude oil trade. This especially holds true given that Canada's oil trade with Singapore is currently negligible and with Japan is practically non-existent.

9. Conclusion

In this project, we have created an analytical and predictive pipeline to model risk around the supply of heavy crude oil. Informed by background geopolitical research, we have incorporated numerous event scenarios that have the potential to affect, positively or negatively, the supply and/or demand of heavy crude oil. Further, we have created visualizations to illustrate key findings from our analysis. Our pipeline and codebase are in a state where additional work could further develop the pipeline and create more robust modeling results.

After concluding our project, we developed some key findings that could be used to inform policy decisions. Among those key findings are that Canada's oil industry remains the strongest worldwide source of heavy crude oil, especially given that world oil production has shifted towards light crude oil in recent years, with this being underlined by the other large heavy crude producer, Venezuela, having significantly diminished production numbers compared to a decade prior. Consumers of heavy crude oil include heavy consumers of oil generally, such as the United States and China, but also countries like Singapore and Japan that have significant demand for marine fuels that heavy crude oil is especially suitable for fulfilling. Finally, despite this strategic opportunity, Canada's current heavy crude trade is almost exclusively with the large general oil consumers, China and especially the United States, with infrastructure constraints maintaining the status quo. Canada has the opportunity to diversify its oil trade, which could help bolster the Canadian oil sector during an oil disruption; it, however, needs to further develop its oil infrastructure to allow for exports to new markets.

10. Appendix

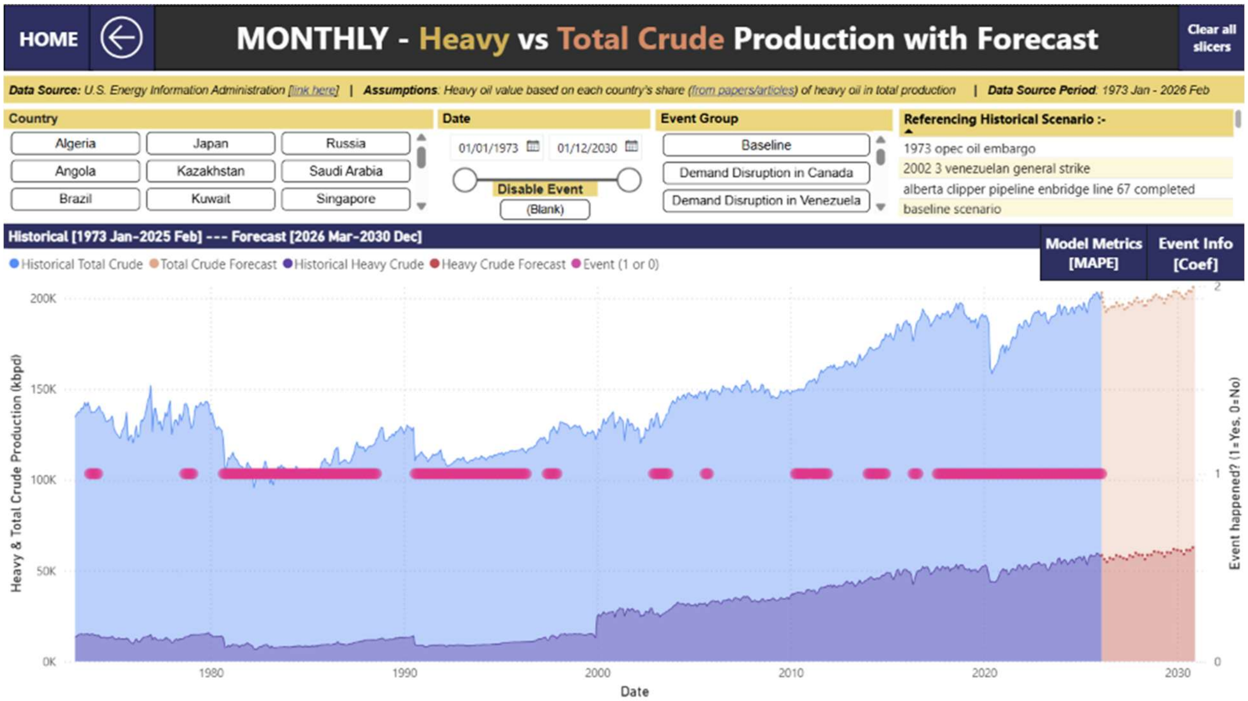

Figure 1: Visualization of Heavy vs. Total Crude Oil production by year with forecast.

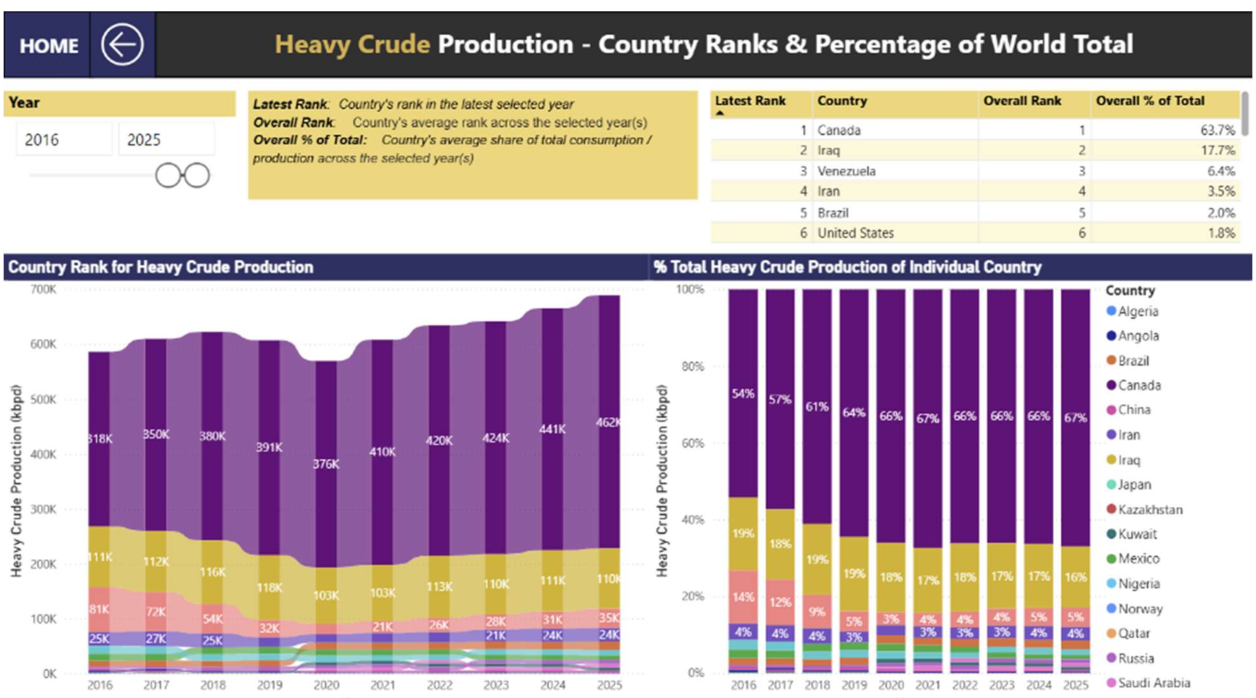

Figure 2: Visualization of Heavy Crude Oil production by top producing countries.

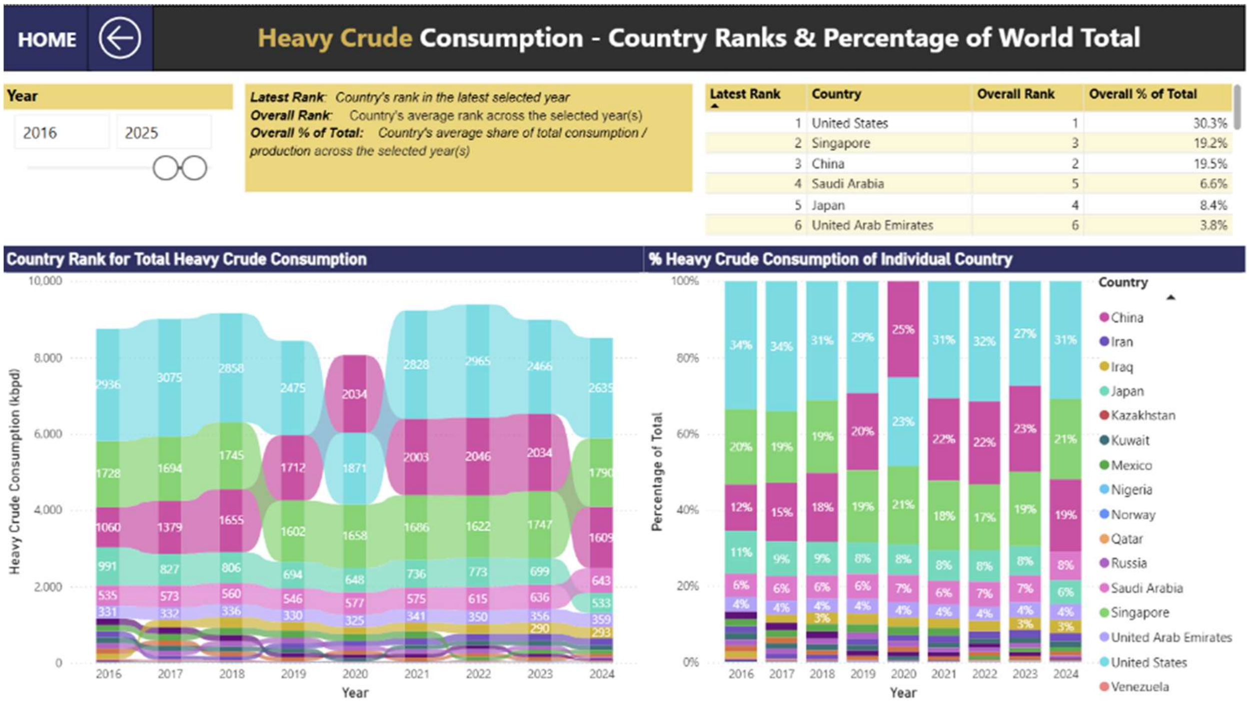

Figure 3: Visualization of Heavy Crude Oil consumption by top consuming countries.

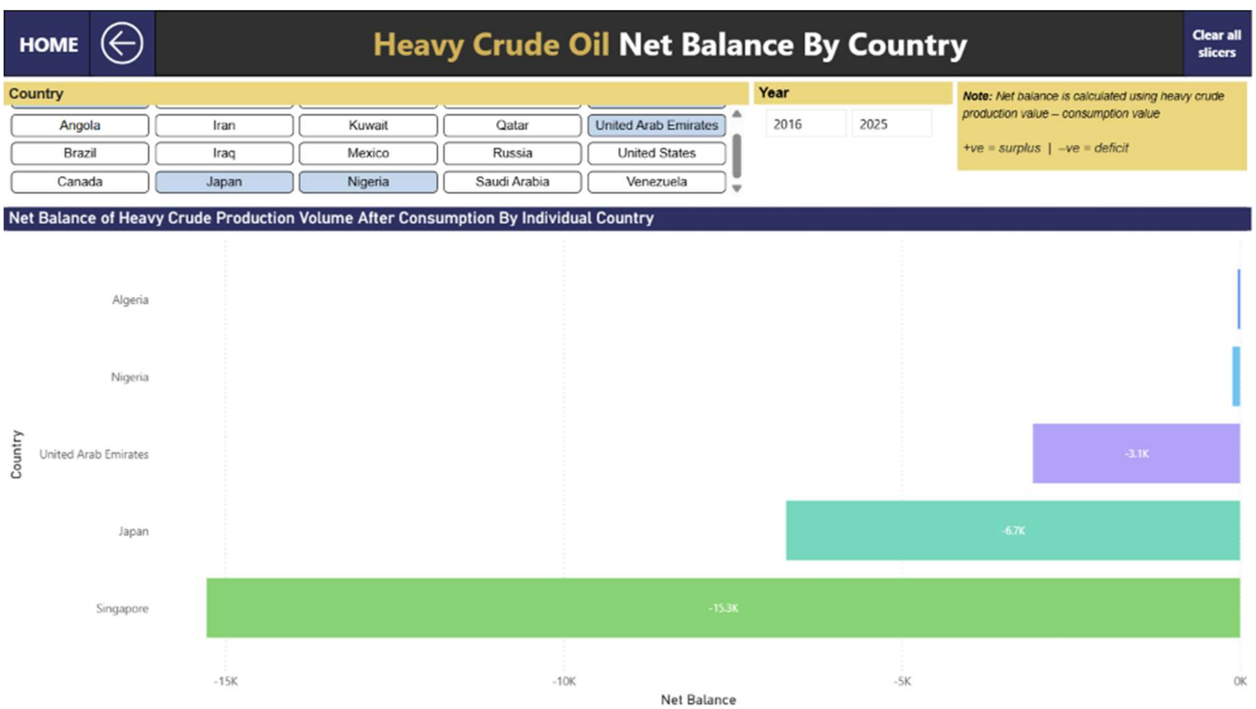

Figure 4: Visualization of countries with a negative Net Balance between production and consumption.

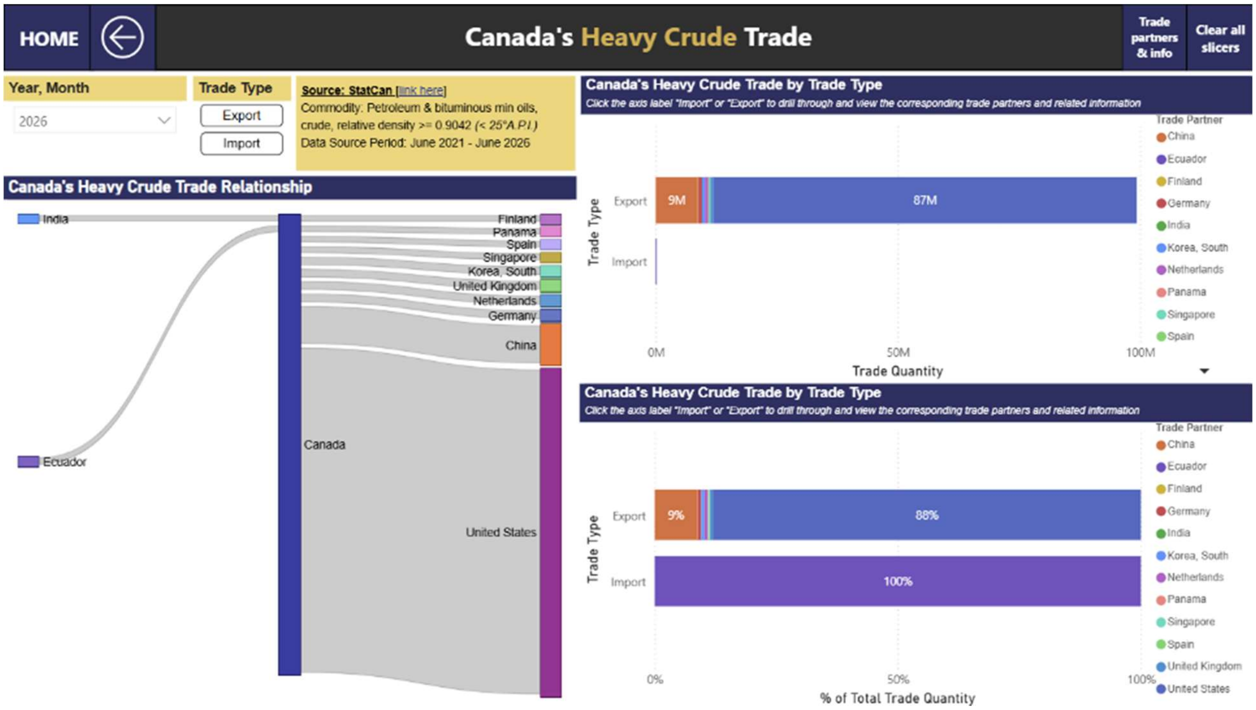

Figure 5: Visualization of Canada's Heavy Crude Oil trade relationships.

11. References

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