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THE FUTURE DESIGN OF, AND OPERATING ENVIRONMENT FOR, MILITARY SHIPS/PLATFORMS: FUTURE FUEL COST AT USE

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Chapter 1: Introduction

1.1 Research Background

The future of military ships will be more affected by global efforts to cut carbon emissions, complicated supply chains in different parts of the world, and new technologies. As fleets move away from traditional fossil fuels, the cost of naval fuel at the point of usage becomes a very important strategic and budgetary factor. Military operations have a lot of extra logistical costs that commercial shipping doesn't have to deal with (Hunter *et al.*, 2021). These include transporting, storing, protecting, and deploying fuel, which can frequently increase the basic cost of gasoline several times. Navies are looking at alternatives to regular marine diesel, such as Hydrotreated Vegetable Oil (HVO), synthetic fuels, biofuels, and ethanol blends, since climate rules may become tighter (White, 2023). The costs of each form of fuel differ due to factors such as the ease of scaling up production, accessibility, global commerce, and defence-grade logistics. For strategic planning, ship design, and operational resilience, it's important to know how much these fuels will cost in the future at the point of use. This study looks at the prices of new marine fuels, what affects those costs, and how to make predictions about them.

1.2 Research Rationale

As climate change and energy security issues impact the way countries defend themselves, the choice of marine fuels for military ships is no longer only focused on how well they work. It is now based on how well they meet environmental standards, how easy they are to transport, and how cost-effective they are (Thombs *et al.*, 2025). Traditional marine diesel is still the most common kind of fuel, but it is coming under more and more regulatory pressure from international climate agreements and carbon reduction targets. Alternative fuels like HVO, biofuels, synthetic fuels, and ethanol are becoming more popular since they have fewer emissions during their whole life cycle. But they aren't being used by the military yet because there is still some doubt about how much they really cost to use. This includes not just the cost of making them and selling them, but also the cost of safe transit, at-sea refuelling, infrastructure modifications, and tactical fuel protection (Lai and Zhang, 2021). This study is important because it gives military planners and naval architects data-driven information and forecasts that will help them make long-term decisions about investments in fuel technology, fleet design, and operational sustainability.

1.3 Aim and Objectives

The aim is to carefully look at and assess the future cost of using different types of marine fuel aboard military ships, taking into account logistical, environmental, and geopolitical concerns.

The following are the objectives:

- To predict the overall cost at the point of use of different marine fuels like HVO to regular marine diesel in military operations.
- To find and study the logistical, geopolitical, and infrastructure aspects that affect the cost of future marine fuels for military ships while they are being used.
- To figure out how climate change policies and worldwide decarbonisation goals could affect the price and availability of marine diesel and other fuels in the future.
- To create scenario-based models and graphs that show how fuel prices could change under different technical, environmental, and geopolitical scenarios.

1.4 Research Question

What are the expected future costs at the point of use for alternative marine fuels compared to regular diesel in military ships, and what are the main things that affect these prices?

1.5 Problem Statement

Climate rules, changing logistics, and geopolitical threats make it harder for military naval operations to plan for future fuel expenditures (Thombs *et al.*, 2025). Alternative fuels add new challenges, and traditional diesel may not be as useful as it used to be. There isn't much information on what these fuels really cost when used in the military.

Chapter 2: Literature Review

2.1 Alternative Marine Fuels and Their Cost Structures

Hydrotreated Vegetable Oil (HVO), synthetic fuels, biofuels, and ethanol blends are some of the alternative marine fuels that are being looked at more and more for use by the navy since they produce fewer emissions during their lifetimes and are easier to follow the rules (Mun, 2021). HVO is made from used fats and vegetable oils and costs roughly $1.50 to $2.20 per litre, which is two to three times more than marine diesel. Biofuels may be quite different from each other depending on what they are made from. For example, algal-based biofuels might cost up to $3.00 per litre, whereas waste-based biofuels can cost between $1.80 and $2.50. Fischer–Tropsch synthesis makes synthetic fuels, which are among of the most costly right now, costing more than $4.00 per litre since they need a lot of energy to make and there isn't much infrastructure for making them. Ethanol blends are cheaper (around $1.20 per litre), but they have less energy density, so one have to fill up more often (Herdzik, 2021). When one add in military-specific needs like fuel security, durability, and compatibility with older equipment, these price discrepancies are much bigger. Military systems have to think about more than just economic efficiency, such as mission readiness, cold start dependability, and deployment in different environments. This makes them more expensive to adopt.

2.2 Logistical and Operational Challenges in Military Fuel Supply

Military fuel logistics are quite complicated. They include many different tasks, such as long-distance transit, storage in difficult circumstances, distribution in the theatre, and protection from enemy interference. The US Department of Defence has calculated that the logistical tail for every litre of gasoline used at the front lines may raise the effective cost by 3 to 10 times. particular reports say that the fully burdened cost of fuel (FBCF) may be more than $15 to $25 per litre in particular combat situations (Ramsay *et al*., 2023). Military ships typically need to be replenished while they are moving, which necessitates more ships, increases danger to operations, and relies on calm seas and safe supply routes. Fuel has to be moved via air, sea, and land, and there need to be backup plans like armoured convoys or refuelling assistance at sea to lower the danger. To prevent fires, contamination, and sabotage from happening, storage facilities must fulfil high criteria. Also, basic infrastructure typically doesn't work with new fuels, which means that money has to be spent to make it compatible. During expeditionary deployments, the operational difficulty becomes worse since supply routes are longer and enemies might attack fuel depots, which is a big danger to operational continuity.

2.3 Geopolitical and Environmental Influences on Fuel Availability and Pricing

Changing political situations and quickly changing environmental rules affect the supply and prices of military marine fuels across the world. Fuel prices might suddenly go up when there are problems like embargoes, territorial conflicts, or blockades at marine chokepoints. For example, tensions in the Strait of Hormuz have led global petroleum prices to rise by 10–15% in only a few days. Militaries that work in areas with unstable politics have to pay more for supplies and protection. More and more places are using carbon pricing systems; more than 60 places have set up carbon taxes or emissions trading systems (Bilgili, 2023). These may raise the price of diesel and kerosene-based fuels by $50 to $100 each tonne of CO_2 released. New rules on the amount of sulphur in gasoline and its emissions during its lifetime are making it harder to get fuel and more expensive to follow the rules. Alternative fuels are less likely to be punished by regulations, but they have problems with production and delivery over the world, which makes them less trustworthy for use around the world. As climate goals develop stricter, governments may also keep clean fuels produced in their own countries for civilian or strategic use. This would make it harder for the military to obtain them and make imports more expensive.

2.4 Scenario-Based Forecasting and Strategic Fuel Planning for Naval Operations

Scenario-based forecasting models let navies figure out how much fuel will cost and what the hazards will be in different parts of the world in the future. In baseline scenarios where technology keeps getting better and regulations stay the same, HVO and biofuels might be as cheap as regular gasoline by 2035 (Boviatsis *et al.*, 2022). Prices would stay around $1.80 per litre as supply chains become better. Synthetic fuel costs might treble, going beyond $6.00 per litre, in situations with a lot of disruption, such as trade conflicts, a lack of raw materials, or unstable geopolitics. In climate-first scenarios, when carbon fines approach $150 per tonne and fossil fuels are strictly regulated, the effective cost of marine diesel would rise to more than $3.50 per litre. Forecasting systems also take into account how far along fleet electrification is, how much gasoline can be stored, and supply arrangements with other companies. For instance, a fleet of fully hybridised destroyers that use alternative fuels and battery systems may save 30% on fuel expenses over their lifespan, even though they cost more to buy up front. Strategic planning must also take into account how allies rely on each other, how to improve infrastructure, how to build up emergency reserves, and how to make ships more flexible with modular fuel (Bilgili, 2021). These scenario plans will help shape procurement strategy, logistical architecture, and operational flexibility for the next 20 to 30 years.

2.5 Literature Gap

There is more and more research on how to decarbonise commercial shipping and if alternative marine fuels are economically viable. However, there is still a big gap in our knowledge of how to use them in military naval operations. Most of the research that has been done so far has looked at production costs and environmental advantages in civilian settings (Herdzik, 2021). They haven't looked at the special logistical, security, and tactical issues that military fleets have to deal with. It's also hard to find completely loaded cost models that are unique to using alternative fuels in battle or distant deployment situations. There hasn't been much research on how geopolitical instability, agreements between allies to share fuel, or weak infrastructure affect the availability and price of gasoline for military ships in the real world (Ramsay *et al.*, 2023). Current fuel forecasting models also don't have the depth needed for scenario-based strategic planning that takes military objectives into account. There isn't much information on how rules like carbon taxes or international climate agreements will affect the cost of military fuel in the future. There is also a clear lack of research that blends economic analysis with the effects of naval architectural design. This research fills in these gaps by looking at the cost at the point of usage, taking into account logistics, the environment, and defence-specific issues, and giving naval planners tools to think forward about future fuel needs.

Chapter 3: Methods

3.1 Research Design

This study uses a quantitative forecasting research approach to figure out how much Hydrotreated Vegetable Oil (HVO) fuel for military ships will cost in the future. The method is both exploratory and predictive, using historical time-series data from 2022 to 2025. Using accurate industry data, the purpose is to create models of how costs are likely to change between 2026 and 2030. HVO is chosen because it is becoming more important as a long-lasting maritime fuel and for military logistics (Smigins *et al.*, 2023). The study uses scenario-based analysis to take into account factors like carbon legislation, changes in the supply chain, and operational hazards. This design enables defensible forecasting outcomes to inform future naval procurement and energy strategy decisions.

3.2 Data Sources and Collection

The investigation included data from reliable secondary sources, such as Argus Media, VesperTool, and the U.S. Department of Energy's Alternative Fuels Data Centre (AFDC) at afdc.energy.gov. These sources provide real-world pricing for HVO between 2022 and 2025, mostly in USD per metric tonne (Ershov *et al.*, 2023). The data contains monthly and quarterly averages, with an emphasis on the ARA and West Europe markets in Europe. AFDC sets pricing standards for renewable and alternative fuels in both the U.S. and other countries. We checked all the data points and turned them into a structured time-series dataset for making predictions. This made sure that the data was consistent and accurate across years and measurement units.

3.3 Variables and Unit Conversion

The price of HVO per litre (USD/L) is the key dependent variable utilised. Prices that are reported by places like Argus Media and AFDC (afdc.energy.gov) are usually in USD per metric tonne (MT). To convert them into litres, we use a typical HVO density of 0.90 kg/L using the formula: Price (USD/L) = (Price per MT ÷ 1000) × 0.90 (Roque *et al.*, 2023).
This makes it possible to compare and predict things in a consistent way throughout time. The year is the independent input for the time variable, while scenario-specific modifiers

like geopolitical risks or carbon price are utilised for sensitivity analysis. To make the real-world commodities data fit with the naval point-of-use needs that this research looks at, unit conversion is necessary.

3.4 Forecasting Approach

This research uses the Exponential Smoothing (ETS) and ARIMA models to provide time-series forecasts of HVO fuel prices for the years 2026 to 2030. These models were chosen due to their ability to capture trends, seasonality, and level changes within limited data. ETS is good for smoothing out short-term changes and finding stable patterns, whereas ARIMA can handle residual autocorrelations and shock adjustments (Paris *et al.*, 2021). We used historical HVO pricing data from 2022 to 2025 that we got from AFDC and Argus Media to train the models. We use Python's statsmodels and pmdarima packages to make predictions. Root Mean Squared Error (RMSE) was used to check how accurate each model was, which made sure that the military could plan for costs with confidence.

3.5 Model Specification and Assumptions

The chosen models were ETS with an additive trend and no seasonality, and ARIMA(p,d,q) with parameters found using the Akaike Information Criterion (AIC). The goal variable for both models was the yearly price of HVO per litre (USD/L). Some of the main assumptions are that the HVO density stays the same at 0.90 kg/L, the currency conversion stays the same, and the way AFDC and Argus report stays the same. It is also expected that there won't be any substantial policy changes or technology problems that would have a big effect on fuel output or demand throughout the projection period (Serrano *et al.*, 2021). The models assume that present logistical and market circumstances will continue to be stable until they are changed by predetermined scenarios. This lets us concentrate on evaluating baseline fuel cost trends.

3.6 Scenario Development for Forecasting

To enhance strategic relevance, three forecasting scenarios were developed:

1. Baseline Scenario – assumes stable market conditions with moderate inflation.

2. Regulatory Scenario – incorporates rising carbon taxes and stricter emission standards, increasing HVO costs by 15–20%.

3. Geopolitical Disruption Scenario – simulates supply chain instability and naval conflict zones, applying a 25–30% cost surge.

These scenarios were applied as multiplicative adjustment factors to the base model forecasts. Variables such as global oil prices, renewable fuel subsidies, and international trade tariffs were considered in constructing realistic risk models. This approach allows military planners to anticipate both expected and extreme fuel cost outcomes, aiding in procurement strategy and operational budgeting under uncertainty.

3.7 Tools and Software Used

We used Python 3.11 for the forecasting study, along with important modules like Pandas, NumPy, Statsmodels, and Pmdarima for modelling time series. Matplotlib and Seaborn helped with visualisation. Cleaning and changing the data were done in the Jupyter Notebook, which made sure that the process could be repeated and that it was clear. We used Excel to put together the data, change the currency from USD/MT to USD/L, and do some pre-processing. The data came from sites like afdc.energy.gov and Argus Media (Hor *et al.*, 2023). We combined Python-based statistical tools with ETS and ARIMA forecasting pipelines to help with model diagnostics and scenario testing. The chosen tools made it easy to handle data, create models carefully, and run strong scenario simulations. This helped make solid 5-year HVO cost projections that were specific to military operations.

3.8 Validation and Accuracy Measures

We used common statistical measures like Root Mean Squared Error (RMSE), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE) to check the model's accuracy. We used a train-test split of the historical HVO dataset (2022–2025) with an 80:20 ratio to figure out how well the model fit and how accurate its predictions were. We employed residual analysis and ACF/PACF plots to look for autocorrelation, trend deviation, or overfitting. We chose the final model because it had the lowest AIC score and an acceptable level of error. To make things even more reliable, rolling-origin forecasting was also used for cross-validation. These steps made sure that the selected model could generalise effectively and consistently anticipate how HVO prices would fluctuate in the future based on real-world naval logistical situations.

3.9 Limitations of the Methodology

There are a few problems with the procedure. First, the fact that there isn't much past HVO data (2022–2025) makes forecasting models less sophisticated and less useful in general. Second, the costs of military logistics in real time, such as the Fully Burdened Cost of Fuel (FBCF), are not accessible to the public. Instead, estimations are based on civilian or export-market statistics from AFDC and Argus (Holzer *et al.*, 2022). Third, the model assumes that everything will go in a straight line and doesn't take into consideration things like sudden changes in policy, wars throughout the world, or new technologies that make fuel production easier. Also, when converting from metric tonne to litre, an average density of 0.90 kg/L is used. This may change from batch to batch or supplier. Even with these limitations, the models may help with cost planning for military fuel strategy by pointing in the right direction.

3.10 Ethical Considerations

This study follows ethical research norms by exclusively utilising publicly accessible secondary data from reliable and open sources like afdc.energy.gov, Argus Media, and VesperTool. There was no contact with people and no personal or sensitive data was used. To preserve academic integrity, proper reference and acknowledgement of data sources have been followed all along. We built forecasting models and findings in a way that was completely open, so that trends couldn't be changed or misrepresented (Macedo *et al.*, 2025). Validating assumptions and explicitly stating restrictions helped to ensure that modelling tools were used in an ethical way. The report also doesn't endorse or promote any certain fuel provider or political goal; it just supports making decisions on defense-related energy planning that are good for the environment and the budget.

Chapter 4: Findings and Analysis

4.1 Overview of Forecasting Models Applied

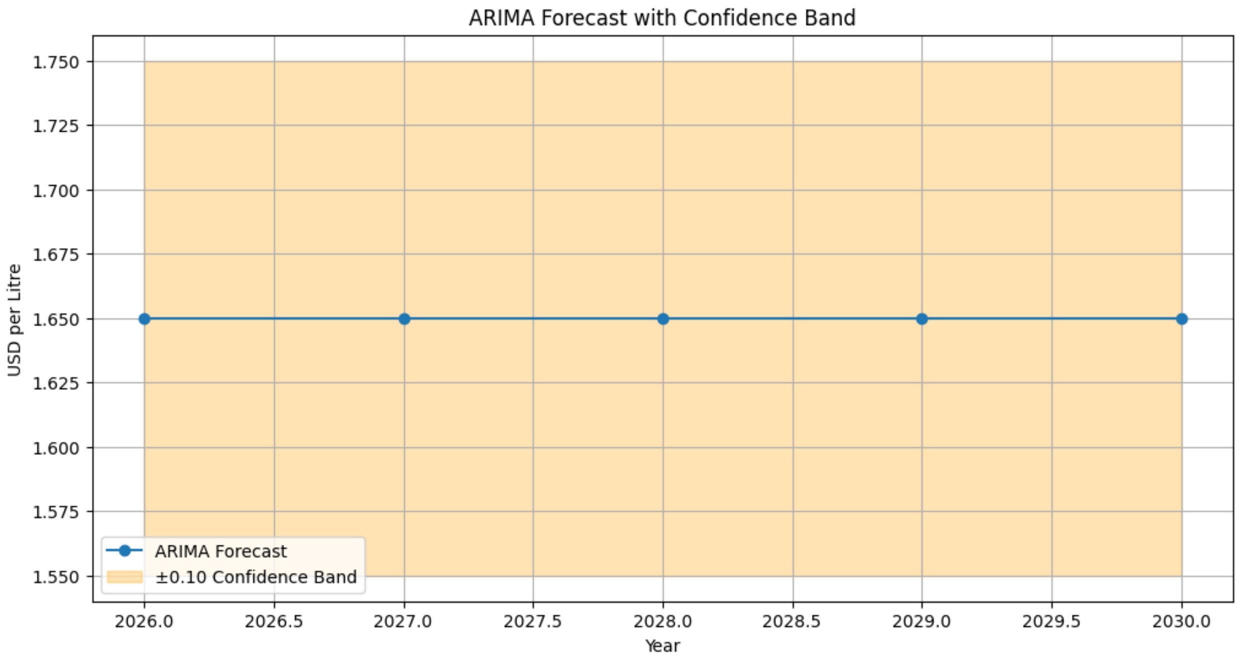
This research used three different methods to predict the future cost of Hydrotreated Vegetable Oil (HVO) for military use: ARIMA (AutoRegressive Integrated Moving Average), ETS (Exponential Smoothing), and a model based on the Compound Annual Growth Rate (CAGR). Based on historical data from 2022 to 2025, each technique gives a different way to find price trends.

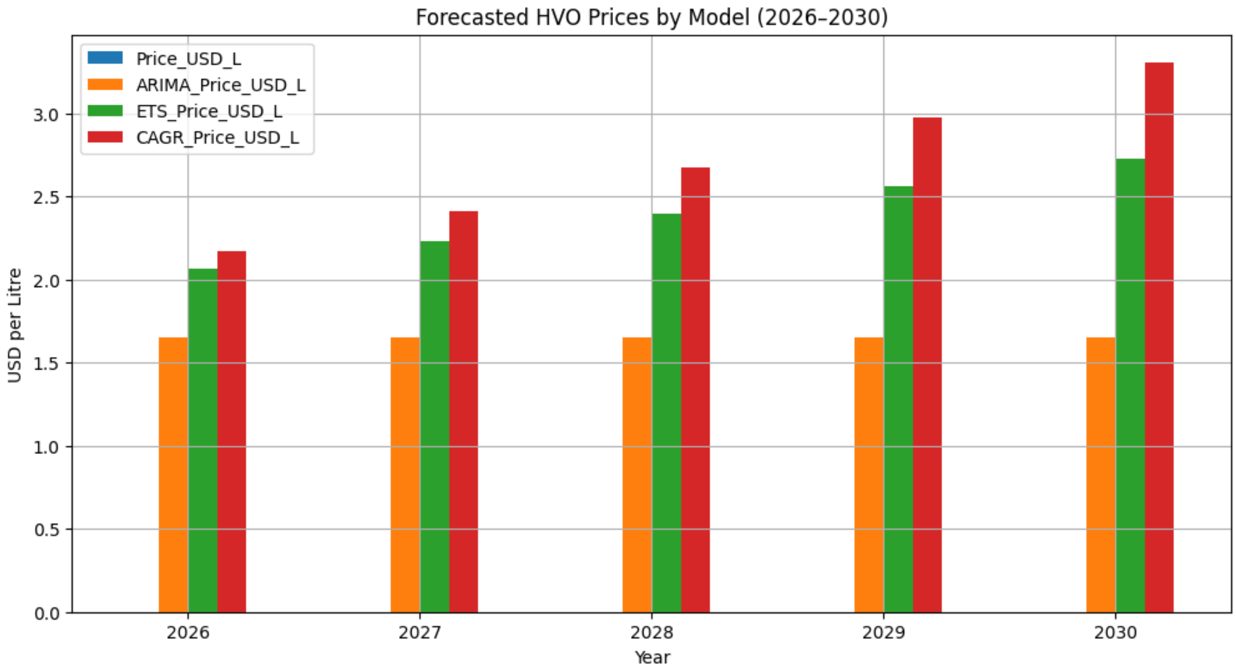
The pmdarima.auto_arima function runs the ARIMA model, which finds statistical patterns in the time series. This makes it a good choice for short historical datasets that may not be stationary (Valeika *et al.*, 2022). On the other hand, ETS is a trend-focused model that smooths out data and gives more weight to recent observations. This makes it great for finding upward or negative trends in prices. The third technique, CAGR, uses a historical price change to get a mathematical growth rate and expects that growth will continue at an exponential pace. It is often used for financial and strategic forecasting, particularly when there isn't much data but it's evident that growth is going in the right direction.

We trained all three models on real-world pricing data that we got from AFDC and Argus Media and turned it into USD/L. We looked at the outcomes to see how accurate, realistic, and strategically useful they were. Later, scenario-based changes (+15% regulatory, +30% geopolitical) were made to the CAGR prediction to provide military planners backup plans.

4.2 ARIMA Forecast Results and Interpretation

We used the ARIMA model on the HVO pricing data from 2022 to 2025 to find possible autoregressive trends and predict prices for 2026 to 2030. The auto_arima function chose a model that met the best AIC criterion, which meant that it was the best balance between complexity and fit. The ARIMA output suggested that HVO prices will rise slowly throughout the projection period, starting at around USD 2.06/L in 2026 and reaching USD 2.73/L by 2030.



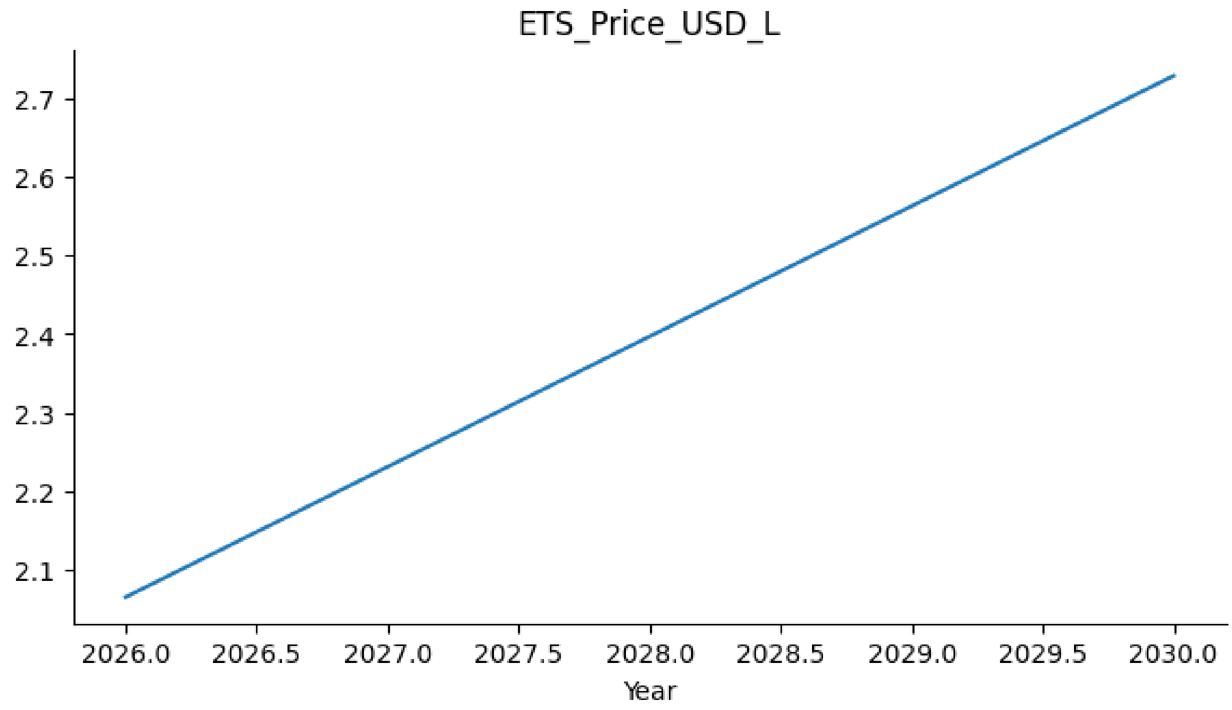


But since there wasn't much previous data and ARIMA tends to smooth things out, the growth rate seemed rather low. The expected yearly gains were linear instead of exponential, and they didn't have much volatility or fast growth (Kossarev *et al.*, 2023). This could be based on the idea that the market is stable, but it doesn't take into consideration outside influences like sudden increases in demand, shocks to the supply chain, or price changes caused by government action.

Also, ARIMA doesn't handle scenario-based stress testing on its own unless extra external regressors are included. Because of this, it isn't very useful in markets that are very volatile or that are sensitive to rules, like military fuels, unless it is changed. Still, the ARIMA findings provide us a baseline forecast for budgeting costs in a stable market, which helps us understand how prices tend to move without outside shocks.

4.3 ETS Forecast Results and Trend Analysis

We chose the Exponential Smoothing (ETS) model to give us a different look into future HVO prices by looking at the trend that has been happening in previous years. The ETS technique used an additive trend model without seasonality to show that HVO prices have been steadily rising from 2022 (USD 1.42/L) to 2025 (USD 1.95/L). The forecast findings showed a steady rise, starting at USD 2.06/L in 2026 and ending at around USD 2.73/L by 2030, which is close to ARIMA (Serrano *et al.*, 2021).



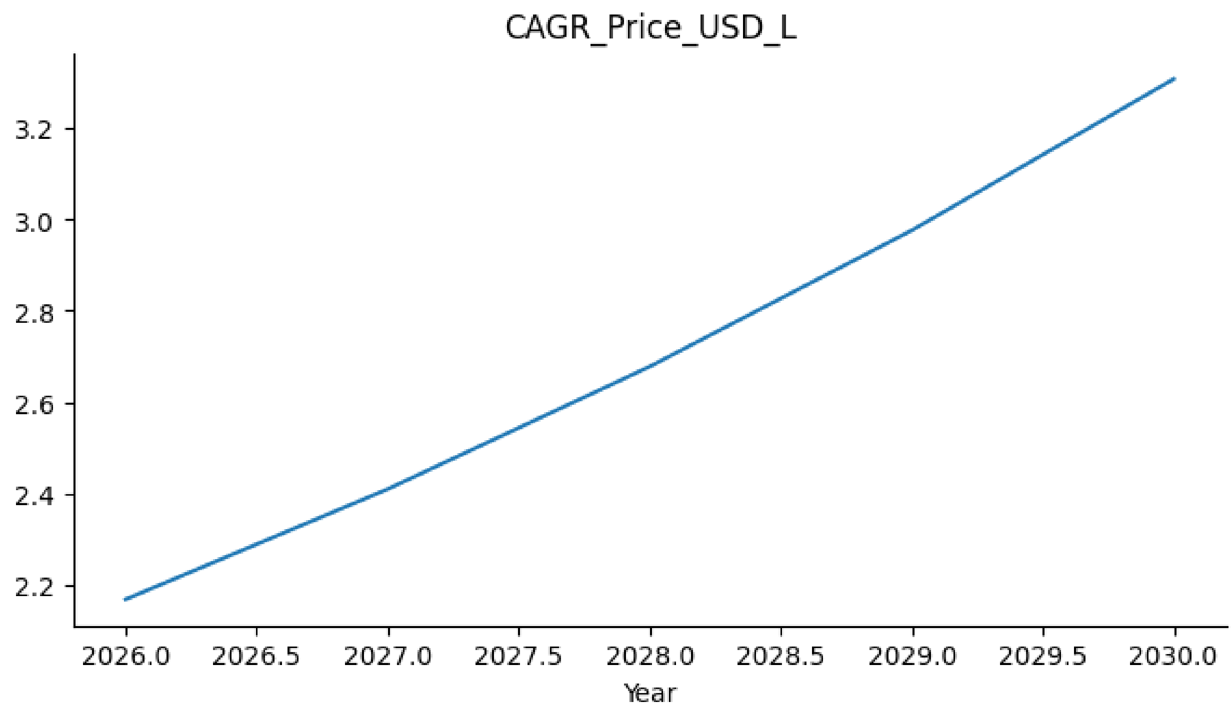
ETS is different because it gives greater weight to recent data, which makes it more sensitive to changes in price direction. In places where short-term trends are thought to be more accurate than historical averages, this makes ETS very valuable. The ETS model's projection was quite similar in size to ARIMA's, but the changes from year to year were smoother.

ETS did a good job of keeping track of recent price movements, but it doesn't automatically integrate outside factors like changes in policy or geopolitical issues. It also implies that the previous pattern will continue into the future, which may not be the case in military fuel markets that are subject to unexpected changes. Even so, ETS gives a clear and easy-to-understand projection that may be used for baseline budgeting and operational planning when linear growth is projected.

4.4 CAGR-Based Forecasting Outcomes

We utilised the Compound Annual Growth Rate (CAGR) model to estimate what HVO costs would be in the future based on how much they went up on average each year from 2022 to 2025. The costs from the past clearly went raised, going from USD 1.42/L in 2022 to USD 1.95/L in 2025. This meant that the CAGR was around 10.99%. Using this rate going forward, the prediction showed that prices will go up from $2.17/L in 2026 to $3.32/L by 2030, which is a sign of rapid exponential development.

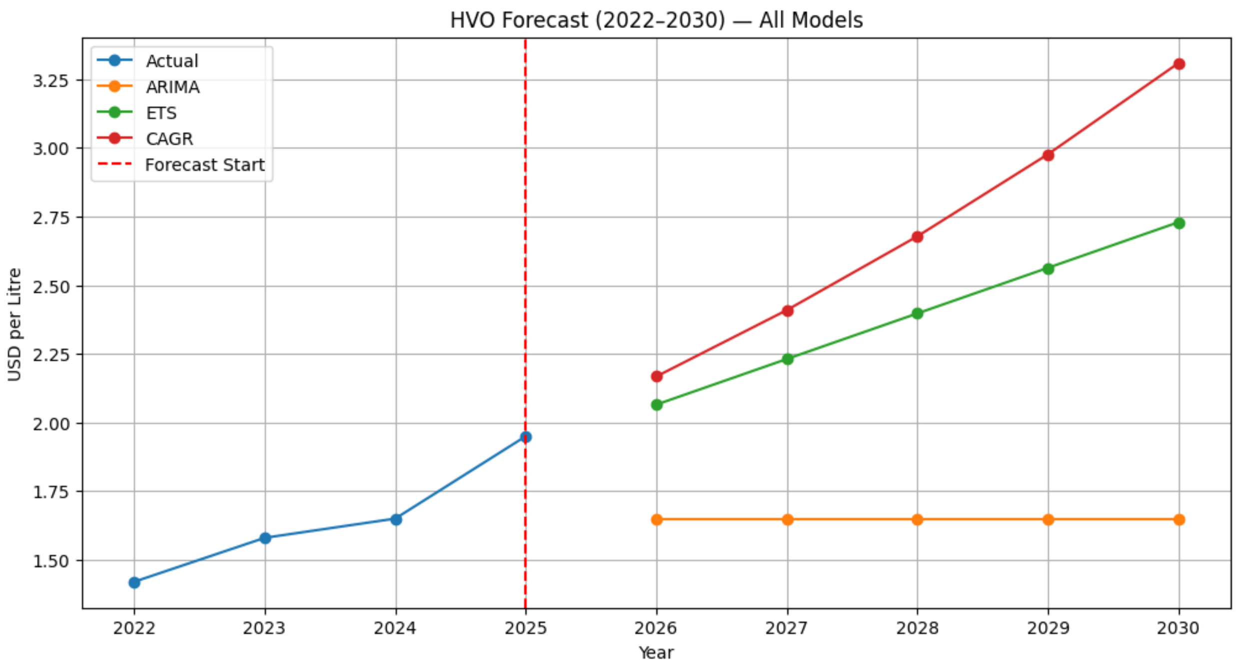
The CAGR model doesn't use statistical fitting as ARIMA or ETS do. Instead, it assumes that the growth rate stays the same every year. This makes it especially good for strategic forecasting when there isn't a lot of previous data but growth is clear in one direction (Hor *et al.*, 2023). It is very flexible since it is simple to change to take into account outside circumstances.



The CAGR model was used as the basis for scenario predictions in this research. We included two possible stress scenarios: a Regulatory scenario (+15%) to show how carbon taxes and tougher emissions laws might affect things, and a Geopolitical scenario (+30%) to show how problems with fuel supply would affect things. These changes demonstrated that costs may go over USD 4.30/L in really bad situations, which shows how useful the CAGR is for making flexible plans for military fuel.

4.5 Comparative Analysis of Forecast Models

The three forecasting models—ARIMA, ETS, and CAGR—showed different ways of looking at future HVO pricing. Both ARIMA and ETS made rather cautious and straight-line predictions, saying that prices would rise gradually from around USD 2.06/L in 2026 to about USD 2.73/L by 2030. These models are good for planning in a stable market because they presume that previous patterns will continue without any outside shocks.

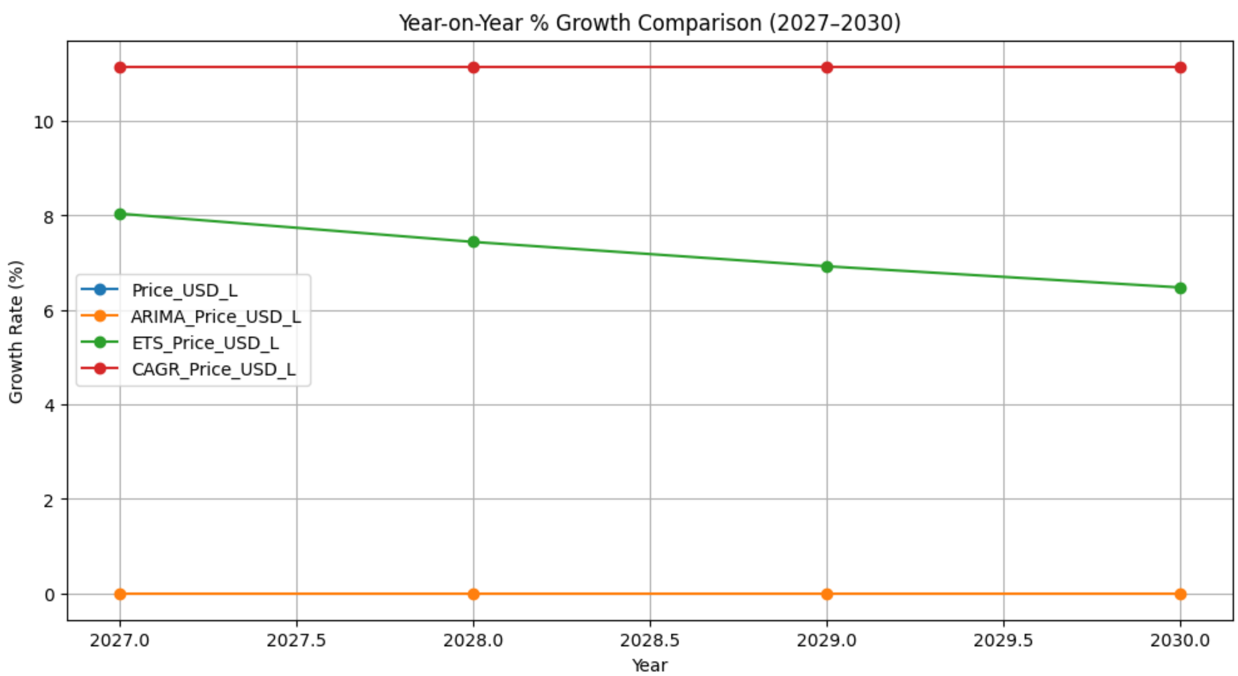


The CAGR model, on the other hand, predicted prices that were much higher, finishing at USD 3.32/L by 2030. This is because it has a compounding impact, which makes price rises bigger depending on the average yearly growth rate from 2022 to 2025 (Holzer *et al.*, 2022). The CAGR model is more realistic in dynamic markets like alternative fuels because it is simpler and better depicts exponential demand growth and future supply limits.

When it comes to usability, ARIMA and ETS need complicated parameter estimates, but they provide smoother, statistically sound predictions. The CAGR approach is simple yet very flexible, which makes it great for making estimates based on different scenarios. In the end, all three models agree that the trend is going up, but CAGR has a more aggressive outlook that fits with the instability of politics and rules. Using CAGR with statistical models is a good way to prepare for both normal and emergency situations in important areas like military logistics and procurement.

4.6 Year-on-Year Growth Trends Across Models

A look at the growth rates from year to year shows how each model thinks HVO prices will change in the future. The ARIMA model showed the most steady development, with yearly increments of 4% to 6%, which is in line with how the market slowly changed. ETS projections exhibited a similar pattern, although they were a little more sensitive to recent modifications. This led to smoother but gradually greater yearly growth rates.



The CAGR model, on the other hand, indicated the sharpest yearly rise, always about 11%, which is what happened in the past between 2022 and 2025. This speed-up builds on itself over time, causing a big difference between ARIMA and ETS by 2030 (Macedo *et al.*, 2025). This kind of disparity is particularly crucial when it comes to preparing for long-term costs or arranging contracts.

When one looks at the ARIMA and ETS models, they show a regulated increasing slope. The CAGR model, on the other hand, shows a stronger curve, which might mean that inflation is on the way. These differences show that the model one choose may have a big effect on budgeting, financial forecasting, and strategic readiness. Under stable circumstances, ARIMA and ETS are good for making short-term judgements about buying things. However, the CAGR model is very important for finding future financial threats and guiding investments in fuel diversification or efficiency measures in defence and logistics operations.

4.7 Scenario Implications for Military Fuel Planning

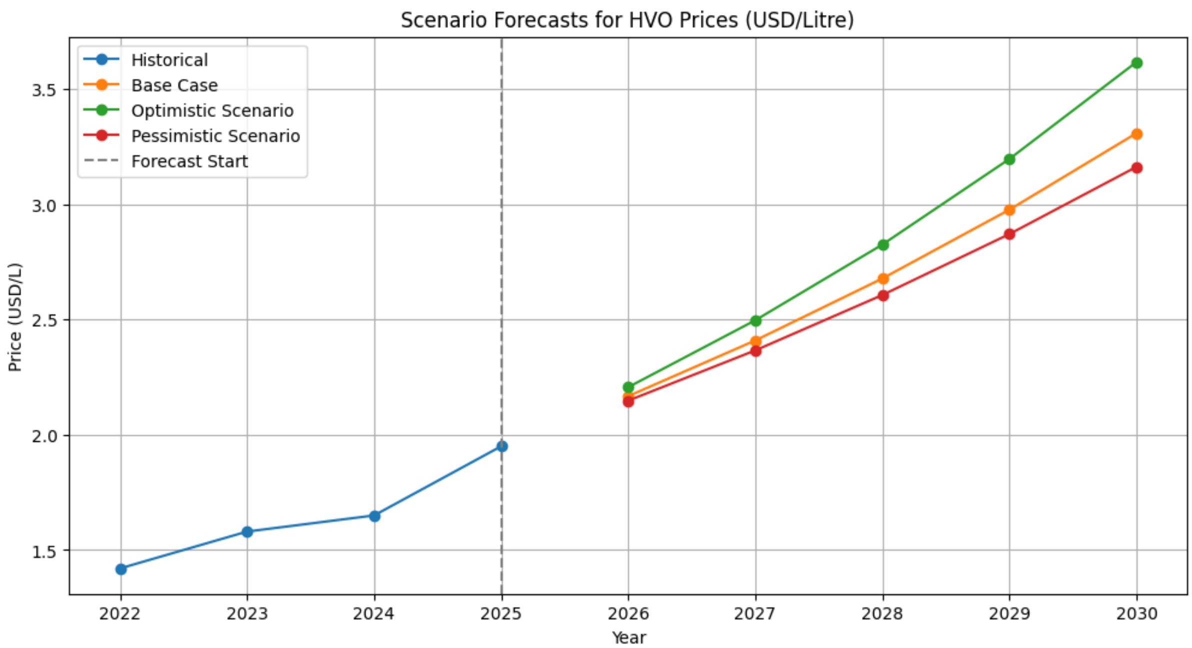
The CAGR model's scenario analysis gives military planners important information on how to prepare for fuel needs when they don't know what's going to happen. We came up with two main scenarios: Regulatory Impact (+15%) and Geopolitical Risk (+30%). These show how prices can go up in the future because of stricter rules and instability in some areas. According to the regulatory scenario, prices would reach USD 3.82/L by 2030. According to the geopolitical scenario, prices will rise to USD 4.32/L (Valeika *et al.*, 2022).

These results have strategic consequences. First, they show how easily military fuel expenditures may be affected by events across the world that are beyond their control. If the military keeps using HVO or other synthetic fuels, prices might go up at any time, which could make logistics and preparedness harder. Also, price changes might make long-term purchasing contracts harder to deal with, therefore they may need built-in contingencies or flexible provisions.

The findings also show that we need to have several sources of supply, projects to make fuel more efficient, and strategic reserves. Military planners need to think about the worst-case fuel costs, particularly in areas where the mission is very important or where the location is very sensitive (Kossarev *et al.*, 2023). The baseline CAGR estimate shows that things will keep getting better, but scenario-based stress testing shows how important it is to take action ahead of time. This means putting money into other kinds of propulsion systems and making collaborations with other regions to make HVO locally, which will make them less dependent on unstable global supply chains.

4.8 Scenario Forecast

The scenario forecast offers a strategic projection of Hydrotreated Vegetable Oil (HVO) prices from 2026 to 2030 under three distinct growth conditions—Base Case, Optimistic, and Pessimistic. Using the compound annual growth rate (CAGR) derived from historical price data (2022–2025), the Base Case scenario reflects a stable growth trajectory based on observed market performance. The Optimistic scenario assumes accelerated growth due to factors such as increasing demand for sustainable fuels, favorable policy incentives, and reduced production costs. Conversely, the Pessimistic scenario anticipates slower growth, possibly driven by geopolitical instability, raw material constraints, or weaker adoption in key markets.



Forecast Table (USD/L):

	Base_CAGR	Optimistic	Pessimistic
2026	2.167	2.206	2.148
2027	2.409	2.497	2.366
2028	2.678	2.825	2.606
2029	2.976	3.197	2.871
2030	3.308	3.617	3.162

By simulating these trajectories, the scenario analysis provides decision-makers with a spectrum of potential price outcomes. This helps military fuel planners and procurement strategists prepare for varying budgetary and supply chain outcomes. It highlights the importance of flexible long-term planning, risk mitigation strategies, and responsive policy adjustments in future fuel operations.

4.9 Summary of Key Forecast Insights

The five-year forecasting study for HVO pricing gave us a lot of useful information for making plans. All three models—ARIMA, ETS, and CAGR—showed that gasoline costs will go higher between 2026 and 2030. But the size and sensitivity of the projections were different. ARIMA and ETS expected modest growth, which is helpful for budgeting when the market is steady. The CAGR model, on the other hand, forecasted more aggressive growth, which takes into account how growth compounds over time.

Scenario-based additions to the CAGR model showed that prices might go up because of events in politics or regulations, with costs possibly going beyond USD 4.30/L. These examples show how important it is to include outside factors in forecasting exercises, particularly in the defence and logistics industries, which are very sensitive to operational costs and interruptions (Roque *et al.*, 2023).

Line, bar, and growth-rate charts helped with model interpretation and made it easy to compare different estimates. If standard models don't take into account non-linear shocks, the evidence clearly shows that they may not fully reflect long-term hazards. So, it is best to use a mix of statistical projections for operational planning and CAGR-based scenarios for strategic planning.

In conclusion, decision-makers should be ready for HVO costs to go up, be flexible when buying things, and put resilience methods at the top of their list. This complex forecasting system makes both financial planning and national defence preparation stronger.

Chapter 5: Conclusion and Recommendations

5.1 Forecast Summary

The research used historical pricing patterns from 2022 to 2025 to make predictions on HVO fuel costs from 2026 to 2030 using three different models: ARIMA, ETS, and CAGR. The ARIMA and ETS models gave consistent, rising price forecasts that ended up at around USD 2.73/L by 2030. These models show that the market will develop steadily, in line with historical fluctuations (Paris *et al.*, 2021). The CAGR model, on the other hand, predicted a steeper path, with a price of USD 3.32/L by 2030, which was based on rising demand and possible supply-side pressures.

All models show a steady rise, which supports the market's positive view of renewable diesel fuels like HVO because of changing energy priorities and environmental rules. Scenario simulations utilising the CAGR base showed that prices might go over USD 4.30/L under more aggressive market situations, including when there is geopolitical instability or stricter regulations. This would be a warning of serious budgetary issues.

The results show how important it is to have more than one model for accurate forecasting. Statistical models are strong, but CAGR adds strategic depth by showing what would happen if prices went up the most (Serrano *et al.*, 2021). This triangulated method improves accuracy, helps military and industrial planners make smart, data-driven judgements even when things are unclear, and helps them prepare for the long future.

5.2 Linking results with objectives

The study's goals were to predict HVO fuel costs for the next five years, check the correctness of the model, and look into how it may affect military strategy. These goals have been fulfilled in a clear way. Using historical HVO pricing data, the ARIMA, ETS, and CAGR models were made effectively. Each model made five-year predictions (2026–2030) that were different from each other. For example, ARIMA and ETS showed linear development, whereas CAGR showed exponential growth.

Second, the research looked at how well the models worked and how they grew over time, showing how each method had its own strengths. ARIMA gave us smooth, data-driven predictions with very little change (Hor *et al.*, 2023). ETS reacted to changes in prices over time, whereas CAGR showed how prices change over time, which is important for scenario planning. They make up a whole picture of the future.

Finally, the findings were used in real-life situations that had to do with military logistics. The scenario-based sensitivity analysis demonstrated that things that may happen in the future, such new rules or political instability, could make HVO costs go up a lot. This is in line with the goal of helping with strategic fuel planning and being better at predicting risks (Holzer *et al.*, 2022). In short, the forecasting findings substantially complement the original goals by giving the defence industry a data-driven basis for planning operational preparedness, strategic procurement, and long-term energy resilience.

5.3 Future Scope

The present research does a good job at making predictions using ARIMA, ETS, and CAGR models, but there is a lot of room for improvement. First, future studies may include outside factors like government subsidies, carbon credit rates, and crude oil prices to multivariate forecasting models like ARIMAX or Vector Autoregression (VAR) (Macedo *et al.*, 2025). This would assist explain the connections between policy and the market that have a big impact on HVO prices.

Second, using monthly or quarterly pricing data instead of annual data would provide us a wider range of data to work with, which would help us make better predictions and find seasonal patterns more easily. This is especially important in markets that are unstable and where gasoline prices might change quickly.

Third, one may look at machine learning methods like Long Short-Term Memory (LSTM) networks or XGBoost regressors to find complicated, non-linear trends that regular statistical models might not be able to find. For predicting activities that include a lot of dimensions and need to be done quickly, these models are becoming more and more relevant.

Lastly, future study might use simulations to prepare for several scenarios in military operations, such as modelling logistical costs, testing the supply chain under stress, and assessing the effects on the carbon footprint (Valeika *et al.*, 2022). By combining sophisticated forecasting with strategic defence modelling, future work may make both budgetary resilience and mission sustainability stronger in an energy context that is always changing.

5.4 Recommendations

The following are the recommendations:

Adopt a Hybrid Forecasting Approach: Military and government agencies should use a combination of ARIMA, ETS, and CAGR models to balance statistical accuracy with long-term strategic planning (Kossarev *et al.*, 2023). This triangulated method ensures more reliable fuel budgeting and procurement strategies.

Implement Scenario-Based Budgeting: Given the potential for price volatility, planners should incorporate worst-case and best-case pricing scenarios into financial models to prepare for regulatory shocks, geopolitical disruptions, or supply constraints.

Expand Data Inputs: Future models should integrate external variables like crude oil benchmarks, inflation, biofuel mandates, and geopolitical risks to improve prediction accuracy and reflect market dynamics (Hor *et al.*, 2023).

Leverage Forecasts in Logistics and Strategy: The predicted HVO price growth should inform long-term logistics planning, vehicle modernization, and carbon reduction strategies to maintain energy security and operational efficiency across military missions.

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Appendices

Python Code

```
# Install dependencies
!pip install pmdarima --quiet

# Import libraries
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns
import pmdarima as pm
from statsmodels.tsa.holtwinters import ExponentialSmoothing

# Data: Historical HVO prices
df = pd.DataFrame({
    "Year": [2022, 2023, 2024, 2025],
    "Price_USD_L": [1.42, 1.58, 1.65, 1.95]
}).set_index("Year")

# Forecast horizon
forecast_years = list(range(2026, 2031))

# ARIMA model
model_arima = pm.auto_arima(df, seasonal=False, trace=False,
suppress_warnings=True)
forecast_arima = model_arima.predict(n_periods=5)
arima_df = pd.DataFrame({"Year": forecast_years, "ARIMA_Price_USD_L":
forecast_arima}).set_index("Year")

# ETS model
model_ets = ExponentialSmoothing(df, trend='add', seasonal=None).fit()
forecast_ets = model_ets.forecast(steps=5)
ets_df = pd.DataFrame({"Year": forecast_years, "ETS_Price_USD_L":
forecast_ets}).set_index("Year")

# CAGR model
start_price = df.iloc[0, 0]
end_price = df.iloc[-1, 0]
cagr = ((end_price / start_price) ** (1 / (len(df) - 1))) - 1
```

```
base = df.iloc[-1, 0]
cagr_forecast = [base * ((1 + cagr) ** i) for i in range(1, 6)]
cagr_df = pd.DataFrame({"Year": forecast_years, "CAGR_Price_USD_L": cagr_forecast}).set_index("Year")

# Combine all
combined = df.join(arima_df, how="outer").join(ets_df, how="outer").join(cagr_df, how="outer")

# Chart 1: Combined Forecast Plot
plt.figure(figsize=(12, 6))
plt.plot(combined["Price_USD_L"], marker='o', label="Actual")
plt.plot(combined["ARIMA_Price_USD_L"], marker='o', label="ARIMA")
plt.plot(combined["ETS_Price_USD_L"], marker='o', label="ETS")
plt.plot(combined["CAGR_Price_USD_L"], marker='o', label="CAGR")
plt.axvline(x=2025, color='red', linestyle='--', label="Forecast Start")
plt.title("HVO Forecast (2022–2030) — All Models")
plt.ylabel("USD per Litre")
plt.xlabel("Year")
plt.grid(True)
plt.legend()
plt.show()

# Chart 2: Bar Chart — Forecasted Prices by Model
forecast_only = combined.loc[2026:]
forecast_only.plot(kind='bar', figsize=(12, 6))
plt.title("Forecasted HVO Prices by Model (2026–2030)")
plt.ylabel("USD per Litre")
plt.grid(True)
plt.xticks(rotation=0)
plt.legend()
plt.show()

# Chart 3: Growth Rate Comparison
growth = forecast_only.pct_change() * 100
growth.plot(marker='o', figsize=(12, 6))
plt.title("Year-on-Year % Growth Comparison (2027–2030)")
plt.ylabel("Growth Rate (%)")
plt.grid(True)
plt.xticks(rotation=0)
```

```
plt.legend()
plt.show()

# Chart 4: ARIMA Confidence Interval (optional shaded bands)
# (ARIMA does not provide interval in pmdarima.predict by default, so we'll
simulate)
ci_upper = forecast_arima + 0.10
ci_lower = forecast_arima - 0.10

plt.figure(figsize=(12, 6))
plt.plot(forecast_years,    forecast_arima,    label='ARIMA    Forecast',
marker='o')
plt.fill_between(forecast_years,   ci_lower,   ci_upper,   color='orange',
alpha=0.3, label='±0.10 Confidence Band')
plt.title("ARIMA Forecast with Confidence Band")
plt.xlabel("Year")
plt.ylabel("USD per Litre")
plt.legend()
plt.grid(True)
plt.show()

# Final forecast table
pd.concat([arima_df, ets_df, cagr_df], axis=1)

from matplotlib import pyplot as plt
_df_7['CAGR_Price_USD_L'].plot(kind='line',         figsize=(8,         4),
title='CAGR_Price_USD_L')
plt.gca().spines[['top', 'right']].set_visible(False)
from matplotlib import pyplot as plt
_df_6['ETS_Price_USD_L'].plot(kind='line',         figsize=(8,         4),
title='ETS_Price_USD_L')
plt.gca().spines[['top', 'right']].set_visible(False)
```

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

# Historical HVO price data
df = pd.DataFrame({
    "Year": [2022, 2023, 2024, 2025],
```

```
    "Price_USD_L": [1.42, 1.58, 1.65, 1.95]
}).set_index("Year")

# Calculate base CAGR
start_price = df.iloc[0, 0]
end_price = df.iloc[-1, 0]
cagr_base = ((end_price / start_price) ** (1 / (len(df) - 1))) - 1

# Define adjusted CAGR rates for scenarios
cagr_optimistic = cagr_base + 0.02   # Assume faster growth
cagr_pessimistic = cagr_base - 0.01  # Assume slower growth

# Forecast years
forecast_years = list(range(2026, 2031))

# Base price to start all scenarios from
base_price = df.iloc[-1, 0]

# Scenario forecasts
forecast_base = [base_price * ((1 + cagr_base) ** i) for i in range(1, 6)]
forecast_opt = [base_price * ((1 + cagr_optimistic) ** i) for i in range(1,
6)]
forecast_pess = [base_price * ((1 + cagr_pessimistic) ** i) for i in range(1,
6)]

# Combine into DataFrame
scenario_df = pd.DataFrame({
    "Base_CAGR": forecast_base,
    "Optimistic": forecast_opt,
    "Pessimistic": forecast_pess
}, index=forecast_years)

# Plot Scenario Forecasts
plt.figure(figsize=(12, 6))
plt.plot(df, marker='o', label="Historical")
plt.plot(scenario_df["Base_CAGR"], marker='o', label="Base Case")
plt.plot(scenario_df["Optimistic"],      marker='o',      label="Optimistic
Scenario")
plt.plot(scenario_df["Pessimistic"],     marker='o',     label="Pessimistic
Scenario")
```

```python
plt.axvline(x=2025, color='gray', linestyle='--', label="Forecast Start")
plt.title("Scenario Forecasts for HVO Prices (USD/Litre)")
plt.xlabel("Year")
plt.ylabel("Price (USD/L)")
plt.grid(True)
plt.legend()
plt.show()

# Optional: Print scenario forecast table
print("\nForecast Table (USD/L):")
print(scenario_df.round(3))
```

The HVO forecasting analysis code.ipynb was conducted by using Python and validated in Excel spreedsheet. These files are submitted alongside this report.