

TECHNO-ECONOMIC ANALYSIS OF WASTE-OIL HVO WITH CCUS/EOR AND CARBON TRADING FOR INDONESIA'S DECARBONIZATION

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Abstract. Indonesia's transport and industrial sectors remain deeply dependent on diesel fuel, which accounts for 30% of transport-related CO₂ emissions. Conventional biodiesel blending has delivered limited mitigation due to technical constraints and feedstock competition, underscoring the need for advanced alternatives. This study evaluates the techno-economic feasibility of producing Hydrotreated Vegetable Oil (HVO) from used cooking oil (UCO), combined with process optimization, carbon capture utilization and storage (CCUS) through enhanced oil recovery (EOR), and integration into carbon trading mechanisms. Using Aspen Hysys simulation, a base case retrofit yielded 21.307 kg/h of HVO with an emission intensity of 0,068 kg CO₂ per litre. Incorporation of a refrigeration cycle reduced utility demand by 36%, eliminated direct heater emissions, and lowered carbon intensity to 0,0042 kg CO₂ per litre, representing a 92,5% reduction. Liquefied CO₂ captured from the process provided additional revenue of about US\$ 38,8 million annually when sold for EOR. Coupled with carbon credit monetization under Indonesia's Carbon Economic Value framework, the effective HVO price declined from IDR 25.000 to about IDR 19,500 per litre, while return on investment increased by up to 42% and internal rate of return improved by nearly 25%. Integrating EOR and carbon trading not only strengthens project returns but also directly addresses Indonesia's reliance on diesel, which contributes 30% of transport-related CO₂ emissions. By lowering the effective cost of HVO, these mechanisms enable 50% HVO–Pertamina Dex blends to approach Pertamina Dex prices while delivering higher cetane numbers, offering a technically superior and economically viable pathway beyond the limits of conventional biodiesel blending.

Keywords: carbon capture, carbon trading, enhanced oil recovery, hydrotreated vegetable oil, used cooking oil

INTRODUCTION

The global energy system faces a fundamental trilemma that requires the simultaneous delivery of affordable, secure, and sustainable energy for economic and social development (Atstāja, 2025). This condition is not merely a conceptual framework, but a tangible operational reality that increasingly constrains policy and industry decisions. Recent global developments demonstrate that even advanced economies remain vulnerable to fuel price fluctuations, disruptions in energy supply, and challenges in integrating renewable energy sources into established fuel infrastructure (Bashir et al., 2025; Huang & Tan, 2025). For emerging economies such as Indonesia, the urgency is greater due to the need to maintain affordability for households and industries, ensure resilience against market volatility, and meet environmental commitments (Aditya et al., 2025). These challenges persist while fossil fuels continue to supply approximately 80% of global primary energy demand, and the substitution by renewable energy sources progresses at a gradual pace, intensifying the tension between the three pillars of the trilemma as depicted in Figure 1 (Pambudi et al., 2023).

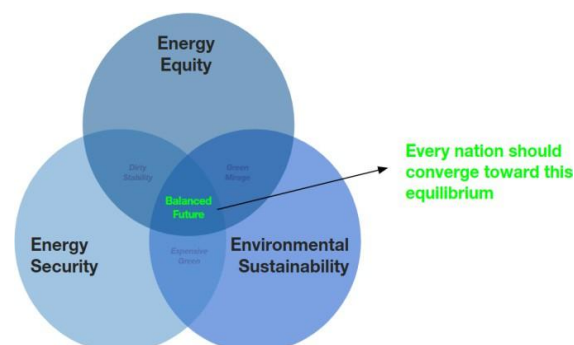


Figure 1. Energy trilemma as tangible operational reality in Indonesia (Adapted From: (Setyowati, 2020))

The same trilemma also manifests sharply in Indonesia’s transport sector, where high energy demand collides with the urgency to reduce emissions (Massagony et al., 2025). As illustrated in Figure 2, transportation consumes nearly half of the nation’s total energy, with diesel-powered operations forming the backbone of heavy-duty logistics, mining, shipping, agriculture, and remote power generation. This segment alone contributes about 36% of total transport-related CO₂ emissions, a figure far higher than its share of energy use would suggest, because these applications demand sustained torque, long operating ranges, and high energy density, which current electric or hydrogen alternatives cannot yet provide at scale (Kementerian ESDM, 2025; Sarikoç, 2020). In contrast, gasoline use in passenger vehicles is already on a gradual electrification pathway, supported by mature EV and hybrid technologies. This divergence leaves diesel as the most emission- intensive and hardest to abate fuel in the transport system (Wijaya & Sinclair, 2025).

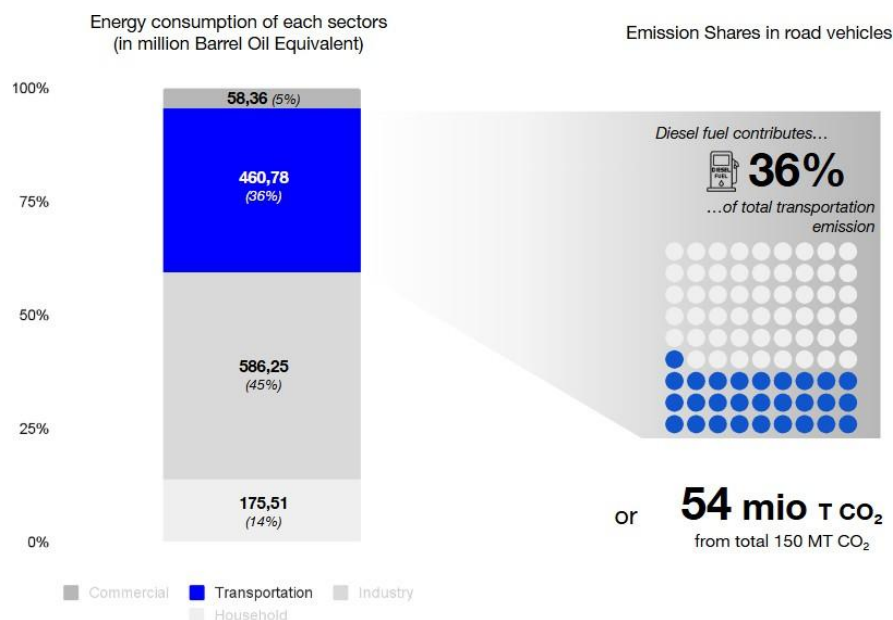


Figure 2 Transport energy & emission mix showing diesel’s significant contribution (Adapted From: Kementerian ESDM, 2025)

This difficulty in decarbonizing diesel comes from intrinsic engineering and operational characteristics of the technology itself. Decarbonizing diesel is technically more challenging than gasoline because the engines are designed for high compression ratios, superior thermal efficiency, and heavy torque output, enabling them to move large loads for extended durations under severe conditions (Dahham et al., 2022; Wan Mahdi et al., 2025). These operating demands translate into energy requirements that cannot be practically met by batteries or fuel cells without imposing prohibitive penalties in weight, volume, or refueling time (Guo et al., 2023). Diesel fuel offers unmatched volumetric energy density, chemical stability, and storability for long range operations, attributes that most alternative fuels struggle to match in real-world heavy duty application (Wan Osman et al., 2024). This entrenched dependency explains why national diesel consumption has remained near 27 million kilolitres per year, and why even with B35 biodiesel blending, the overall reduction in diesel transport emissions has been modest (Kementerian ESDM, 2025; Wirawan et al., 2024).

To address this challenge, Indonesia’s policy response has focused on leveraging domestic palm oil resources to substitute biofuels for diesel (Halimatussadiah et al., 2025). Since 2014, a progressive blending mandate (B10 to B20 to B30 by 2019) has been implemented, increasing biodiesel production capacity to around 12 billion litres by 2020 and reducing diesel imports significantly (Farobie & Hartulistiyoso, 2022). On-road biodiesel use rose from just 0,18 million kilolitres in 2010 to 5,9 million kilolitres in 2019, even as overall diesel demand in freight and industrial sectors remained high (IESR, 2021). However, conventional biodiesel (Fatty Acid Methyl Ester, FAME) faces technical limits, including engine compatibility and cold

flow issues at high blends, as well as competition with edible oil supply (Ershov et al., 2023). To address these constraints, Indonesia has begun developing hydrotreated vegetable oil (HVO), or “green diesel”, from used cooking oil (UCO) (Pertamina Patra Niaga, 2024).

In the Indonesian context, HVO’s significance lies in its ability to bridge the gap between immediate decarbonization needs and the operational realities of sectors that cannot easily electrify (Wirawan et al., 2024). Its chemical similarity to fossil diesel delivers superior performance characteristics such as higher cetane number, greater energy density, and improved cold flow properties while avoiding the water absorption and engine deposit issues of FAME (d’Ambrosio et al., 2022). These qualities make it ideal for mining fleets, maritime vessels, remote generators, and other high torque applications that underpin economic activity (Ajeeb et al., 2025). However, despite Pertamina’s initiation of HVO production at the Cilacap Green Refinery, current output of around 300.000 kilolitres per year drawn from palm oil and limited volumes of used cooking oil represents barely one percent of Indonesia’s annual diesel consumption of approximately 27 million kilolitres (Kementerian ESDM, 2025; Kilang Pertamina Internasional, 2025). The primary constraint is cost, with domestic HVO production due to high feedstock prices and the capital intensive hydrogenation process. Even with mature refining technology, feedstock accounts for the largest share of production cost, and supply of sustainable alternatives such as used cooking oil is scarce (Cavalcanti et al., 2022). Without targeted fiscal incentives or a dedicated mandate, HVO remains economically disadvantaged compared to both fossil diesel and subsidized FAME blends, slowing its scale up despite its technical superiority and strategic relevance to Indonesia’s hardest to abate diesel uses (Wan Mahdi et al., 2025).

Addressing these cost and complexity challenges requires not only policy support but also improvements in process efficiency. As shown in Figure 3, the distribution of energy consumption across the major stages of hydrotreated vegetable oil (HVO) production indicates that heating and pressurization, heat removal, and separation account for most of the utility load. Among these, depressurization which is responsible for approximately 9,76% of the total occurs when reducing high pressure product streams to near atmospheric conditions (Di Vito Nolfi et al., 2021). In current refinery retrofits, this step is typically executed through an expander or control valve, resulting in the loss of compression work contained in the gas stream (Cavalcanti et al., 2022; Di Vito Nolfi et al., 2021).

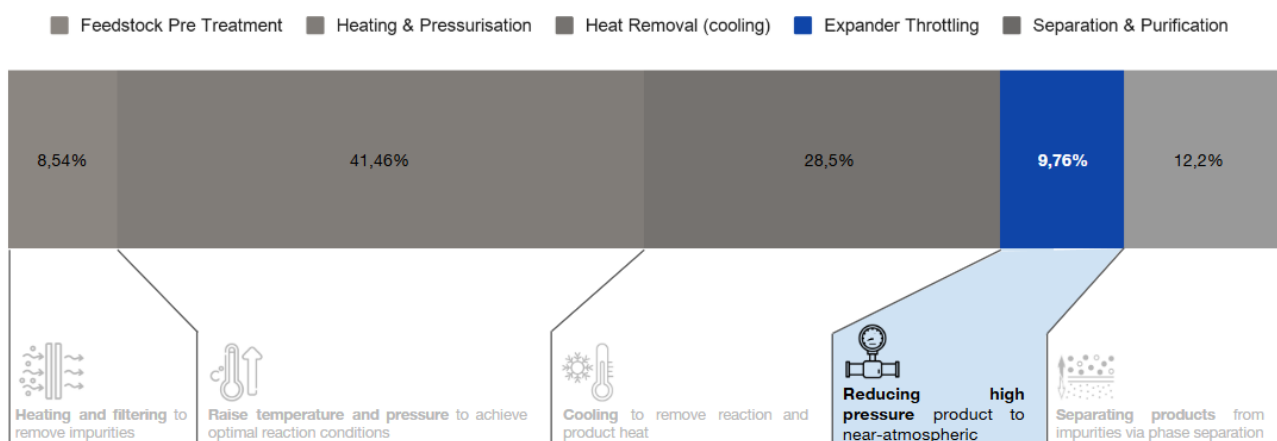


Figure 3. HVO energy intensity distribution across HVO production stages (Adapted From: (Di Vito Nolfi et al., 2021))

The CO₂-rich off-gas, before leaving the expander and separator stage, often remains at relatively high pressure as a result of reaction process conditions (Chang et al., 2021). If this stream is simply depressurized without any subsequent utilization, the compression work embedded in the gas is lost, meaning that the substantial energy previously invested to achieve this pressure is effectively wasted (Cavalcanti et al., 2022). This creates a clear opportunity for process integration strategies that preserve the high pressure state for downstream applications, rather than releasing it to the atmosphere (Ibrahim et al., 2023). In broader process

integration concepts, such streams could be channeled into applications where elevated pressure is not a by product to be discarded, but a valuable starting point for further utilization.

METHODOLOGY

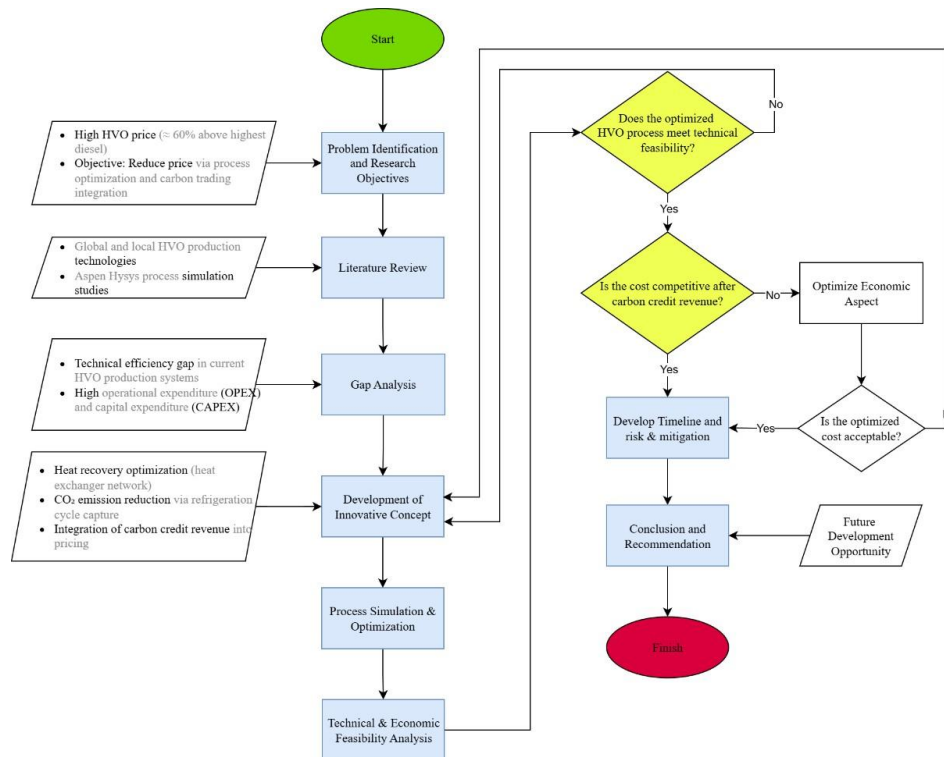


Figure 4. Research workflow integrating simulation and carbon trading

The complete workflow for this research is illustrated in the methodology diagram (Figure 4), which outlines the logical sequence from problem identification to final recommendations. The flow begins by establishing the research objectives and reviewing relevant literature to provide a strong foundation in both technological and economic contexts for HVO production. It then progressed to a gap analysis that highlights the critical challenges of low production output despite abundant feedstock (used cooking oil) and the high operational and capital costs that keep HVO prices uncompetitive. Based on these findings, the methodology advances to the development of an innovative concept that integrates process optimization and carbon trading to address both technical and economic barriers.

The diagram also captures the use of Aspen Hysys for detailed process simulation and optimization, ensuring that every unit operation is tested for energy efficiency and emission reduction before proceeding to feasibility analysis. Decision points are clearly represented to confirm whether the optimized process meets technical standards and whether the cost becomes competitive after accounting for carbon credit revenue. If either condition is not met, the workflow loops back to targeted economic or technical adjustments. This structured and iterative approach ensures that only technically sound and economically viable solutions, while keeping pathways open for future scale-up and diversification.

Definition and Fundamental Properties of HVO

Hydrotreated Vegetable Oil (HVO) is a renewable diesel fuel produced via the hydrotreatment of vegetable oils or animal fats. In this process, triglycerides and free fatty acids undergo hydrogenation, removing oxygen atoms from the molecules to form straight-chain paraffinic hydrocarbons that are chemically almost identical to fossil diesel (d'Ambrosio et al., 2022; Mussa et al., 2024). HVO exhibits a very high cetane number, contains no sulfur or aromatics, and offers excellent cold flow properties (Ershov et al., 2023). These

attributes enable it to function as a true drop-in fuel, capable of directly replacing petroleum diesel in existing engines and distribution infrastructure without modifications. Low oxidation reactivity further ensures long term storage stability across diverse climates (d'Ambrosio et al., 2022).

Key Differences Between HVO, FAME, and Fossil Diesel

A major distinction between HVO and biodiesel produced via Fatty Acid Methyl Ester (FAME) transesterification lies in their molecular composition (Ershov et al., 2023). FAME retains approximately 11% oxygen in its structure, whereas HVO is a pure hydrocarbon. This difference leads to superior combustion characteristics for HVO, enabling more complete burning and resulting in lower emissions of particulate matter, carbon monoxide, and nitrogen oxides (NO_x) compared to both conventional diesel and FAME (Szeto & Leung, 2022). Laboratory and field engine tests, including diesel generator trials, have confirmed substantial reductions in NO_x, CO₂, and particulate matter when using HVO (d'Ambrosio et al., 2022).

Table 1 presents a comparative summary of critical fuel properties for fossil diesel, FAME, and HVO. It shows that HVO consistently meets or exceeds performance specifications across most parameters, including ignition quality (high cetane number), cold-weather operability (low cold filter plugging point), and ultra-low sulfur content (Szeto & Leung, 2022). It also maintains competitive viscosity and lubricity, ensuring compatibility with modern diesel engine requirements (Hunicz et al., 2021). The overall takeaway is that HVO delivers the most balanced performance profile, combining the clean combustion benefits of biodiesel with the physical characteristics of petroleum diesel (Hunicz et al., 2021; Szeto & Leung, 2022).

Table 1. Comparative physicochemical properties of diesel, FAME, and HVO (Adapted From: (Hunicz et al., 2021))

Parameter	Unit	Diesel Fuel	FAME	HVO	Notes
Cetane Number	-	54,1	55,2	74,5	Larger values are preferred
Cold Filter Plugging Point	°C	-22	-11	-44	Smaller values are preferred
Lower Heating Value	MJ/kg	42,8	38,3	43,7	Larger values are preferred
Density	g/ml	0,837	0,882	0,764	
Sulphur Content	mg/kg	6,1	1	<1	Smaller values are preferred
Viscosity	mm ² /s	2,94	4,43	2,88	
Lubricity	µm	406	190	344	
Ash Content	%wt	0,014	0,01	0,002	

■ Worst Value ■ Best Value

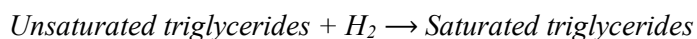
Production Process of HVO from Used Cooking Oil (UCO)

The production of Hydrotreated Vegetable Oil (HVO) from used cooking oil (UCO) involves a sequence of discrete, interlinked operations, each serving a specific function to ensure the quality, yield, and efficiency of the final fuel product. The process can be divided into four main stages (Di Vito Nolfi et al., 2021):

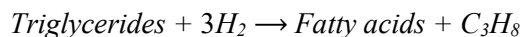
1. Pre-treatment: Removal of water, solids, and impurities, as well as reduction of free fatty acid (FFA) levels when necessary. UCO typically contains 50–52% FFA, with the remainder being triglycerides.
2. Feedstock Conditioning: Heating to approximately 350–375 °C at 3–5 MPa to remove residual water and volatile compounds before hydroprocessing.
3. Hydroprocessing: Conducted in a pressurized reactor containing metal catalysts such as palladium on carbon (Pd/C). Under mildly acidic conditions (pH ≈ 5) and elevated pressure, the process combines hydrogenation of unsaturated triglycerides with three oxygen-removal pathways:

hydrodeoxygenation (HDO, 90% of total deoxygenation), decarboxylation (5%), and decarbonylation (5%). The reactions are (Hor et al., 2023):

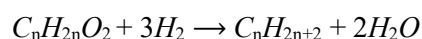
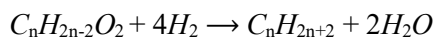
Hydrogenation of Triglycerides



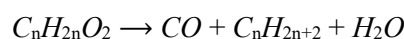
Hydrodeoxygenation (HDO) of Triglycerides



Hydrodeoxygenation of Fatty Acids



Decarbonylation (DeCO) of Fatty Acids



4. Product Separation and Recycling: The output is a mixture of straight-chain alkanes and light gases (H₂, CO, CO₂). Unreacted hydrogen is recirculated to minimize fresh hydrogen demand.

Environmental Performance and Emission Benefits

Life Cycle Assessment (LCA) data show that fossil diesel emits approximately 88–111 gCO₂eq/MJ, FAME from UCO emits 17–21 gCO₂eq/MJ, and HVO from UCO emits only 11–12 gCO₂eq/MJ, representing an 80–90% reduction in life cycle emissions compared to petroleum diesel (IEA, 2024). Engine studies confirm that HVO can reduce particulate matter emissions by 50% or more, significantly lower hydrocarbon and carbon monoxide emissions, and maintain NO_x levels equal to or slightly lower than diesel, whereas FAME often increases NO_x emissions by 2–5% despite lowering particulate matter (Smigins et al., 2023).

Enhanced Oil Recovery (EOR) with Process CO₂

Enhanced Oil Recovery (EOR) is a tertiary method capable of raising total recovery factors to 30 to 60% through injection of high purity CO₂ (≥95%) at pressures exceeding the minimum miscibility pressure (MMP) (Saxena et al., 2024). The injected CO₂ dissolves into crude oil, reducing viscosity and mobilizing residual volumes; in the United States, CO₂ EOR accounts for approximately 60% of total EOR output, injecting over 2 billion cubic feet of CO₂ daily (US Department of Energy, 2023). HVO hydroprocessing naturally produces high pressure CO₂ (approximately 4 MPa) as an off gas (Cavalcanti et al., 2022). In conventional retrofits, this stream is expanded to near atmospheric pressure, dissipating compression energy (Ibrahim et al., 2023). Adjusting the pressure drop to approximately 2 MPa preserves usable pressure for direct conditioning to EOR specifications (Yang et al., 2025), enabling sale to operators such as Pertamina Hulu Energy or upstream player for EOR or well stimulation (Wang et al., 2023).

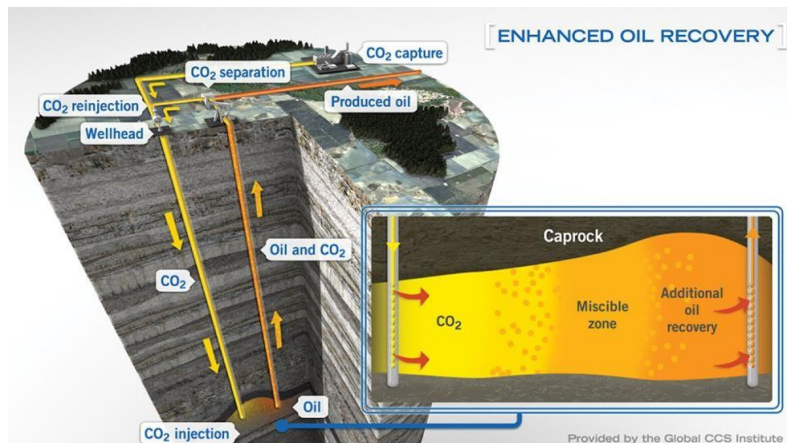


Figure 6. Schematic of CO₂-based enhanced oil recovery process (Global CCS Institute, 2023)

Carbon Trading Opportunities for HVO

Integrating HVO from used cooking oil (UCO) into the global voluntary carbon market presents a viable strategy to offset high production costs (Prajapati et al., 2025). One carbon credit represents the verified avoidance or removal of one tonne of CO₂ equivalent. High quality credits characterized by low life cycle emissions, strong additionality, and robust monitoring command substantial price premiums (Haya et al., 2023). HVO UCO, with cradle to pump intensities of 10 to 20 gCO₂eq/MJ, qualifies as a high integrity fuel, enabling access to premium markets (IEA, 2024). Global and domestic purchasing patterns indicate three clear buyer segments:

- Low cost bulk buyers such as Shell which acquired 14.5 million credits in 2024 at an average of US \$4,15 each (Shell, 2024)
- Premium buyers willing to pay significantly higher prices such as Microsoft which purchased 5,5 million credits with 80% from BECCS projects at an average of US \$189 per credit (Microsoft, 2024).
- Domestic buyers from the IDX Carbon Exchange, prices in this market vary widely depending on project type and certification, ranging from around US \$2–5 per credit for largescale forestry offsets to US \$10–15 per credit for high quality renewable energy or industrial gas projects (IDX Carbon, 2024)

Tesla's regulatory credit sales have generated over US \$2,76 billion, illustrating through a real world example the potential scale of such revenue streams in international markets (Tesla, 2024). In this context, integrating HVO from used cooking oil (UCO) into the global voluntary carbon market can follow similar pathways, with strategic targeting of premium buyers, particularly airlines under the CORSIA scheme via the Aviation Carbon Exchange, energy majors including BP, TotalEnergies, Repsol, Shell, and technology companies such as Microsoft, Google, and Apple. With the right certification, including VCS and Gold Standard, pricing in the US \$40–50 per TCO₂e range is realistic, referencing the 2023 premium of US \$60–80 and projected growth towards US \$150 by 2035 (World Bank, 2024).

RESULTS AND DISCUSSION

Indonesia's hydrotreated vegetable oil (HVO) program is currently in an early phase, with production undertaken through pilot-scale and co-processing operations (Kilang Pertamina Internasional, 2025). Pertamina's roadmap projects an increase in capacity from around 3,000 barrels per day at present to approximately 6,000 barrels per day by 2026 at the Cilacap Green Refinery. Additional developments are planned at Dumai, Balikpapan, and a standalone facility at Plaju, targeting a national capacity of about 32,000 barrels per day by 2035 (Pertamina, 2025).

This trajectory establishes the business-as-usual baseline for analysis: HVO is technically feasible, but current volumes are small, costs remain high, and economic returns are limited without further integration with carbon markets or process innovations. The following sections build upon this baseline to evaluate the potential

of enhanced configurations such as CO₂ utilization and carbon trading to improve overall project viability.

Results

Base Case

The base case represents this business-as-usual configuration, modeled as a retrofit of an existing diesel hydrotreater to process waste cooking oil (UCO) alongside fossil feed (Figure 7). In this setup, pre-treatment removes water and solids before the feed is heated to 375 °C and 5 MPa. Within the hydrotreater, 31,150 kg/h of UCO reacts with 1,400 kg/h of hydrogen, producing 21,307 kg/h of HVO and 1,458 kg/h of CO₂ along with water and light gases. Unused hydrogen is recycled, and the product stream is separated into liquid paraffins (C₁₅–C₁₈) and gas. Under this baseline scenario, the resulting emission intensity is 0.068 kg CO₂ per litre of HVO, which characterizes the reference case.

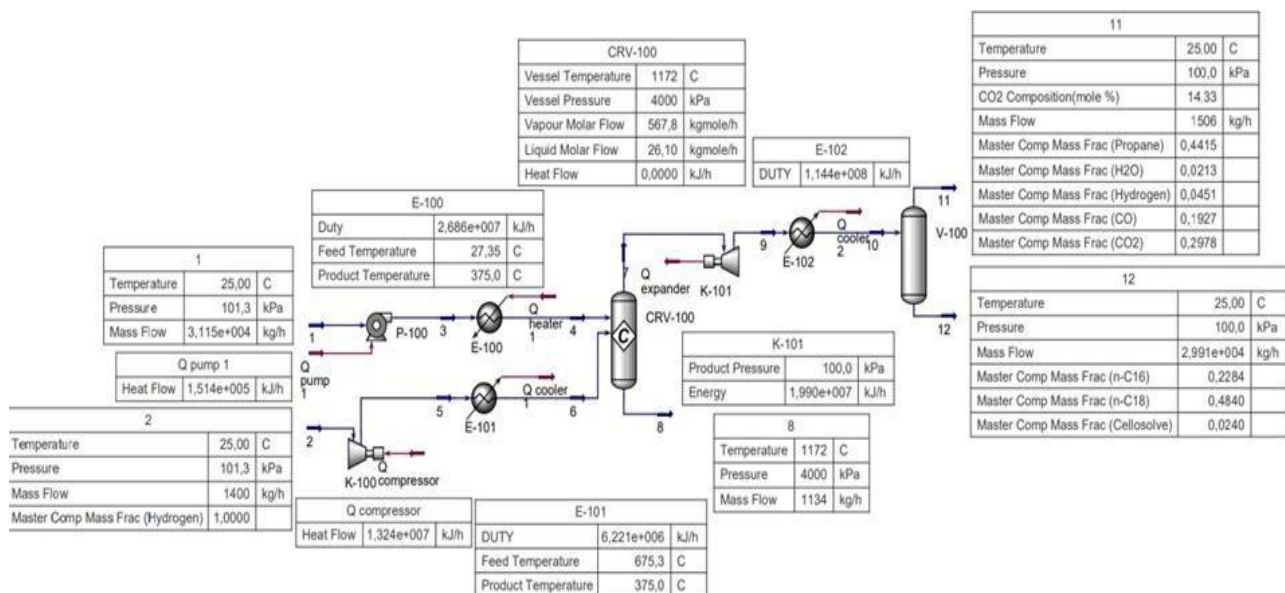


Figure 7. Base case retrofit HVO refinery process configuration

Under the base case economic scenario, selling HVO alone is not sufficiently attractive. The required capital outlay to build a green refinery (total capital investment roughly 136 million IDR) combined with high operating costs such as purchasing used cooking oil, hydrogen, and catalyst replacement that reduces profitability. Even with a selling price of IDR 25.000,00 per litre (Pertamina Patra Niaga, 2024), HVO can only be sold in small volumes, yielding limited operating cash flows. The resulting internal rate of return (IRR) is in the 19–20% range, only slightly above industry standard; thus, the project remains moderate in terms of risk-adjusted return. Without additional revenue streams, the net present value (NPV) of the investment remains modest, and the payback period is lengthy. Therefore, simply selling HVO does not ensure financial viability.

Refrigeration Cycle & EOR Integration

To move beyond emission abatement and create a new revenue stream, the refinery is retrofitted with a refrigeration block that condenses the CO₂-rich off-gas from HVO production into a high purity (97%) liquid at –10 °C and 2 MPa (Figure 8). This liquefied CO₂ can be sold to oil-field operators for enhanced oil recovery (EOR) (Yang et al., 2025). While the cold box adds roughly 1.2% to CAPEX and requires electrical power for its compressors, it captures about 92.5% of the emitted CO without increasing overall energy demand. Once the CO₂ product is delivered to the field and injected, it increases oil mobilization and sequesters the captured carbon (Saxena et al., 2024).

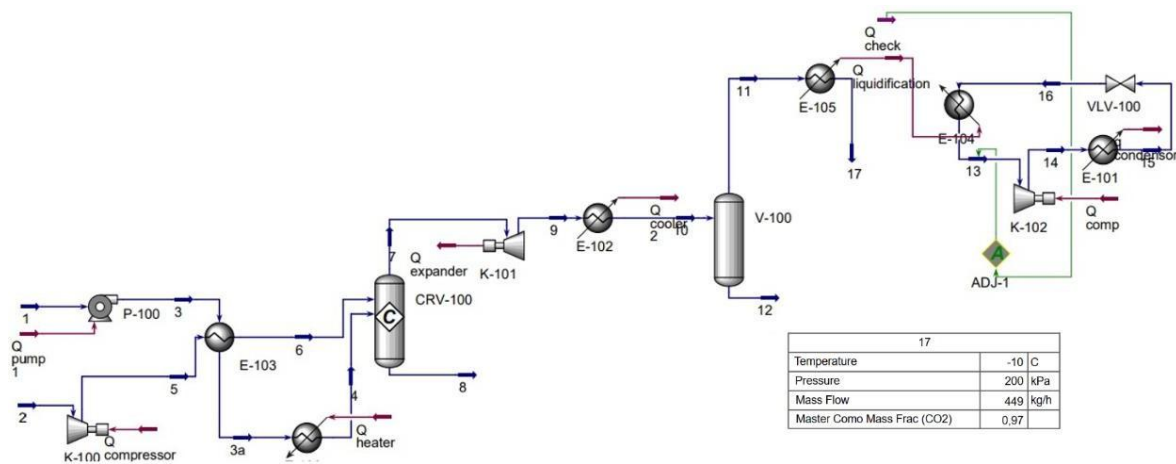


Figure 8. Optimized plant with refrigeration cycle for CO₂ capture

Figure 9 shows that total utility demand falls from about 1.475×10^8 kJ/h in the base case to 9.374×10^7 kJ/h after integration (36% reduction). The fired heater is eliminated entirely: heating duty drops from 2.686×10^7 kJ/h to zero, because the feed is pre-heated against hot reactor effluent and overhead vapours, rather than combustion.

Cooling utilities decline from about 1.206×10^8 kJ/h to 9.374×10^7 kJ/h (22% reduction) even after adding the CO₂ condenser; this counter-intuitive result arises because the recovered hot duty is reused internally to raise high-pressure steam, reducing the burden on cooling water (Ibrahim et al., 2023). Carbon emissions fall from 8.241 kg/h to 5.239 kg/h, demonstrating that heat recovery more than compensates for the electricity consumed by the refrigeration unit (Thanasoulas, 2025). In short, the plant shifts from a heat-dumping posture to a heat-recycling posture.

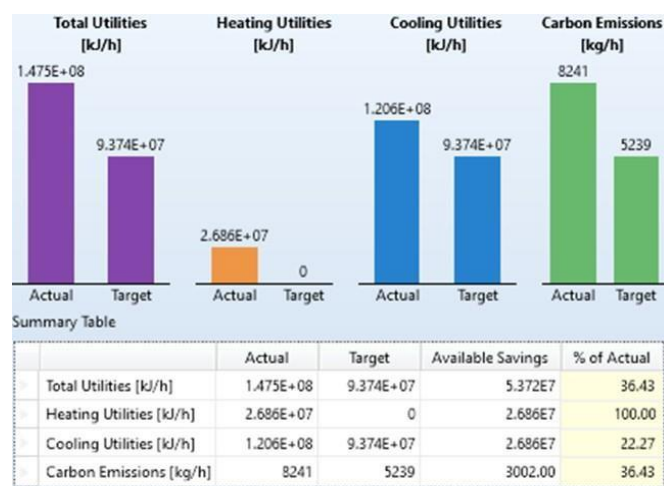


Figure 9. Summarized energy analysis

The refrigeration circuit operates with a minimum approach temperature of about -10 °C, which is tight enough to achieve CO₂ liquefaction without excessive compressor power (Saxena et al., 2024). Emission data show that fired-heater elimination removes its direct CO₂ contribution, while emissions associated with refrigeration can be decarbonized through renewable electricity. High pressure steam generation appears as a source in the accounting frame because recovered heat is credited as steam export. The net effect is a reduction of approximately 3 T/h in facility emissions. Expressed per unit of fuel, the carbon intensity falls from about 0,068 kg CO₂/L in the base case to 0,0042 kg CO₂/L after integration (92.5% reduction) qualifying the product as ultra low emission fuel and high quality carbon market (Bakhchin et al., 2023).

Captured liquid CO₂ is injected at reservoir pressure, which lowers compressor load at the field relative to gas phase CO₂, and any unreacted CO₂ becomes sequestered in the formation (Zhang et al., 2022). Optional polishing steps (molecular sieves and guard beds) dry and purify the liquid to meet $\geq 95\%$ purity specifications for miscibility and corrosion control (Saxena et al., 2024).

Beyond process integration, the geographical context further strengthens the case for implementing CO₂ capture and utilisation. The Dumai Refinery is located within close proximity to Pertamina Hulu Rokan's upstream oil fields, significantly reducing the logistical and compression requirements for CO₂ transport to injection sites. Shorter transfer distances lower pipeline capital costs, minimise pressure drop losses, and preserve the thermodynamic advantage of delivering CO₂ in liquid phase at reservoir pressure (McLaughlin et al., 2023). This contrasts with facilities such as Cilacap Refinery, which are geographically isolated from major upstream assets, making EOR integration economically less attractive due to the need for long distance CO₂ transportation and intermediate recompression.

Figure 10 maps the refinery's geographic position relative to upstream oil fields targeted for EOR. The short transport distance, typically less than 350 km, enables direct liquid CO₂ delivery by insulated pipeline or short-haul cryogenic tanker, minimizing boil-off losses and lowering logistics cost (Al Baroudi et al., 2021). Proximity also reduces the need for intermediate compression and storage, as the product can be dispatched at reservoir-compatible pressure directly from the cold box (Ali Awan & Din Kirmani, 2025). This locational advantage strengthens the project's economics by cutting transport energy demand and ensuring a stable offtake pathway for captured CO₂.

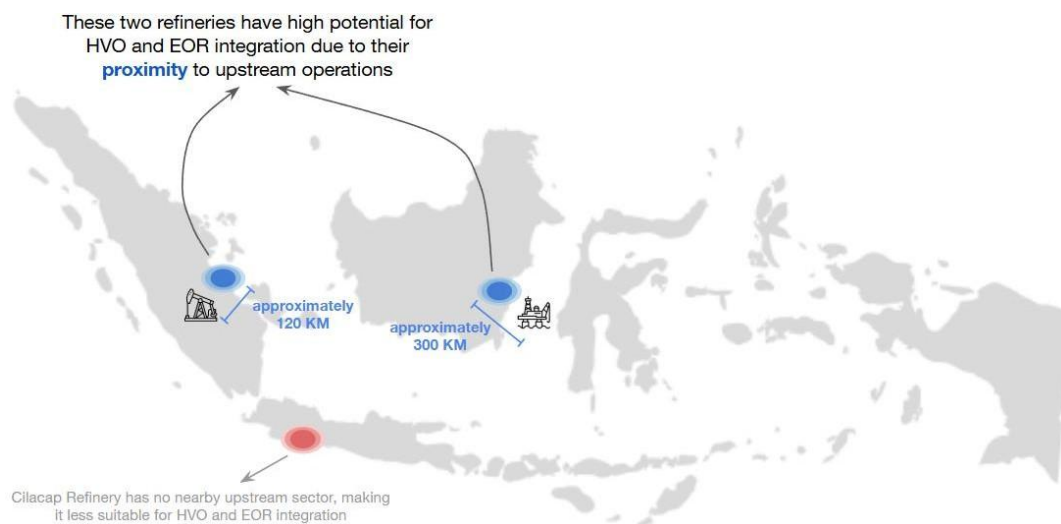


Figure 10. Refinery proximity map enabling cost-efficient EOR

The plant produces only HVO; all liquefied CO₂ is sold for EOR. The product becomes carbon-negative, qualifying for premium export markets. Annual additional revenue comes from CO₂ sales and EOR is US \$ 38.826.368,00 annually.

Effect on HVO price

1. 100% HVO + CCUS/EOR: All plant capacity is dedicated to HVO production, with all captured CO₂ sold for EOR. The resulting revenue offsets part of the production cost, allowing the HVO selling price to be reduced from Rp 25.000,00 /L to Rp 24.971,00/L.
2. 50% HVO Blend + CCUS/EOR: Using the Rp 23.000,00/L benchmark from the 100% HVO case, blending with 50% fossil diesel results in an average price of around Rp 19.560,00/L for a Pertamina Dex-HVO blend with cetane number at 63,75, and Rp 19.410,00/L for Dextrite-HVO blend, with cetane number at 62,75.

Carbon Trading Integration

With EOR revenue alone, the cost reduction is meaningful but not sufficient to fully close the price gap with fossil diesel. By adding carbon credit sales under Indonesia’s Carbon Economic Value (NEK) framework via the IDXCarbon Exchange, the refinery can monetize avoided emissions at a domestic market reference price of approximately Rp. 255.000,00 (\$ 15) per ton CO₂. For an annual avoided emission volume of 13.669.700 T CO₂, this translates into an additional revenue stream of Rp 12.380.760.000.000 (US \$ 728.280.000,00) in the domestic compliance market, dramatically improving the project’s financial performance. Both compliance and voluntary markets thus create a strategic opportunity to convert environmental performance into tangible financial returns.

Effect on HVO price

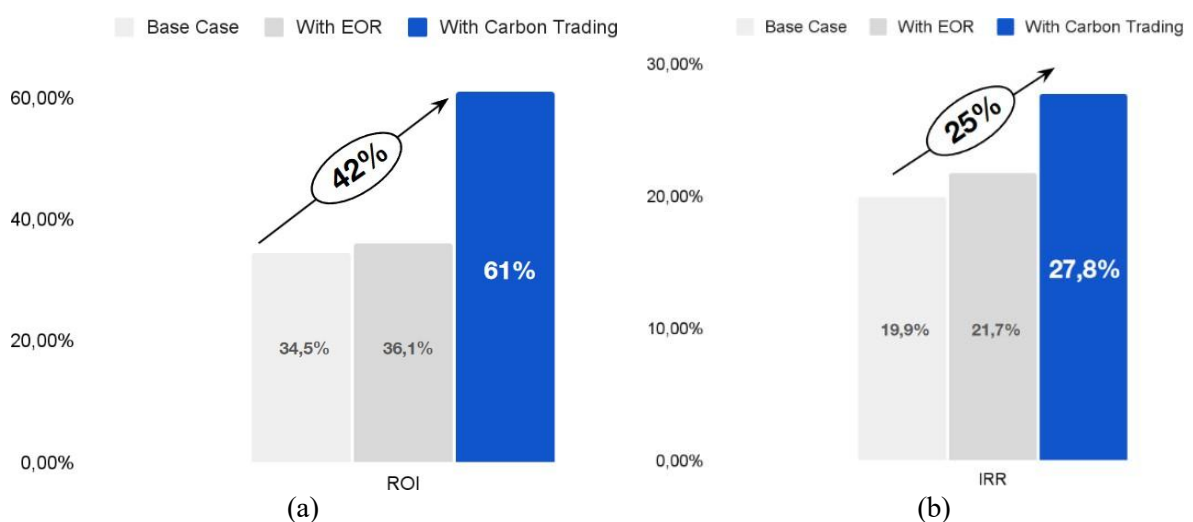
1. 100% HVO + CCUS/EOR + Carbon Trading: In addition to EOR revenue, participation in carbon credit markets further reduces the net cost. Monetizing the avoided emissions brings the effective selling price down to approximately Rp 19.535,00/L for 100% HVO
2. 50% HVO + CCUS/EOR + Carbon Trading: Using the same blending approach, carbon credit revenue reduces the effective blended price to roughly Rp 16.842,00/L for a Pertamina Dex- HVO blend and Rp 16.692,00/L for Dexlite-HVO blend.

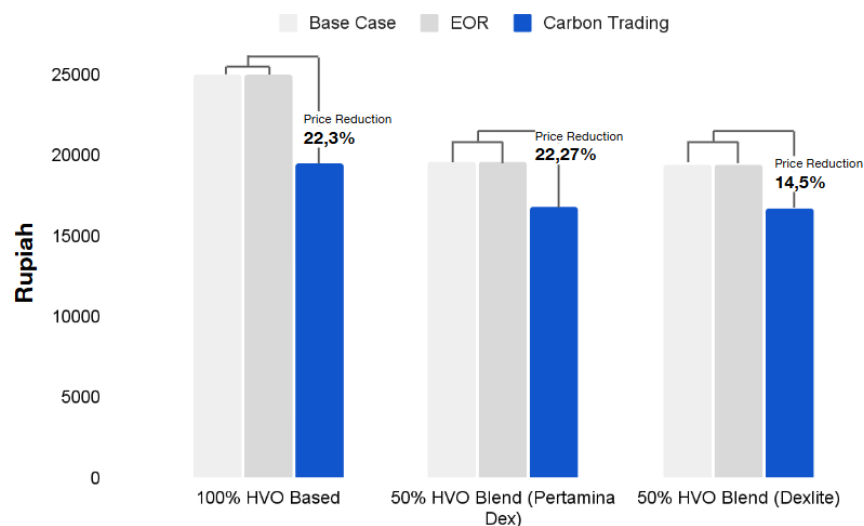
For further explanation and detailed calculations, please refer to the each sections/sheets on the Financial and Emission Calculation Sheet, including the carbon price assumptions and revenue calculation.

Discussion

Five scenarios were assessed: (i) HVO base case, (ii) 50% HVO with liquefaction and EOR, (iii) 100% HVO with liquefaction and EOR, (iv) 50 % HVO with carbon trading, and (v) 100 % HVO with carbon trading. Integration of carbon revenues significantly improves performance. As shown in Figure 11, ROI rises by up to 42 %, IRR increases by nearly 25 %, and effective HVO prices fall by 14–22 % compared to the base case.

These shifts underline two key points. First, carbon commercialization and trading directly strengthen investment returns, making refinery upgrades financially attractive. Second, the trajectory differs across pathways: full HVO with CCUS/EOR yields the highest NPV but requires major capital, while a 50% HVO blend with EOR offers a more balanced and realistic near-term route.





(c)

Figure 11. (a) Project IRR improvement with EOR and carbon trading, (b) ROI comparison across base, EOR, and carbon trading scenarios (c) HVO and blended fuel prices reduced through EOR and carbon credits

CONCLUSION

Integrating waste-oil HVO production with process optimization, CCUS/EOR and carbon trading is a viable strategy for Indonesia to decarbonize diesel-dependent sectors while maintaining energy security. Simulation confirms that retrofitting with a refrigeration cycle lowers total utility demand by 36%, eliminates direct fired-heater emissions, and cuts carbon intensity from 0,068 kg CO₂/L in the base case to 0,0042 kg CO₂/L, a 92,5% reduction. Captured high purity CO₂, when liquefied and sold for Enhanced Oil Recovery, generates additional revenue of about US \$38.8 million annually. The Dumai Refinery's proximity to Pertamina Hulu Rokan fields and Balikpapan's strategic location near other upstream assets provide logistical advantages for cost efficient CO₂ EOR deployment. Financial modelling further demonstrates that adding carbon trading revenue under Indonesia's NEK framework reduces the effective 100% HVO price from IDR 25.000/L to IDR 19.535,00/L, while boosting ROI by up to 42 % and IRR by nearly 25 %. Overall, the study establishes that while 100 % HVO with CCUS/EOR and carbon trading delivers the highest net present value, a 50 % HVO blending pathway represents a more realistic near term transition, given feedstock scarcity and capital constraints. Sensitivity analysis highlights that higher carbon credit values or greater used cooking oil availability significantly improve margins, whereas high hydrogen costs remain a critical vulnerability.

Policy measures should prioritize strengthening UCO collection, advancing carbon pricing and certification, and directing incentives toward capture and transport infrastructure in Dumai, Rokan, and Balikpapan hubs. Practitioners are advised to adopt phased deployment, starting with 50 % blends and scaling to full HVO as feedstock and credit markets expand. Future research should refine techno- economic modelling with dynamic carbon pricing, assess alternative waste feedstocks, and explore CO₂ transport optimization between pipeline and cryogenic modes to suit Indonesia's dispersed geography.

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