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# The Role of Oil Fuels on the Energy Transition toward Net Zero Emissions in Indonesia: A Policy Review

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**Abstract:** The vision of achieving Net Zero Emissions introduces a sense of uncertainty within the oil and gas industry. Several studies have reviewed the potential contributions of the oil and gas industry to the NZE vision. However, these studies have overlooked the intricate dynamics between the oil and gas sector and its counterparts, specifically the biofuel and electric vehicle industries. Our research seeks to fill this gap by conducting a thorough review of energy policies governing transportation sector energy provision with Indonesia as a case study. The initial phase of our analysis entails assessing the continued relevance of the current oil supply targets outlined in the National Energy General Plan considering prevailing conditions. In the second stage, we engaged in purposeful discussions with a diverse array of key stakeholders to gain a nuanced understanding of the intricate dynamics inherent in energy policies. We found a consistent decline in crude oil imports since 2016, culminating in actual oil imports in 2020 that were only 40% of the anticipated imports outlined in the RUEN targets. Production from the Cepu block surpassed expectations, leading to the actual oil production from 2016 to 2020 exceeding the targets outlined in the RUEN. Indonesia also has consistently redirected its emphasis on oil exports to contribute to economic development capital. The State-owned Oil and Gas Company acquired crude oil from 80% of the 43 contractors in 2020 and distributed it within domestic markets. The escalating domestic crude oil supply, stemming from heightened oil production and constraints on oil exports, underscores the imperative for additional oil refinery capacity. In addition, Indonesia has implemented programs to develop biofuels and electric vehicles. Implementing these measures is crucial for adapting to shifts in the energy landscape and ensuring the sustainability and security of the energy supply for the transportation sector.

**Keywords:** Oil production, oil export limitation, refinery capacity, biofuels, electric vehicles, net zero emission.

## 1. Introduction

The Net Zero Emissions (NZE) vision creates uncertainty for the oil and gas industry. The risks faced by this industry include a reduction in oil and gas demands due to the shift in energy demand towards renewable energy. Historically, global oil consumption has witnessed a notable surge, escalating from 61.4 million barrels per day (b/d) in 1980 to 98.3 million b/d in 2019<sup>1)</sup>. Gasoline and gasoil claimed the largest and most significant

portions, constituting 24.8% and 28.4% of total oil consumption, respectively. Simultaneously, oil reserves proved to have experienced a remarkable rise from 682.6 thousand million barrels in 1980 to 1,733.9 thousand million barrels in 2019<sup>1)</sup>. Certain countries experienced substantial increases in oil reserves from 1980 to 2019, with the Middle East nations, Venezuela, Canada, the United States, Libya, Nigeria, and China leading the way.

In contrast, others, notably Mexico and Indonesia,

faced challenges in discovering new oil fields, resulting in their struggle to maintain sufficient reserves. In contrast to Mexico, Indonesia has emerged as a leading global biodiesel producer<sup>2-4)</sup>. This transformation was spurred by the pressing challenge of dwindling oil production, plummeting from 1,577 thousand b/d in 1980 to 1,006 thousand b/d in 2008<sup>1)</sup>, the same year Indonesia withdrew from OPEC for the first time. Indonesia's oil exports in 2008 amounted to US\$ 29.1 billion, while oil imports reached US\$ 30.5 billion<sup>5)</sup>. During this period, oil reserves contracted significantly, diminishing from 11.6 thousand million barrels to 3.7 thousand million barrels<sup>6)</sup>. Simultaneously, oil consumption surged from 386 thousand bpd in 1980 to 1,286 thousand bpd in 2008.

Despite the ongoing decline of the oil and gas industry in Indonesia, the potential contribution of this industry to achieving the NZE vision cannot be overlooked. Sustainable oil supply remains crucial during the transition process, given the transportation sector's continued heavy reliance on oil-based fuels. The transportation sector consumed 364.3 million barrels of oil equivalent (BOE) in 2020, with oil fuels accounting for 99.9% of this consumption<sup>7)</sup>. Oil fuel usage in other sectors remained relatively modest, contributing only 13.3% to the overall oil consumption.

Several studies have already analysed how the oil and gas industry can contribute to the transition towards NZE vision. Smit & Powell (2023) reviewed the role of global oil companies in the NZE transition and concluded that the experiences and expertise of these companies will expedite the transition process<sup>8)</sup>. The transition still requires chemical energy carriers that are more cost-effective compared to other energy storage technologies. During this transition, emissions from the production and use of oil and gas should be reduced. Hastings & Smith (2020) proposed that the oil and gas industry should transform itself into NZE enterprises, with a specific focus on carbon dioxide storage<sup>9)</sup>. The same idea was also proposed by Wang et al (2023), who reviewed the impact of NZE on the oil and gas sector. Rahman et al. examined oil policies in Indonesia through five dimensions: global politics, domestic logistics, oil subsidy policy, emission reductions, and progress in renewable energy development<sup>10)</sup>. Their analysis, however, did not account for substantial reduction in oil imports<sup>10)</sup>. Sunny et al (2022) reviewed the efforts towards NZE in oil refinery operations in the medium term and the reduction of emissions from the combustion of refinery products, such as the use of synthetic fuels, and the use of liquefied plastic waste as alternative feedstock<sup>11)</sup>. Bao et al (2023) developed a methodology to minimize CO<sub>2</sub> emissions in shale oil recovery<sup>12)</sup>. Choo et al (2022) attempted to minimize CO<sub>2</sub> emissions from the mobility of engineers during oil drilling operations by implementing a digitally live remote-control system<sup>13)</sup>. Xie and Harjono reviewed the importance of oil fuel imports, the construction of new refineries, and the increase in biodiesel production for

energy resilience in Indonesia<sup>14)</sup>.

The existing review studies have concluded the importance of the oil and gas industry in the transition process towards NZE. Yet, these studies have not delved into the interactions between the oil and gas industry and its competitors, namely the biofuel and electric vehicle industries. Our study aims to address this gap by conducting a comprehensive overview of energy policies for energy provision in the transportation sector. We chose Indonesia as a case study because, as a former member of OPEC, the country is working to maintain domestic oil production while becoming one of the leading biodiesel producers. Drawing on our diverse practical experiences as policymakers, academics, and researchers, we offer insightful discussions on the transformations occurring in the oil market in Indonesia (Section 3.1). Additionally, we assess the effectiveness of policies in achieving oil supply targets (Section 3.2) and review emerging external factors that may impact oil supply in the future (Section 3.3). Our analysis concludes in Section 4. The results of our analysis will serve as input for the Indonesian government in adjusting strategies and policies, as well as for other countries to synchronize energy policies for the transportation sector.

## 2. Material and Methodology

This study employed a mixed-methods research approach, combining qualitative and quantitative methods. The first stage of the analysis involves evaluating whether the existing energy supply plans and targets are still relevant to the current conditions. To achieve this, we compare the planning data in the National Energy General Plan (referred to as RUEN) with actual data. A significant portion of the study focused on scrutinizing secondary data obtained from crucial government entities, including the Ministry of Energy and Mineral Resources (e.g., the Directorate General of Oil and Gas, the Directorate General of New-Renewable Energy and Energy Conservation), the National Energy Council, and the Ministry of National Development Planning.

The second stage involves reviewing policies related to the import and export of oil, the addition of refinery capacity to boost oil production, the biofuel production, and the adoption of electric vehicles. Deliberate discussions were held with members of the mentioned agencies and other influential policy-making bodies to review existing and future policies. This multifaceted research approach enhances the robustness of our analysis and provides a nuanced understanding of the complex dynamics involved in energy policies.

## 3. Results and Discussions

Indonesia has experienced two peak oil productions in its history. The first peak occurred in 1977 when the country reached a production level of 1,685 thousand bpd, following a rapid increase from 486 thousand bpd in

1965<sup>1)</sup>. The primary contributor to this surge was the new exploitation of the Minas oil field, which was managed by Chevron Pacific Indonesia (CPI). The second peak transpired in 1991, with a production level of 1,669 thousand bpd. This peak was attributed to new exploitation in the Duri oil field, also managed by CPI. Additionally, enhanced oil recovery (EOR) measures, such as water and steam injections in various oil fields overseen by CPI, contributed to the second peak. The Cepu block represented the last significant discovery of a relatively large oil field, and subsequent explorations yielded no substantial finds. Following these peaks, Indonesia's oil production experienced a natural decline, dwindling to 1 million bpd in 2010, 781 thousand bpd in 2019, and further to 708 thousand bpd in 2020<sup>1,7)</sup>.

RUEN outlines an ambitious target of oil production, projected to reach 567.7 thousand bpd in 2025<sup>15)</sup>. The strategies delineated in RUEN to achieve these targets include a phased reduction in oil imports, augmentation of refinery capacity, curtailment of oil exports, enhancements in oil reserves, implementations of enhanced oil recovery techniques, and investments in new oil exploitation ventures.

### 3.1. Policy Effectiveness in Achieving Oil Supply Targets in RUEN

The escalating oil demand in Indonesia has significant implications for both oil fuel imports. Since 2003, the country has consistently experienced higher oil consumption than production. The oil supply deficit has surged from 54 thousand bpd in 2003 to 951 thousand bpd in 2019<sup>1)</sup>, prompting Indonesia to withdraw from OPEC in 2008. While the country rejoined the organization in 2014 to facilitate direct oil imports from producer countries, challenges persisted due to the complex oil sales system involving traders and tanker services. Ultimately, Indonesia left OPEC again in 2016 due to disagreements over oil production quotas<sup>16)</sup>.

Indonesia has steadily decreased its oil imports. Table 1 indicates that crude oil imports have been on a declining trend since 2016, with actual oil imports in 2020 amounting to only 40% of the projected oil imports in the RUEN. Additionally, the import of refined products has also seen a decrease since 2018, as illustrated in Figure 1. Gasoline remains the primary imported product, while gasoil imports have decreased from 7 million kiloliters (kl) in 2017 to 3 million kl in 2020. The rise in oil production and the restrictions on oil exports have reduced the country's dependence on foreign oil.

Oil production experienced a decline over the past two decades, primarily due to the absence of significant oil reserve discoveries until the exploration and exploitation of the Cepu block. Production from this block exceeded expectations, resulting in actual oil production from 2016 to 2020 surpassing the projections in RUEN, as detailed in Table 2. Indonesia has implemented four additional strategies to exceed the RUEN targets.

Table 1. The comparison of actual oil import and RUEN's projection<sup>15,17)</sup>

Crude oil import (thousand bpd)	2015	2016	2017	2018	2019	2020
RUEN projection	446	387	435	497	619	654
Actual data	446	484	462	411	291	260

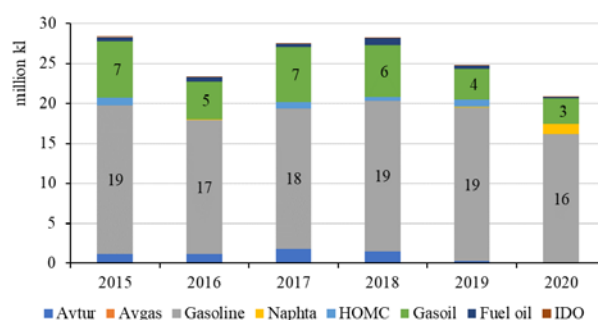


Fig. 1: Import of refined products<sup>18)</sup>

Table 2. The comparison of actual crude oil production and RUEN's projection<sup>15,18)</sup>

Oil production (thousand bpd)	2015	2016	2017	2018	2019	2020
RUEN projection	786	820	750	650	580	520
Actual data	786	831	801	772	745	708

The first strategy involves maintaining the current production rate through a routine program. All oil cooperation contractors are encouraged to execute work programs with a focus on being massive, aggressive, and efficient. Simultaneously, the government is expediting decisions related to extending the periods for oil and gas blocks and investments in oil drilling.

The second strategy involves transforming resources into production (R to P) by expediting the monetization of the "big barrels opportunity" across all working areas of the State-owned Oil and Gas Company, with a total potential of 2.5 billion BOE. To achieve this, several strategic oil and gas projects are set to commence commercial operations, including Tangguh Train-3 in Q4 2022, Jambaran Tiung Biru in Q2 2022, Indonesia Deep Water Development (IDD) in Q4 2025, and Masela in Q2 2027. Additionally, the government is actively promoting the completion of upstream oil and gas projects, the monetization of undeveloped discoveries, the development of marginal fields, and the optimization of existing oil fields. One notable project in progress is the development of the Sakakemang block, slated for completion within the next 1.5 years.

The third strategy involves the implementation of EOR

technologies. Global EOR players have committed investments that could reach up to US\$446 million. These investments are earmarked for EOR developments in 23 main oil fields, with 16 of them located in Sumatra, including Rantau Bais, Duri Ring, Bekasap, Minas, Makmur, Bangko, Gemah, Rantau, Pedada, Batang, Melibur, Jirak, Kaji Semoga, Rama, Krina, and Belida. The remaining fields are distributed across four in Java (i.e., Zulu, E-Main, Sukowati, and Mudi), two in Kalimantan (i.e., Tanjung and Handil), and the Kepala Burung field in West Papua.

The fourth strategy focuses on exploring massive new oil fields with the potential for 80 billion barrels of oil and 363 trillion cubic feet (Tcf) of gas. Indonesia still has 68 unexplored basins out of a total of 128 basins, presenting a significant opportunity to boost national oil and gas production. Ten areas have been identified as potential exploration priorities, with two of them located in deep-sea regions. To attract investors, the government is offering two contract options—gross split or cost recovery—along with fiscal incentives. The current value of Commitment to Exploration Work Certainty has reached US\$1.2 billion, aimed at increasing oil production by 109 thousand bpd.

With the implementation of these strategies, Indonesia has established a new target to produce crude oil at a rate of 1 million bpd by 2030. The first strategy is designed to counteract the declining trend in oil production, while the second strategy aims to maintain oil production within the range of 700 to 800 thousand bpd until 2030, after which a downward trend may resume. The crucial factors for sustaining and increasing oil production over an extended period are EOR and new exploration strategies. EOR investments are anticipated to contribute to an additional oil production of 106 thousand bpd in 2030 and 552 thousand bpd in 2044. Furthermore, the government envisions an additional oil production of up to 300 thousand bpd from the new exploration initiatives.

On the downstream side, Indonesia has consistently shifted its focus on oil exports towards contributing to economic development capital. This policy is designed to enhance people's prosperity by optimizing energy usage for national economic development, creating higher added value, generating more job opportunities, and, most importantly, ensuring national energy security<sup>10,16,19</sup>. Consequently, oil contractors and their affiliates are required to offer their crude oil shares to the State-owned Oil and Gas Company and other business entities holding an Oil Processing Business License. As a result of this policy, the State-owned Oil and Gas Company has purchased crude oil for 80% of the 43 contractors in 2020 and distributed it in domestic markets. The percentage has sharply increased compared to the average purchase percentage during 2015-2018, which was only 37% of total oil production.

Table 3. The comparison of actual oil export and RUEN's projection<sup>15,18)</sup>

Oil export (thousand bpd)	2015	2016	2017	2018	2019	2020
RUEN projection	297,9	267,7	246,9	208,1	179,9	155,3
Actual data	315,1	343,9	281,3	204,0	70,5	81,4

Consequently, oil exports were lower than the projections in RUEN. As shown in Table 3, oil exports decreased from 204 thousand bpd in 2018 to 70.5 thousand bpd in 2019 and 81.4 thousand bpd in 2020. These export figures represented 26% of the national oil lifting in 2018 and 10% in 2019. This underscores that the policy is a tangible implementation of the energy policy, aiming to utilize energy as an economic development capital rather than treating it solely as an export commodity.

The growing domestic crude oil supply resulting from increased oil production and the limitations on oil exports necessitate additional oil refinery capacity. The most recent refinery constructed was the Balongan refinery in 1994. The current total oil refinery capacity stands at 1,151 thousand barrels per stream day (MBSD), with average inputs of 992 thousand bpd and outputs of 728 thousand bpd from 2015 to 2020, as outlined in Table 4. Refinery input has seen an increase from 866 thousand bpd in 2015 to 963 thousand bpd in 2020. Notably, the domestic oil share in refinery input has risen from 62% of the total refinery input in 2015 to 78% in 2020.

Table 4. Refinery capacity, inputs, and outputs in 2015 to 2020<sup>7,15)</sup>

Indicator	2015	2016	2017	2018	2019	2020
Refinery capacity (MBSD) – RUEN	1,167	1,173	1,173	1,173	1,273	1,273
Refinery capacity (MBSD) – Actual	1,159	1,169	1,169	1,169	1,169	1,151
Refinery input (thousand bpd)	866	990	1,023	1,053	1,059	963
Fuel products (thousand bpd)	682	729	733	769	768	687

The refinery strategies outlined in RUEN include the Refinery Development Master Plan (RDMP), aiming to revitalize four refineries (i.e., Balikpapan, Cilacap, Dumai, and Balongan) and develop new grassroots refineries

(GRR) West I, West II, and Bontang<sup>20,21</sup>). However, the government faced challenges in meeting the targeted refinery construction outlined in RUEN, as indicated in Table 4. Among the four RDMP refineries, only RDMP Balikpapan, with a capacity of 100 MBSD, has secure partners, prepared land, and signed the Engineering, Procurement, and Construction (EPC) contract. Nevertheless, the progress of RDMP Balikpapan in 2020 reached only 27.9%, falling significantly below its completion target set for the end of 2019.

Hence, the government revised the refinery capacity targets, as detailed in Table 5. Most refinery projects experienced delays, and the RDMP Cilacap project was ultimately canceled due to disagreement between the investor and the State-owned Oil and Gas Company<sup>22</sup>). The initial capacity target for 2025 was adjusted from 1,258 MBSD to 252 MBSD. The first project set for completion is RDMP Balongan Phase 1, with a capacity of 50 MBSD in 2022. Following this, in 2023, RDMP Balikpapan Unit 1, with a capacity of 50 MBSD, is slated for completion. Subsequent refinery projects include three RDMP projects (i.e., Balongan Unit 2, Balikpapan Unit 2, and Cilacap) in 2025, RDMP Dumai in 2026, and two GRR projects in 2026. This collective effort is projected to add 952 MBSD of new refinery capacity from 2022 to 2026, bringing the country's total refinery capacity to 2,121 MBSD. Consequently, the average refinery inputs are expected to increase from 920 thousand bpd in 2019 to 1.78 million bpd in 2026. This surge in capacity is anticipated to boost fuel production to 1.5 million bpd in 2026, doubling the production recorded in 2019.

Table 5. Revised targets of refinery capacity (MBSD)<sup>15,17</sup>

Indicator	RUEN targets	New targets				
		2022	2023	2024	2025	2026
Additional capacity	1,258 in 2025	50	50		152	700
RDMP Balongan	150 in 2023	50			50	
RDMP Balikpapan	100 in 2019		50		50	
RDMP Cilacap	22 in 2022				52	
RDMP Dumai	130 in 2023					100
GRR West I Tuban	300 in 2021					300
GRR West II (MBSD)	300 in 2024					
GRR Bontang	300 in 2023					300
Accumulative capacity	2,425 in 2025	1,219	1,269	1,269	1,421	2,121

In conclusion, oil still plays a crucial role in meeting energy needs in the transportation sector. The role of oil

remains vital during the transition to Net Zero Emissions (NZE). Indonesia's efforts have successfully increased oil production in 2016, but this increase has only slowed down the decline in oil production. The government also needs to formulate clean energy policies to reduce oil consumption and ultimately decrease oil imports. Some of these policies include the development of biofuels and electric vehicles.

### 3.2. Clean Energy Policies to Reduce Oil Imports

#### 3.2.1 Biofuel Policies

Indonesia embarked on its biofuel initiative as early as 2006, with a directive that mandated all ministers, governors, mayors, and regents to expedite and endorse the utilization of biofuels<sup>23</sup>). Two years later, the government instituted a regulation specifying the minimum biofuel blend requirements in the transportation, industrial, commercial, and power sectors<sup>24</sup>). In 2009, another policy was introduced to oversee the supply and distribution of biofuels<sup>25</sup>). At that time, biodiesel production stood at 190 thousand kiloliters (kl), with allocations for both the domestic market (62.2%) and exports (36.8%)<sup>26</sup>).

The government has been expediting the blending level mandatory in accordance with the preparedness of biodiesel industries and automotive manufacturers. Between 2013 and 2015, the mandatory biofuel blend was revised three times<sup>24,27,28</sup>). Biodiesel utilization, as a mixture of gasoil, saw a continuous increase from 0.92 million kl in 2015 to 6.4 million kl in 2019, as indicated in Table 6<sup>17</sup>). Consequently, gasoil consumption reduced from 8.1 million kilolitres (kl) in 2009 to 545 thousand kl in 2019. Meanwhile, biodiesel consumption surged from 2.3 million kl to 26.2 million kl during the same period<sup>17</sup>). By the beginning of 2020, the mandatory blending level had reached 30% (known as B30 fuel), making it the highest mandatory mix globally<sup>29</sup>). This resulted in biodiesel consumption in 2019 exceeding the target outlined in RUEN. Despite a 10% decline in fuel consumption due to the Covid-19 pandemic, biodiesel consumption reached around 8.4 million kl in 2020. Biodiesel consumption is expected to continue rising, particularly after the mandatory biodiesel blend increased to 35% in February 2023.

Table 6. The comparison of actual biodiesel consumption and RUEN's projection<sup>15,17</sup>

Biodiesel consumption (million kl)	2015	2016	2017	2018	2019	2020
RUEN projection	2.3	3.4	4.3	5.3	6.4	7.7
Actual data	0.9	3.0	2.6	3.8	6.4	8.4

A crucial factor contributing to the increased consumption of biodiesel is the stability of crude palm oil

(CPO) prices. The government supports biodiesel consumption through subsidies, which are calculated based on the Market Price Index (HIP) of biodiesel (B100) and gasoil. These subsidies are funded by CPO export levies managed by the Palm Oil Plantation Fund Management Agency (BPDPKS) under the Ministry of Finance.

Until the first quarter of 2020, CPO levies were sufficient to cover the B30 subsidy. However, the sharp decline in oil prices due to the Covid-19 pandemic, affecting the Mean of Plats Singapore (MOPS) price, coupled with restrictions on labor in palm plantations in Malaysia, created challenges. As a result, the gap between gasoil HIP and biodiesel HIP widened to IDR 5,000/liter or US\$ 34 ¢/liter, making it financially unsustainable for BPDPKS to cover the subsidy. In response, in May 2020, the government announced the distribution of additional biodiesel subsidies from the central government budget.

In contrast, the mandate for bio-gasoline has not been successful, leading to a continuous increase in gasoline consumption from 21.4 million kl in 2009 to 35.3 million kl, representing 52% of the total fuels consumed by the transportation sector in 2019<sup>17)</sup>. Between 2006 and 2009, a small volume of gasoline marketed in Indonesia was blended with ethanol at a 2% ratio, known as E2. However, the implementation of mandatory ethanol blends faced challenges due to rising ethanol production costs, lower gasoline prices, and the absence of subsidies<sup>30)</sup>. To address these issues, the Ministry of Energy and Mineral Resources relaxed the ethanol blend mandate in 2015, reducing it from 5% to 1%. Despite this adjustment, the new mandate still could not be effectively implemented<sup>24,28,31)</sup>.

Likewise, the mandate for crude vegetable oil blends has proven to be ineffective. The State-owned Electricity Company has shown a preference for higher quality biodiesel over crude vegetable oils. In 2018, Indonesia attempted to reintroduce crude vegetable oils as fuels for 3,000 MW oil-fueled power plants<sup>26)</sup>. The National Standardization Agency of Indonesia has established a quality standard for crude vegetable oil for use in low-speed diesel engines<sup>32)</sup>. However, various trials indicate that the quality standard is still not compatible with the fuel specifications for diesel power plants. The use of crude vegetable oil as fuel leads to the rapid formation of deposits in various key components of diesel power plants<sup>33–35)</sup>.

Indonesia is also actively engaged in the development of green fuels in various forms, including green diesel<sup>36–39)</sup>, sustainable aviation fuels<sup>40)</sup>, and green gasoline<sup>38,41)</sup>. The production of these green fuels can capitalize on existing and under-construction refineries by utilizing the zeolite-based catalyst currently being developed by the Bandung Institute of Technology<sup>42,43)</sup>. This catalyst has been tested to produce green diesel in the RU Dumai and to produce green gasoline and green aviation gasoline in the RU Cilacap. These refineries utilize the Residue Fluid

Catalytic Cracking (RFCC) unit to co-process refined bleached deodorized palm oil (RBDPO) and vacuum gas oil (VGO) to produce green fuels<sup>44)</sup>. The co-processing technology implemented in the RU II Dumai, RU IV Cilacap, and RU IV Balongan has the potential to produce green fuels at a rate of 2,000 bpd, equivalent to 100 thousand kl per year. Furthermore, the State-owned Oil and Gas Company has committed to constructing a standalone green fuel refinery in the RU III Plaju, with a plan to produce one million kl of green diesel annually starting in 2024. The government is also encouraging private sectors to invest in standalone green fuel refineries with a capacity of 1.6 million kl per year. Another measure is the revamping technology to modify the RU IV Cilacap, with capacity 6,000 bpd, to process RBDPO into green diesel, green jet fuel, naphtha, and LPG. The technology is expected to produce 300 thousand kl of green diesel per year, starting in 2023.

### 3.2.2. Electric Vehicle Policies

The average annual growth rates of vehicles from 2010 to 2019 were relatively high, approximately 8.1% for cars and 8.7% for motorcycles<sup>45)</sup>. As a result, the number of cars reached 15.6 million units, and motorcycles reached 112.8 million units by the end of this period<sup>45)</sup>. Due to this substantial increase in the vehicle population, the government has been actively promoting electric vehicles as a strategy to reduce gasoline consumption. The targets in RUEN are 2,200 units of electric cars and 2.13 million electric motorcycles by 2025<sup>21)</sup>.

In 2019, the government took significant steps to accelerate the battery electric vehicles (BEVs) program for road transportation, as evidenced by the release of a presidential decree<sup>46)</sup>. Subsequently, various ministries have actively followed up on this Presidential Decree with related initiatives. The Ministry of Industry issued specifications, a roadmap, and local content requirements for electric vehicles<sup>47)</sup>. The Ministry of Transportation released two ministerial decrees focusing on safety requirements for electric vehicles and regulations for the conversion of internal combustion (IC) motorcycles into electric motorcycles<sup>48)</sup>. The Ministry of State-owned Enterprises directed its enterprises to collaborate and provide spare parts for electric vehicles<sup>49)</sup>. The Ministry of Energy and Mineral Resources established regulations for the standardization of electric charging stations<sup>50)</sup>. The Ministry of Finance introduced tax incentives and a fuel subsidy shifting formula<sup>46)</sup>. The Ministry of Domestic Affairs and several local governments have also provided tax incentives for electric vehicle users<sup>51)</sup>.

The public launch of BEVs on December 17, 2020, marked a significant milestone for Indonesia. It led to a revision of the RUEN targets for electric vehicles, as outlined in Table 7. By the end of 2025, the expected figures for electric motorcycles and electric cars are 757 thousand units and 19 thousand units, respectively. In addition, the targets for battery swap stations and battery

charging stations are set at 11,240 and 88,045 stations, respectively. Notably, the public transportation sector has also embarked on the use of electric buses, with a target of 220 units in 2021 and an ambitious goal of 10,227 units by the end of 2025.

Table 7. Targeted volumes of battery swab stations, charging stations, and electric vehicles<sup>17)</sup>

Indicators	2021	2022	2023	2024	2025	Total
Battery swab stations	1,072	1,143	3,237	3,328	2,460	11,240
Charging stations	14,610	14,211	16,799	18,261	24,164	88,045
Electric motorcycles	40,444	145,280	178,935	239,726	152,754	757,139
Electric cars	640	1,993	5,774	5,775	5,038	19,220
Electric buses	220	758	3,118	2,675	3,456	10,227
Other electric vehicles	1,032	1,085	1,147	2,260	475	5,999
<b>Total</b>	<b>58,018</b>	<b>164,470</b>	<b>209,010</b>	<b>272,025</b>	<b>188,347</b>	<b>891,870</b>

The primary factor driving the BEVs adoption is its lower cost<sup>52,53)</sup>. BEVs are widely recognized for having lower energy costs compared to internal combustion vehicles (ICEVs)<sup>54,55)</sup>. However, BEVs are more expensive than ICEVs, so the comparison should be made on the total cost of ownership (TCO). BEVs have a lower TCO in high mileage user cases. Otherwise, the price of BEVs should be reduced for the TCO of BEVs to be lower than the TCO of ICEVs<sup>56)</sup>.

To further promote the affordability of BEVs, the Ministry of Energy and Mineral Resources initiated the conversion of old and inefficient motorcycles into electric motorcycles at a cost of US\$ 690 per unit in March 2021. These converted motorcycles underwent rigorous testing for safety and performance through inspections conducted by the Ministry of Transportation, along with a 10,000 km road test<sup>57,58)</sup>. The successful conversion led to the transformation of 100 units of motorcycles owned by the Ministry of Energy and Mineral Resources. This conversion initiative engaged small automotive garages and vocational schools to disseminate skills related to electric motorcycle conversion and maintenance. The government is planning to scale up the program to national level by converting 1,000 motorcycles in 2022, 100,000 motorcycles in 2024, and 6 million motorcycles in 2026. The plan targets old and inefficient motorcycles owned by ministries, local governments, and state-owned enterprises. The conversion program is expected to reduce gasoline consumption by 12.8 million barrels per year starting in 2026. The government plans to scale up this program on a national level by converting 1,000 motorcycles in 2022, 100,000 motorcycles in 2024, and an ambitious target of 6 million motorcycles in 2026. The focus is on old and inefficient motorcycles owned by ministries, local governments, and state-owned

enterprises. The conversion program is anticipated to significantly reduce gasoline consumption by 12.8 million barrels per year, starting in 2026.

## 4. Policy Discussions and Conclusions

The transformation in Indonesia's oil markets, marked by declining oil production and a shift away from oil as a leading export commodity, has prompted strategic changes in the country's energy landscape. The government has imposed restrictions on oil exports, while concurrently expanding refinery capacity to accommodate anticipated surges in oil production resulting from recent upstream oil and gas policies.

In the realm of biofuel policies, Indonesia is actively pursuing various pathways to advance biofuels. One notable avenue is the development of Hydro Processed Esters and Fatty Acids (HEFA) biodiesel within the Hydrotreated Vegetable Oil (HVO) category. HEFA biodiesel, compared to Fatty Acid Methyl Ester (FAME) biodiesel, offers several advantages, including being free of sulfur and aromatics, possessing a higher cetane number, featuring a higher heating value, and exhibiting fuel quality independent of feedstock properties<sup>59,60)</sup>. Importantly, the blending of HVO/HEFA biodiesel with gasoil faces no limit due to their similar properties.

The emerging BEV market has prompted the formulation of electric vehicle battery recycling policies. Proper recycling and waste management are essential components of a holistic and environmentally responsible approach to the development of electric vehicle technologies. The Ministry of Environment and Forestry should regulate battery waste management. Their role includes setting guidelines and regulations for the proper disposal and recycling of electric vehicle batteries to minimize environmental impact. The Ministry of Industry plays a crucial role in establishing and supporting battery waste recycling industries. This involves promoting and overseeing the development of facilities dedicated to the recycling and repurposing of electric vehicle batteries. The Ministry of Trade is responsible for creating a battery trade-in scheme. This scheme facilitates the transportation of used batteries to recycling industries. By encouraging trade-ins, the ministry aims to streamline the collection and recycling processes for electric vehicle batteries.

However, the government needs further evaluation regarding the sustainability of the BEV program. One industry that requires attention is the manufacturing of lithium-ion EV batteries, which constitutes about 50% of the BEV cost. The production of lithium-ion batteries relies on materials like lithium, cobalt, copper, manganese, aluminum, nickel, or graphite. While Indonesia has significant nickel reserves, it lacks other essential resources. Consequently, Indonesia may need to procure raw materials from other countries. Meanwhile, the supply availability of these critical minerals is insufficient to meet the global targets for EV usage<sup>61)</sup>.

This paper concludes that the pathway toward oil



supply security in Indonesia appears to be accountable and reliable. The key factors influencing this pathway include innovation capabilities, efficient models of energy mix, and the increasing growth of electric vehicles. These elements are identified as central issues for policy recommendations in the petroleum industries and resource-based economies, particularly as the global energy landscape undergoes transitions towards cleaner alternatives.

Our conclusion complements the findings of previous studies that oil and gas industries are essential for the transition to NZE<sup>62)</sup>. Xie and Harjono also expressed concerns about the impact of insufficient investments on new refinery and oil productions on the increase in oil fuel imports in Indonesia<sup>63)</sup>. Our study also suggests that the oil and gas industry infrastructure can be utilized to develop clean energy, namely, the production of green fuels in this study, the developments of CCS facilities<sup>9)</sup>, and the production of chemical energy carriers<sup>8)</sup>.

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### Nomenclature

<i>BEVs</i>	Battery electric vehicles
<i>BPDPKS</i>	Palm oil plantation fund management agency
<i>CPI</i>	Chevron Pacific Indonesia
<i>CPO</i>	Crude palm oil
<i>EOR</i>	Enhanced oil recovery
<i>EPC</i>	Engineering Procurement Construction
<i>EVs</i>	Electric Vehicles
<i>FAME</i>	Fatty acid methyl esters
<i>GRR</i>	Grass root refinery
<i>HEFA</i>	Hydro processed esters and fatty acids
<i>HVO</i>	Hydrotreated Vegetable Oil
<i>IC</i>	Internal combustion
<i>LPG</i>	Liquefied Petroleum Gas
<i>MBSD</i>	Thousand barrel per stream day
<i>MIP</i>	Market price index
<i>MOPS</i>	Mean of plats Singapore
<i>NZE</i>	Net Zero Emission
<i>OPEC</i>	Organization of the Petroleum Exporting Countries
<i>PLN</i>	The state-owned electricity company
<i>RBDPO</i>	Refine bleached deodorized palm oil
<i>RDMP</i>	Refinery development master plan
<i>RFCC</i>	Residue fluid catalytic cracking
<i>RUEN</i>	Rancangan umum energi nasional or

National Energy General

*RU* Refinery unit

*US* The United State

*VGO* Vacuum gas oil

### References

- 1) BP, "BP statistical review of world energy june 2020," (2020).
- 2) O. Farobie, and E. Hartulistiyoso, "Palm oil biodiesel as a renewable energy resource in indonesia: current status and challenges," *Bioenergy Res*, 1–19 (2021).
- 3) A. Halimatussadiah, D. Nainggolan, S. Yui, F.R. Moeis, and A.A. Siregar, "Progressive biodiesel policy in indonesia: does the government's economic proposition hold?," *Renewable and Sustainable Energy Reviews*, **150** 111431 (2021).
- 4) REN21, "Renewables 2021 Global Status Report," Renewable Energy Policy Network for the 21 Century (REN21) Secretariat, Paris, 2021.
- 5) BPS, "Tabel input output indonesia 2016," (2021).
- 6) BPS-Statistics Indonesia, "Neraca energi indonesia 2016-2020," (2020).
- 7) MEMR, "Handbook of energy & economic statistics of indonesia 2020," (2021).
- 8) D.J. Smit, and J.B. Powell, "Role of international oil companies in the net-zero emission energy transition," *Annu Rev Chem Biomol Eng*, **14** 301–322 (2023). doi:10.1146/annurev-chembioeng-092220-030446.
- 9) A. Hastings, and P. Smith, "Achieving net zero emissions requires the knowledge and skills of the oil and gas industry," *Frontiers in Climate*, **2** (December) 1–11 (2020). doi:10.3389/fclim.2020.601778.
- 10) A. Rahman, P. Dargusch, and D. Wadley, "The political economy of oil supply in indonesia and the implications for renewable energy development," *Renewable and Sustainable Energy Reviews*, **144** 111027 (2021).
- 11) N. Sunny, A. Bernardi, D. Danaci, M. Bui, A. Gonzalez-Garay, and B. Chachuat, "A pathway towards net-zero emissions in oil refineries," *Frontiers in Chemical Engineering*, **4** (February) 1–8 (2022). doi:10.3389/fceng.2022.804163.
- 12) X. Bao, A. Frago, and R. Aguilera, "Improving oil recovery while helping to achieve net zero emissions from shale reservoirs," *SPE Latin American and Caribbean Petroleum Engineering Conference Proceedings*, **2023-June** (2023). doi:10.2118/213136-MS.
- 13) J. Choo, B. Novia, and A.I. Hakim, "Establishing sustainable oil and gas industry: directional drilling & measurement/logging while drilling remote operations to achieve net zero carbon future in indonesia," *IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition*, D012S002R001 (2022). doi:10.2118/209896-MS.

- 14) "A review of motor vehicle fuel demand and supply in indonesia - international council on clean transportation," (n.d.). <https://theicct.org/publication/a-review-of-motor-vehicle-fuel-demand-and-supply-in-indonesia/> (accessed December 2, 2023).
- 15) GOI, "Presidential decree number 22 of 2017 on the national energy general plan," (2017).
- 16) W. Faisol, S. Indriastuti, and A. Trihartono, "Indonesia and OPEC: why does Indonesia maintain its distance?," in: IOP Conf Ser Earth Environ Sci, IOP Publishing, 2020: p. 12010.
- 17) MEMR, "Handbook of energy & economic statistics of indonesia 2019," (2020).
- 18) MEMR, "Statistik ketenagalistrikan 2020," (2021).
- 19) MEMR, "Handbook of energy & economic statistics of indonesia 2018," (2019).
- 20) A. Fadolly, "Essays on the Development of Oil Refinery and Power Generation in Indonesia: Optimization and System Dynamic Model," Seoul National University Library, 2021.
- 21) GOI, "Peraturan presiden republik indonesia nomor 22 tahun 2017 tentang rencana umum energi nasional," (2017).
- 22) F.A. Adam, "Cancellation of saudi aramco investment in cooperation to develop the oil refinery in cilacap," (2022). doi:10.4108/EAL.14-9-2021.2321383.
- 23) GOI, "Law number 30 of 2007 on energy," (2007).
- 24) MEMR, "Ministerial decree of energy and mineral resources number 12 of 2015 on the third amendment of the ministerial decree of energy and mineral resources number 32 of 2008 on supply, utilizations, and commerce of biofuel as alternative fuels," (2015).
- 25) GOI, "Presidential decree 45 of 2009 on amendment to presidential decree 71 of 2005 on supply and distribution of certain types of oil fuel," (2009).
- 26) M. Darmawan, R., Wargadalam, V., Aldilla, I., Ikhsan, A., Putriyana, L., Moristanto, Dilisusendi, T., Saptono, A., Haviati, E., Farida, M. E., Ariyani, Y., Dharma, I.P., Rachmawati, Y., Yuliani, F., Hargiyanto, S., Hidayat, A., N., K.M., S., S.R., Marsupriad, "Peta Jalan Pengembangan Biofuel Berbasis CPO Untuk Memenuhi Target Bauran Energi 2020 - 2045," P3TKEBTKE & IRAI, Jakarta, 2019.
- 27) MEMR, "Ministerial decree of energy and mineral resources number 25 of 2013 on the amendment of the ministerial decree of energy and mineral resources number 32 of 2008 on supply, utilizations, and commerce of biofuel as alternative fuels," (2013).
- 28) MEMR, "Peraturan menteri energi dan sumber daya mineral nomor 27 tahun 2014 tentang pembelian tenaga listrik dari pembangkit listrik tenaga biomassa dan pembangkit listrik tenaga biogas oleh pt perusahaan listrik negara (persero)," (2014).
- 29) REN21, "Renewables 2020 Global Status Report," Renewable Energy Policy Network for the 21 Century (REN21) Secretariat, Paris, 2020.
- 30) A. Rahmanulloh, "Indonesia Biofuels Annual Report 2019," USDA Foreign Agricultural Service, Jakarta, Indonesia, 2019.
- 31) MEMR, "Peraturan menteri energi dan sumber daya mineral nomor 19 tahun 2013 tentang pembelian tenaga listrik oleh pt perusahaan listrik negara (persero) dari pembangkit listrik berbasis sampah kota," (2013).
- 32) SNI 8483:2018, "Mutu dan metode uji minyak sawit mentah untuk bahan bakar motor diesel putaran rendah," Badan Standarisasi Nasional (BSN), Jakarta, Indonesia., (2018).
- 33) N. Cahyo, H.H. Alif, A. Aprilana, and R.B. Sitanggang, "An experimental study on performance, emission and deposit characteristic in low-speed diesel engine 4,897 kwe fueled with crude palm oil," *AIP Conf Proc*, **2376** (1) 020011 (2021). doi:10.1063/5.0063492.
- 34) N. Cahyo, M. Triani, and R.B. Sitanggang, "Gas emission analysis of low-speed diesel engines when operating using crude palm oil," *ICT-PEP 2021 - International Conference on Technology and Policy in Energy and Electric Power: Emerging Energy Sustainability, Smart Grid, and Microgrid Technologies for Future Power System, Proceedings*, 58–62 (2021). doi:10.1109/ICT-PEP53949.2021.9601103.
- 35) PLN, "Running Test-MAK #2 & Running Test-ALLEN #3 Progress - September 2019," PT Perusahaan Listrik Negara (PLN) Puslitbang Ketenagalistrikan, Jakarta, 2019.
- 36) G.F. Neonufa, T.H. Soerawidjaja, A. Indarto, and T. Prakoso, "An innovative technique to suppress alkene-bond in green diesel by mg–fe basic soap thermal decarboxylation," *International Journal of Ambient Energy*, **40** (4) 374–380 (2019). doi:10.1080/01430750.2017.1399451.
- 37) R. Putra, W.W. Lestari, F.R. Wibowo, and B.H. Susanto, "Fe/indonesian natural zeolite as hydrodeoxygenation catalyst in green diesel production from palm oil," *Bulletin of Chemical Reaction Engineering & Catalysis*, **13** (2) 245–255 (2018).
- 38) A. Sugiyono, I. Fitriana, A.H. Budiman, and A. Nurrohm, "Prospects for the Development of Green Gasoline and Green Diesel from Crude Palm Oil in Indonesia," in: Materials Science Forum, Trans Tech Publ, 2020: pp. 202–208.
- 39) A. Zikri, I. Puspita, Erlinawati, M.S. PLAGus, P.B.E. Zalita, and K. Andre, "Production of Green Diesel From Crude Palm Oil (CPO) Through Hydrotreating Process by Using Zeolite Catalyst," in: 4th Forum in Research, Science, and Technology (FIRST-T1-T2-2020), Atlantis Press, 2021: pp. 67–74.
- 40) J.S. Sabarman, E.H. Legowo, D.I. Widiputri, and A.R. Siregar, "Bioavtur synthesis from palm fatty acid distillate through hydrotreating and hydrocracking

- processes,” *Indonesian Journal of Energy*, **2** (2) 99–110 (2019).
- 41) E. Styani, R. Ekananda, and S.R. Tandaju, “Catalyst to oil mass ratio optimization on fluid catalytic cracking process in green gasoline production,” in: *J Phys Conf Ser*, IOP Publishing, 2020: p. 12012.
  - 42) M.L. Gunawan, T.H. Novita, F. Aprialdi, D. Aulia, A.S.F. Nanda, C.B. Rasrendra, Z. Addarajah, D. Mujahidin, and G.T.M. Kadja, “Palm-oil transformation into green and clean biofuels: recent advances in the zeolite-based catalytic technologies,” *Bioresour Technol Rep*, **23** 101546 (2023). doi:10.1016/J.BITEB.2023.101546.
  - 43) F. Harahap, S. Leduc, S. Mesfun, D. Khatiwada, F. Kraxner, and S. Silveira, “Meeting the bioenergy targets from palm oil based biorefineries: an optimal configuration in indonesia,” *Appl Energy*, **278** 115749 (2020). doi:10.1016/J.APENERGY.2020.115749.
  - 44) O.A. Olafadehan, O.P. Sunmola, A. Jaiyeola, V. Efeovbokhan, and O.G. Abatan, “Modelling and simulation of an industrial rfccu-riser reactor for catalytic cracking of vacuum residue,” *Appl Petrochem Res*, **8** (4) 219–237 (2018).
  - 45) BPS, “Perkembangan jumlah kendaraan bermotor menurut jenis, 1949-2019,” **2017** (2021).
  - 46) GOI, “Presidential decree number 55 of 2019 on the acceleration of the program of battery electric vehicles for road transportations,” 16 (2019).
  - 47) MI, “Peraturan menteri perindustrian nomor 22 tahun 2020 tentang ketentuan dan tata cara penghitungan nilai tingkat komponen dalam negeri produk elektronika dan telematika,” (2020).
  - 48) MOT, “Ministerial decree of transportation number 45 of 2020 on specific vehicles using electric motor drive,” (2020).
  - 49) MSE, “Ministerial decree of state-owned enterprises number sk-28/mbu/01/2020 on the establishment of a team for accelerating the ev battery development by state-owned enterprises,” (2020).
  - 50) MEMR, “Peraturan menteri energi dan sumber daya mineral nomor 3 tahun 2020 tentang perubahan keempat atas peraturan menteri energi dan sumber daya mineral nomor 28 tahun 2016 tentang tarif tenaga listrik yang disediakan oleh pt perusahaan listrik negara (persero),” (2020).
  - 51) MDA, “Ministerial decree of domestic affairs number 8 of 2020 on basic calculation of motor vehicle tax imposition and motor vehicle title fee in 2020,” (2020).
  - 52) D.A. Asfani, I.M.Y. Negara, Y.U. Nugraha, M.N. Yuniarto, A. Wikarta, I. Sidharta, and A. Mukhlisin, “Electric vehicle research in indonesia: a road map, road tests, and research challenges,” *IEEE Electrification Magazine*, **8** (2) 44–51 (2020).
  - 53) E. Guerra, “Electric vehicles, air pollution, and the motorcycle city: a stated preference survey of consumers’ willingness to adopt electric motorcycles in solo, indonesia,” *Transp Res D Transp Environ*, **68** 52–64 (2019).
  - 54) M. Weiss, K.C. Cloos, and E. Helmers, “Energy efficiency trade-offs in small to large electric vehicles,” *Environ Sci Eur*, **32** (1) 1–17 (2020).
  - 55) P. Weldon, P. Morrissey, and M. O’Mahony, “Long-term cost of ownership comparative analysis between electric vehicles and internal combustion engine vehicles,” *Sustain Cities Soc*, **39** 578–591 (2018).
  - 56) D. Kumar, G. Kalghatgi, and A.K. Agarwal, “Comparison of economic viability of electric and internal combustion engine vehicles based on total cost of ownership analysis,” *Energy, Environment, and Sustainability*, 455–489 (2023). doi:10.1007/978-981-99-1517-0\_20/COVER.
  - 57) A.I. Firmansyah, N.K. Supriatna, Y. Gunawan, G.T. Setiadanu, and Slamet, “Performance Testing of Electric Motorcycle Conversion,” in: 2022 7th International Conference on Electric Vehicular Technology (ICEVT), 2022: pp. 165–168. doi:10.1109/ICEVT55516.2022.9924921.
  - 58) Y. Gunawan, N.K. Supriatna, A.I. Firmansyah, S. Slamet, N.A. Wicaksono, K. Ahadi, and N.R. Fadhilah, “Endurance testing of the electric vehicle that converted from the internal combustion engine vehicle,” *International Journal of Sustainable Transportation Technology*, **5** (2) 61–69 (2022). doi:10.31427/ijstt.2022.5.2.2.
  - 59) H. Aatola, M. Larmi, T. Sarjoavaara, and S. Mikkonen, “Hydrotreated vegetable oil (hvo) as a renewable diesel fuel: trade-off between no<sub>x</sub>, particulate emission, and fuel consumption of a heavy duty engine,” *SAE Int J Engines*, **1** (1) 1251–1262 (2009).
  - 60) J.C. Laurentino Alves, “Vibrational spectroscopy for the quantification of hydrotreated vegetable oil (hvo) advanced biofuels in petroleum-derived fuel blends: a minireview,” *Anal Lett*, 1–18 (2021).
  - 61) B. Ballinger, M. Stringer, D.R. Schmida-Lopez, B. Kefford, B. Parkinson, C. Greig, and S. Smart, “The vulnerability of electric vehicle deployment to critical mineral supply,” *Appl Energy*, **255** 113844 (2019). doi:10.1016/J.APENERGY.2019.113844.
  - 62) Z. Wang, S. Li, Z. Jin, Z. Li, Q. Liu, and K. Zhang, “Oil and gas pathway to net-zero: review and outlook,” *Energy Strategy Reviews*, **45** (December 2022) 101048 (2023). doi:10.1016/j.esr.2022.101048.
  - 63) “A review of motor vehicle fuel demand and supply in indonesia - international council on clean transportation,” (n.d.). <https://theicct.org/publication/a-review-of-motor-vehicle-fuel-demand-and-supply-in-indonesia/> (accessed December 2, 2023).