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Review

The Emerging Electric Vehicle and Battery Industry in Indonesia: Actions around the Nickel Ore Export Ban and a SWOT Analysis

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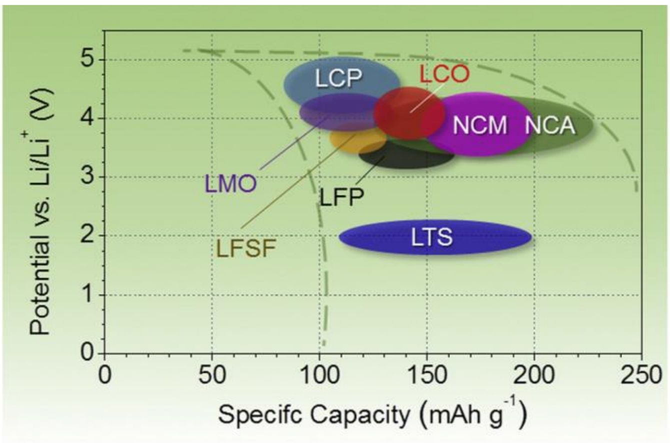
Abstract: As the automotive industry shifts from internal combustion engine (ICE) vehicles to electric vehicles (EVs), many countries are setting new strategies in their transportation sector. The Li-ion battery is currently the most common battery used in EVs due to its high energy density, durability, safety, and cost competitiveness. Nickel is predicted to be an essential component for the lithium nickel cobalt manganese oxide (NMC) as a cathode material of choice for EV applications. Indonesia, one of the world's largest nickel ore suppliers, put an export ban on nickel ore effective from 2020. The bold movement was intended to initiate the domestic EV industry and encourage investors abroad to drive their manufacturing activities into the country. On the other hand, the global Li-ion battery manufacturers who imported nickel from Indonesia had to restrategize their businesses. This review discussed the chronological events leading to the ban and after the ban from the media, government regulations, and literature reviews. The authors of this study also conducted interviews and attended seminars with the national experts and key players in the battery and EV industry to gain their most pertinent insights. The SWOT analysis of the reviewed materials indicated that while the Indonesian battery industry is still new, it needs to diversify its research and development activities and collaborate internationally to optimize the utilization of its resources and meet the purchasing power of the domestic EV market. Finally, this study summarized six key factors to support Indonesia's ambition to be a new regional hub for EVs. These factors are: (1) pricing, (2) technology, (3) policy, (4) investment, (5) infrastructure, and (6) compliance with sustainability standards.

Keywords: battery; electric vehicle; EV battery materials; nickel; Li-ion battery; cathode

1. Introduction

The transportation sector contributes to approximately a quarter of all energy-related greenhouse gas (GHG) emissions [1] or approximately 12 Gt of CO_2-equivalent per year [2]. The high contribution is mainly because fossil fuel (FF)-based internal combustion engine (ICE) vehicles still dominate the sector. A global comparison of the life-cycle greenhouse gas emissions of ICE vehicles and electric vehicles (EVs) concluded that only the battery-based EVs and hydrogen fuel cell EVs have the potential to achieve the required lifecycle GHG emissions reduction needed to meet the Paris Agreement goals [2]. On the other hand, the EV market is regarded as a significant contributor to the rising demand for Li-ion batteries. As a result, the stationary energy storage demand is predicted to experience a significant growth. As reported by the World Economic Forum, the total global battery demand in 2030 is expected to grow at an estimated 25% annual rate exceeding 2600 GWh, almost ten times higher than the demand in 2020 [3]. Since commercialization by Sony in 1991, Li-ion batteries containing $LiCoO_2$ (LCO) as the cathode and graphite as the anode have become the staple technology used in portable electronic devices. However, the high cost of cobalt and limited capacity of $LiCoO_2$ have driven the substitution of Co with Mn and Ni during the past couple of decades, which has led to the development of $LiNi_{1-y-z}Mn_yCo_zO_2$ (NMC) with higher energy density and lower cost. Moreover, due to socioeconomic and sustainability issues, since 70% of today's mined cobalt originates from the Democratic Republic of Congo (DRC), where artisanal mining and child labor are involved [4], LCO is not considered as the cathode of choice for EV applications. Thus, increasing the nickel content and lowering or eliminating the cobalt in NMC cathodes is becoming more prominent for EV applications.

Figure 1 depicts an approximate potential vs. specific capacity of the active materials for the cathode and anode. Here, LCO stands for lithium cobalt oxide, LMO for lithium manganese oxide, NCA for nickel cobalt aluminum oxide, LCP for lithium cobalt phosphate, LFP for lithium iron phosphate, and LTS for lithium titanium sulfide. For EV applications, the layered NMC poses good electronic conductivity and has a close-packed structure with high density, while NCA has been developed to give a maximum energy density (200 mAhg^{-1}); however, it is very reactive and rather complicated to handle. On the other hand, the polyanion oxide (LFP) suffers from poor electronic conductivity and has 20 to 50% lower energy density than other chemistries due to a lower voltage at 3.2 V vs. 3.6 V; however, it has the advantage of lower cost and better safety due to the stable phosphate group. On the anode side, silicon is considered a promising material to replace conventional graphite since it has the highest theoretical specific capacity of ~3579 mAh g^{-1} which is almost ten times that of graphite anodes (theoretical capacity: 372 mAh g^{-1}) [5].



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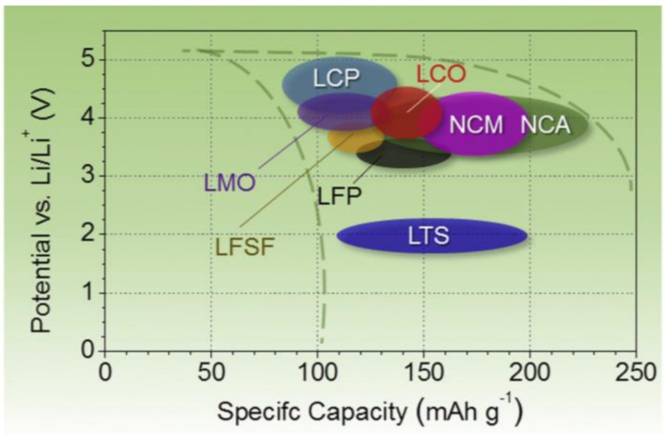


(**b**)

Figure 1. Approximate average discharge potentials and specific capacity of the most common (**a**) cathode and (**b**) anode [6]. Reprinted with permission from ref. [6]. 2015 Elsevier.

In Europe, as shown in Table 1, the development of cathodes for current EV batteries started from relatively high nickel chemistry (NCM 532 to NCM 622) in 2020. These will be progressively eliminated by higher nickel chemistries such as NCM 811. From 2025 onwards, these high nickel chemistries will dominate at least 70–80% of the European cathode. High-voltage spinel or lithium nickel manganese oxide (LNMO) is also expected to be used in Generation 3b. On the anode side, silicon is blended with the graphite or carbon, forming silicon/carbon composites to increase the total energy density of the cells. Beyond 2030, all-solid-state batteries (ASSBs) with Li anodes are envisioned to replace conventional Li-ion batteries by substituting the flammable electrolyte with the solid-state electrolyte to increase the energy density and improve safety.

Table 1. Current cell generation and chemistry.

Cell Generation	Cell Chemistry
Generation 5	• I/O_2 (lithium-air)
Generation 4	• All-solid-state batteries with Li anode • Conversion material (Li-S)
Generation 3b	• Cathode: HE-NCM, HVS (high-voltage spinel) • Anode: silicon/carbon composites
Generation 3a	• Cathode: NCM622 to NCM811 • Anode: graphite + silicon (5–10%)
Generation 2b	• Cathode: NCM532 to NCM622 • Anode: graphite
Generation 2a	• Cathode: NCM532 to NCM622 • Anode: graphite
Generation 1	• Cathode: NCM532 to NCM622 • Anode: graphite

Unlike the EU and Korea, which will concentrate on NCM-based chemistries, in China, the demand growth of LFP cathodes throughout 2021 has been significant, accounting for 51.1% or 47.0 GWh of battery production in EVs [7]. As a result, the largest China-based battery maker, CATL, plans to build a new USD 280 M, 80 ton per year LFP cathode material plant in China [8].

The type of nickel suitable for batteries is type I, which contains 99.8% Ni, whereas type II is mainly for stainless steel production [9]. Indonesia has both types of nickel, and while other countries are experiencing a decline in nickel production, Indonesia has experienced the highest growth in the past few years (Figure 2) [10]. Therefore, it is expected that the world's demand for EVs will continue to grow at an increased pace. Furthermore, in 2018, a Bloomberg report [11] stated that the world battery industry leaders such as Tesla Inc., LG Chem Ltd., and BMW AG are shifting to high-nickel cathodes to increase the battery density. As a result, the nickel needed for EV batteries will be increasingly coming from Indonesia, mainly through high-pressure acid leaching (HPAL) technology [11]. With HPAL technology, battery-grade nickel sulfates can be produced from lower-grade laterite ores. Of the 220,000 tons of the world's HPAL project production capacity being developed, seventy percent are located in Indonesia [11].

To push the domestic EV industry, the Indonesian government had released an export ban for nickel ore. The regulation had formerly been issued and has been revised multiple times since 2009 [12]. It finally became effective in 2020 [13], which is two years earlier than previously scheduled. National regulation uncertainty is usually a significant turn-off for investors [14] as it adds risks to an investment's sustainability. However, international companies such as the German BASF and the Japanese Mitsui Sumitomo establish nickel processing facilities in Indonesia [15]. Furthermore, Indonesia recently established the Indonesia Battery Corporation (IBC) in March 2021 with equal shareholders from four state-owned enterprises operating in aluminum smelting, mining, oil and gas, and electricity (PT Indonesia Asahan Aluminum/Inalum), PT Anyam Tbk (ANTM), PT Pertamina, and PT PLN, respectively). IBC has also signed a memorandum of understanding (MoU) with Hyundai Motor Group and LG Energy Solution (South Korea) in July 2021 to establish an EV battery cell plant [16]. Indonesia and Thailand aim to be new hubs for EVs, especially for the Association of Southeast Asian Nation (ASEAN) region [17]. Meanwhile, in the same year, Tesla decided to make a long-term shift of their battery toward the older and cheaper LFP cells for some of their entry-level EVs [18–20].

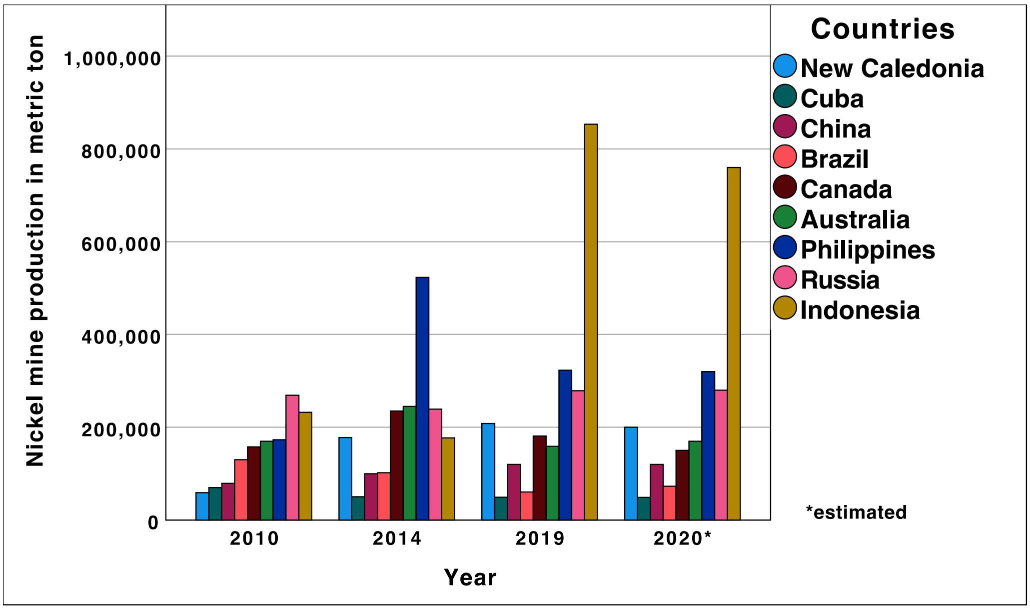


Figure 2. World primary countries' nickel mine production. Plotted from [10] data.

This study aims to summarize the activities around the nickel ore ban issued by the Indonesian government, particularly the domestic EV and the battery industries. Literature reviews are summarized to build and present the chronological events leading to and after the ban to achieve this goal. The output of this study is threefold; (1) factors that could support an emerging EV and battery industry; (2) the strength, weaknesses, opportunities, and threats (SWOT) of the Indonesian EV and battery industry; and (3) policy recommendations for the battery industry in Indonesia. The broader implication of this study would be to help players in the EV industries in other emerging countries to make better-informed decisions.

2. Materials and Methods

This study reviews the governmental laws, past research, and news on the nickel ban and the recent development of Indonesia's EV and battery industry in Indonesia. Furthermore, in-depth interviews and seminars with the national experts and key stakeholders in the EV and battery industries and the government are conducted (Figure 3). Specifically, this study reviewed the Indonesian government laws on mineral exports, such as nickel mining, processing, and exporting regulations in the EV industry. From the collected information, the authors of this study arranged the events to create a chronological timeline. Furthermore, to obtain a more extensive and actual view on the subject, the authors of this study conducted in-depth interviews with national EV experts and the chief executive officer (CEO) of an Indonesian EV company to identify the current regulation, infrastructure development, technology development status, costs, risks, market, and commercialization of EVs. Moreover, the authors of this study participated in a seminar with the president director of a battery company in Indonesia, the Directorate General of Metal, Machinery, Transportation Equipment, and Electronics Industries of the Ministry of Energy and Mineral Resources (MEMR) of the Republic of Indonesia, and the president director of an EV company in Indonesia. This study also provides a snapshot of the total cost of ownership (TCO) of a two-wheeler EV and a four-wheeler EV in Indonesia as reported by the end-user to provide a perspective on the cost comparison between ICE vehicles and EVs. Finally, based on the SWOT analysis of these resources, the present study summarizes key factors and policy recommendations supporting the emerging EV and EV battery industries to sustain in Indonesia.

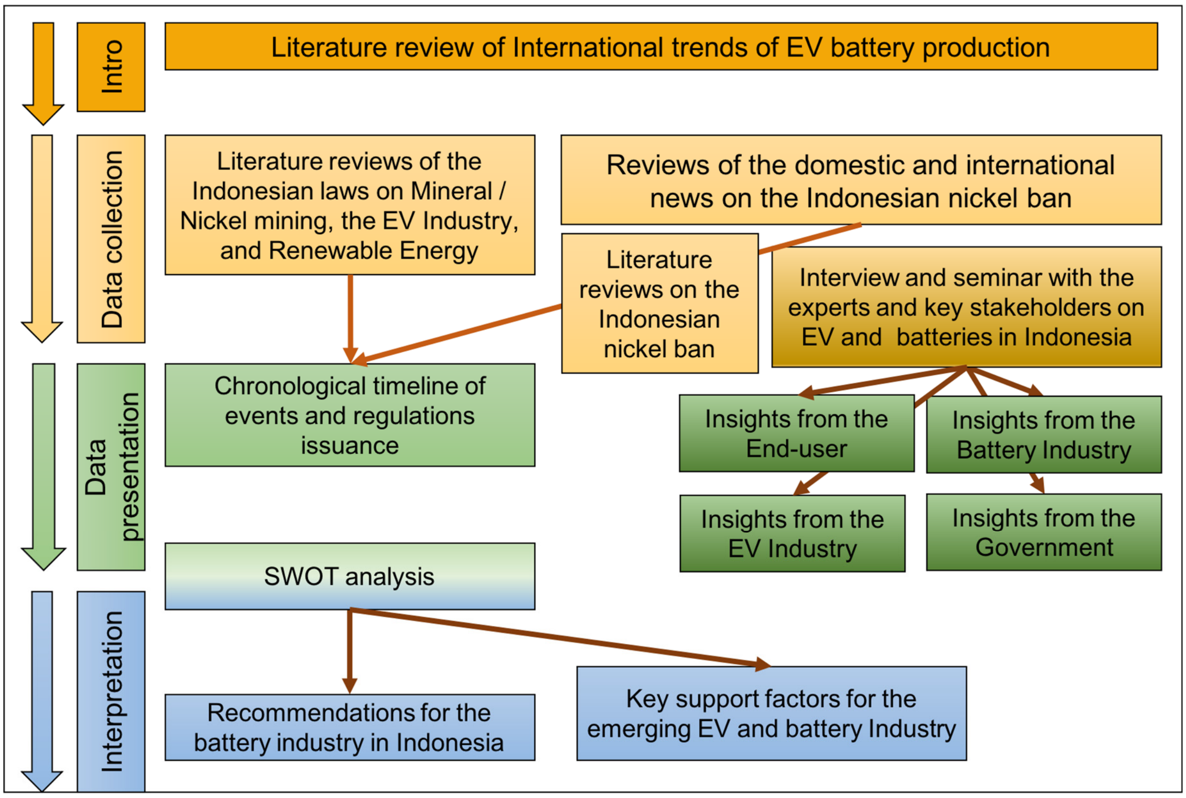


Figure 3. Research framework.

3. Results and Discussion

3.1. Literature Reviews from the Media, Academic Journals, and Records of Official Government Regulations

This study summarized the government laws and regulations about mineral mining, reports from online newspapers both in Indonesian and English, and literatures on the Indonesian nickel ban as a chronological timeline of Indonesia's nickel ore export ban (Figure 4). In 2009, the law about coal and mineral mining (Law Number 4, Year 2009) was first introduced to prohibit mining companies in Indonesia, mainly mineral and coal, from exporting their raw minerals before being processed domestically. The law requires all mining companies in Indonesia to own their smelter to process raw materials into finished or semifinished materials. In the following year, another law was issued (Government Regulation Number 23 Year 2010), making it mandatory for mining companies to process and purify the minerals as an added value for the products before exporting them. However, companies with mining businesses that owned permits (IUP/IUPK) for operation and production before the previous regulation was issued are given relaxation for up to 5 years to equip their smelters with facilities for processing or purification domestically. This policy aims to increase the added value of Indonesia's export goods, and the desired result is to gain better profitability. Four years after the second law was issued, an amendment was made to relax the restriction (Government Regulation Number 1 Year 2014). In the amendment, mining companies with permits and processing and purification facilities can export raw materials in a limited quantity. In the same year, MEMR released a ministry regulation containing guidelines on what is considered to be adding value to the minerals in the purification activities. The regulation also stated that all mining companies should process and purify the minerals domestically. Some companies, however, can still export raw materials in limited quantities, but they are instructed to be able to export finished materials or semifinished materials within three years. In 2017, another government regulation was released, containing concessions for the export of raw minerals for mining companies with several conditions. First, they have to change the Contract of Work (KK) permit into a Mining Business Permit (IUP) or a Special Mining Business Permit (IUPK). Second, after changing the permit, the mining companies must build a smelter or refinery within five years. In 2018, a ministry regulation (Number 25 Year 2018) permitted exporting raw minerals with minimum nickel content. The government also announced for the first time, with this regulation, that the nickel ore export ban would be enforced from 11 January 2022. However, two years before the scheduled banning, in 2020, the law to ban nickel ore export became effective (Law Number 3 Year 2020) [21]. This law also states that all mining companies are obliged to increase the added value of minerals in mining business activities through processing and purification for metal mineral mining commodities, and this must be done domestically.

Shortly before and after the ban was released, several events occurred both domestically and internationally. Goldman Sachs forecasted that the nickel price could spike up for three months. It was also predicted that the ban could impact up to 10% of the global supply [22]. Toward the end of 2020, the European Union (EU) filed the first lawsuit against the World Trade Organization (WTO) in opposition to the ban [23]. It was argued that Indonesia had violated Article XI on the restriction of export and import in the General Agreement on Tariff and Trade (GATT) [24], and the ban hurts the European steel industry due to limited access to nickel ore and other mineral ores such as iron ore and chromium. Compared to China, the amount of nickel the EU imported from Indonesia is less significant, at approximately 3.5% to 5% between 2009 and 2013. Furthermore, there was no record of nickel export to the EU during 2015 and 2016 [25]. However, a significant increase in nickel purchases by the EU from Indonesia was observed in 2019 [23]. This new dependency may have triggered the reactions against the ban. On the other hand, although acquiring about 50% of the world's nickel supply, China is prosperous with its nickel reserve. China also made a USD 4 billion investment in one of Indonesia's largest nickel smelters in Morowali, Central Sulawesi Province. The investment is for the construction of a lithium battery factory and a used battery recycling factory. The investment, made by CATL, also involves multinational companies such as LG, Panasonic, Volkswagen, and Mercedes Benz [26].

Until present, Indonesia had met the EU at the WTO panel two times in early 2020 [27] and early 2021 [28], due to Indonesia's resistance to canceling the ban [29]. The Indonesian president stated that "*there would be no going back on this policy*" [30]. Domestically, some events arose due to the ban. In June 2020, at the beginning of the COVID-19 pandemic, the Indonesian Nickel Miners Association (APNI) appealed to the government to end the export ban because of the reduced earnings and profitability among domestic ore producers. However, this appeal was rejected by the government [31]. Another domestic reaction was a violent demonstration by PT VDNI nickel smelter workers, a leading Chinese ferronickel manufacturer (parent company: Jiangsu Delong Nickel Industry Co., Ltd., Yancheng, China) in Konawe Regency, South Sulawesi, Indonesia; they were disappointed about their employment status and salary [32]. Despite international and domestic resistance, the government argued that there are several reasons why the nickel ore ban is essential to be kept in place. Some of them are: (1) to strengthen the domestic downstream of the nickel industry; (2) to countermeasure concerns about the remaining limited amount of the domestic nickel raw material reserves; (3) to make the most out of the promising growth of the domestic nickel smelter production; (4) to optimally facilitate the development of EVs; and (5) to power Indonesia's trade balance and national economic growth [33]. Finally, in March 2021, Indonesia officially established the IBC.

3.2. Seminar and Interviews with the Battery and EV Experts and Stakeholders

This study conducted in-depth interviews with national experts in the EV industry and participated in a seminar with the key stakeholders of the domestic EV company, battery company, and the government to present an actual and extensive view of the topic. Insights from each stakeholder group are summarized in this subsection.

3.2.1. Insights from the Government

Globally, every country has a strategy in entering the era of EV. For example, Japan aims for carbon neutrality by 2050 [34]. In the transportation sector, the country promotes green hydrogen technology as a significant part of its plan. Japan also includes highly efficient battery-based EVs and hybrid vehicles to maintain its competitiveness in the global automotive market. Meanwhile, the United States, where Tesla is the leading EV manufacturing company in the country, is reconsidering the LFP technology to reduce the cost of the battery. Designing national plans for the automotive sector should emphasize the technical perspective and the economic and commercial aspects. For the penetration of EV technology in Indonesia, this is especially important. With a population of over 270 million [35] in Indonesia, the impact of a new economic policy is immense. Financially, the contribution from the automotive industry in Indonesia is 20% of the overall industrial sector. The industrial sector contributes 20% of the national gross domestic product (GDP) [36]. Presently, approximately 96% of the automotive industry in Indonesia is still ICE-based. Approximately 1.5 million people are working for the ICE-based automotive industry in Indonesia, including the vehicle component manufacturers, assembly, and services [36]. Therefore, shifting the automotive industry from ICE to EV through introducing new policies must be done very carefully. An abrupt shift will disrupt the welfare of the people currently working in the ICE-based automotive industry. Therefore, those workers should be included in the shifting process. The government targets include a minimum requirement of 40% of domestically manufactured EV parts [37]. Indonesia has issued a roadmap for EVs aiming for 25% EV operation in 2025 [38]. Investment opportunities are encouraged with the promotion of high local content vehicles to achieve this goal.

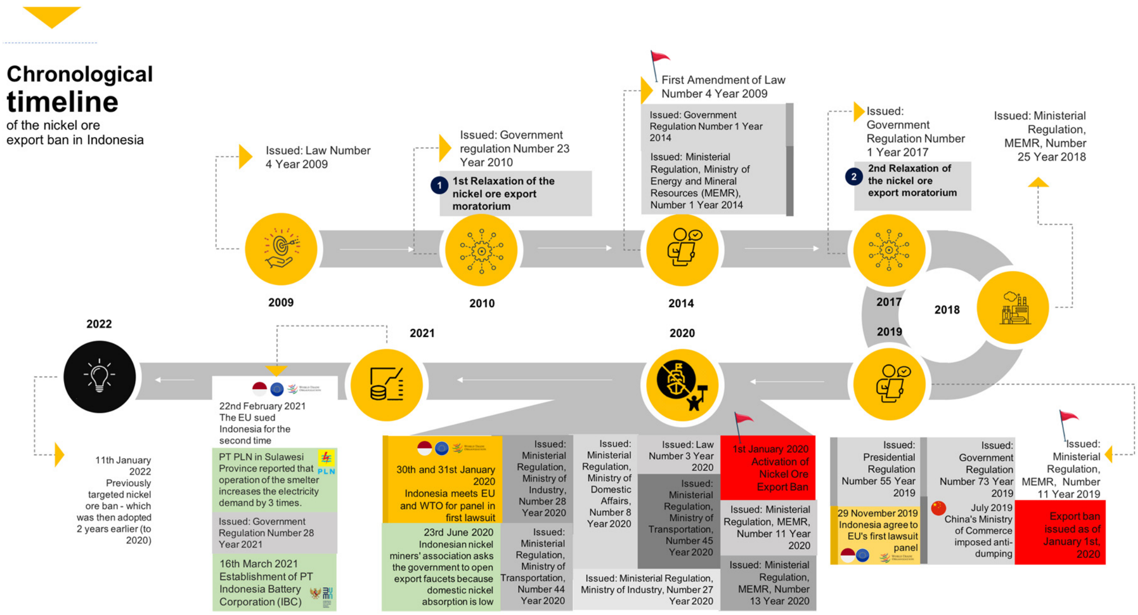


Figure 4. Chronological timeline of events and regulations issuance related to the nickel ban, EV, and EV battery industry (compiled by authors from [13,21,23,25,27,28,32,38–51]).

At present (August 2021), there are 21 EV developer companies in Indonesia; most of them are initiated by Japanese investors. The market growth potential of the automotive business in Indonesia is quite significant. Currently, the car ownership ratio is only 90 cars per 1000 people [52]. While there is still room to increase the car ownership rate, the Indonesian GDP per capita is only USD 3870 [53]. Compared to the European market, the largest consumer of EVs, their GDP per capita is almost tenfold at USD 33,927 [54]. Similarly, Japan's GDP per capita is USD 40,113 [55], and the United States is USD 63,544 [53]. It is then vital to consider the purchasing power of the Indonesian people when targeting the Indonesian market. Designing EVs appropriate to the needs of the Indonesian people and reducing the price by domestically manufacturing the batteries are key because the battery is the most expensive part of an EV. The projected EV selling price that is appropriate for the purchasing power of the Indonesian people is approximately USD 20,000 per unit of car [36]. The government has issued series of policy instruments to accelerate the growth of the EV industry—the government plans to purchase domestically made EVs to be used as their officials' vehicles. Series of tax abatements and discounts have also been released, and the national banks provide soft loans for EV purchases [56,57].

Furthermore, the government also provides a deductible tax for domestic research and innovation at approximately a 300% increase to encourage researchers to contribute to the EV industry [58]. Therefore, it is now a matter of how early and how far Indonesia can master battery technology and create innovations to drop the price of batteries. The price of batteries has gradually decreased over the years. In 2010, the battery price was high at approximately 1000 USD/kWh [59]. However, it has fallen to 100 USD/kWh [60]. As a result, it is forecasted that the EV price can soon become competitive with its ICE counterpart [61].

In Indonesia, some metal smelters are already in operation and under construction to supply materials for the initiated battery industry (Figure 5). The most significant investment is from China, and this is natural because China was also Indonesia's largest nickel importer before the nickel ore ban was introduced [23]. Some added value is created by driving the investment domestically, generating income from employment, investment, tax, and export. In the smelter location map (Figure 5), areas indicated in yellow are the smelter locations under construction. The parts indicated in blue are the battery-producing companies.

Other than nickel, there are other metal reserves in Indonesia that can be used in battery production. Among these are copper, aluminum, manganese, and cobalt (Figure 6). Mining companies such as PT. ANTAM and PT. Inalum target these reserves to supply the battery industry. The cathode and packing material manufacturing industry will also utilize these reserves in the battery supply chain. The type of battery to be produced by these companies is the lithium-ion battery. However, Indonesia does not own a lithium reserve. Lithium has to be imported mainly from China, Australia, and Chile [36]. Environmentally, battery production processes create a large carbon footprint [36], which is destructive to the environment. While it is vital to utilize the available material reserves to improve the Indonesian economy, as a long-term goal, it is necessary to consider other energy storage technologies that produce fewer environmental footprints.

3.2.2. Insights from the Battery Industry

The world demand for Li-ion batteries is predicted to increase rapidly. By 2027, it is predicted that the demand will surpass the supply [9]. By 2030, the demand for Li-ion batteries will likely reach 1800 GWh while the supply will only be available at approximately 1668 GWh [62]. Indonesia has the potential to fill the 132 GWh of this supply gap [63]. Domestically, it is predicted that there will be about 30 GWh demand for Li-ion batteries [63]. This demand is made up of 19 GWh to suffice the demand for four-wheeler EVs, 5.3 GWh for the two-wheeler EVs, and approximately 1.8 GWh for energy storage system (ESS). Battery demand for ESS is predicted to increase because it is needed to support the national renewable energy (RE) targets. Indonesia aims for 23% of new energy and RE in the national energy mix by 2025 and at least 31% by 2050 [64]. Securing the added value towards the downstream of the battery production is crucial because the price-multiplying effect is tremendous (Table 2). The added value of a battery cell relative to the ore price is approximately 90 to 150 times [63]. Other than nickel, Indonesia has various mining reserves necessary for manufacturing batteries (Figure 6). Therefore, there is a wide range of value-adding opportunities for the domestic battery industry to reap benefits.

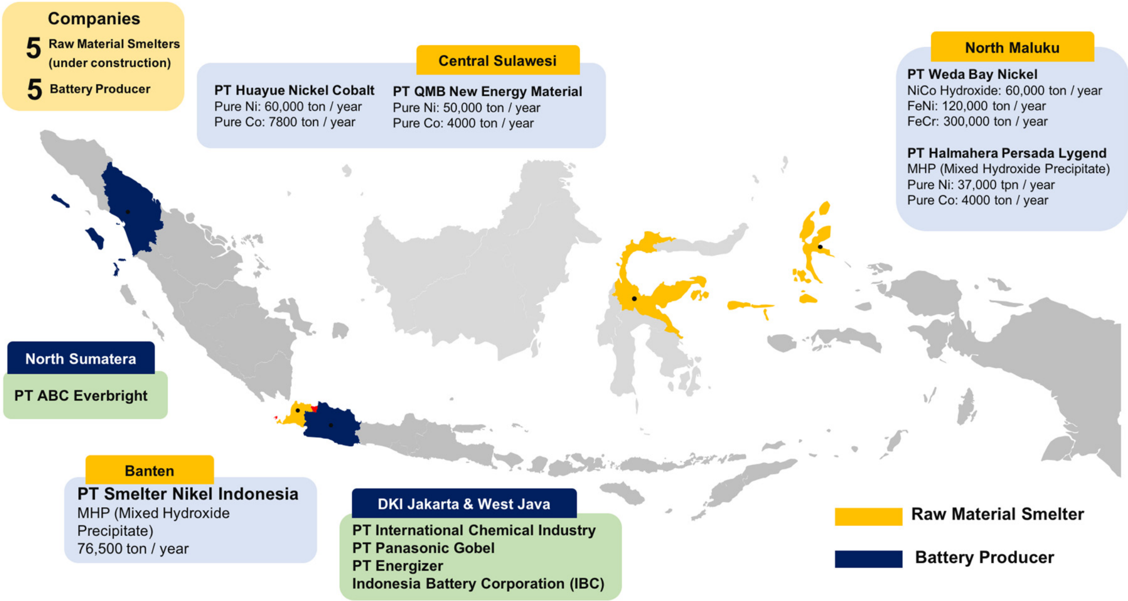


Figure 5. Map of smelters and battery-producing companies in Indonesia (compiled by authors from [36,63]).

Table 2. Added value multiplication effects along the supply chain of an EV battery [63,65].

	Nickel Ore	MHP	$NiSO_4$	Precursor	Cathode	Battery Cell
Increased added value (1000 USD/ton Ni)	1.1 to 1.7	up to 10	up to 14	25 to 30	45 to 55	90 to 150
Value-added relative to the ore price	-	30 to 40 times				90 to 150 times

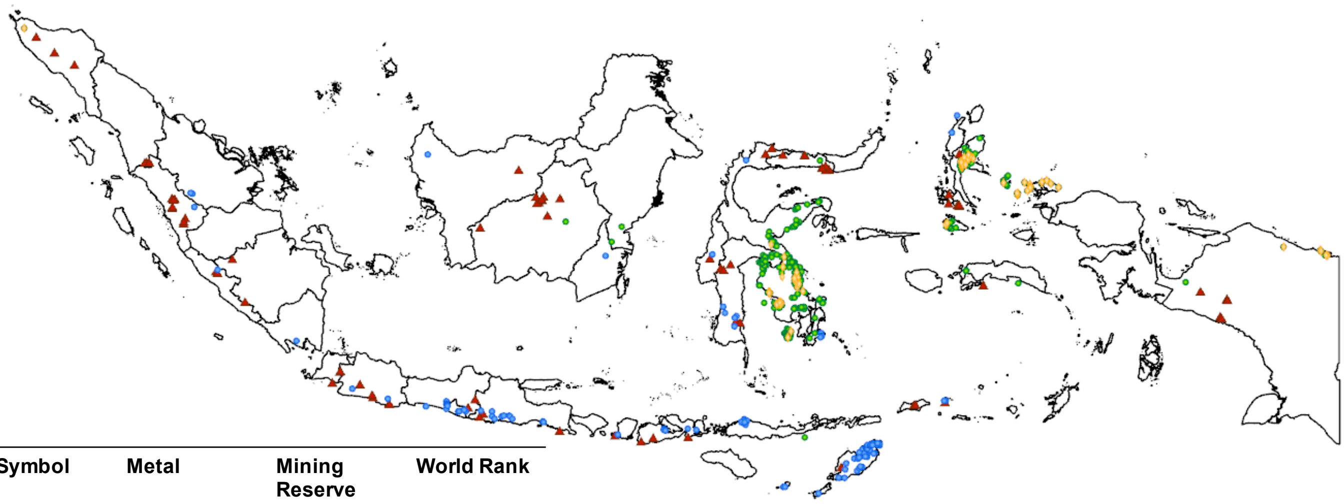
Despite the long history of FF reserve abundance in Indonesia, the country has become a crude oil importer in the past few years [66]. While it is predicted that there will be vehicles powered by various fuels operating in Indonesia (namely the FF, biodiesel, and EV), EV will, in particular, contribute to a significant reduction in cost from the avoidance of importing FF. For example, a 30% ICE conversion to EV will save approximately 2 to 2.5 million USD/year [63]. Furthermore, by joining the forces of major government-owned companies in Indonesia and collaborating with domestic and international investors, Indonesia aims to be the hub of EV production in the ASEAN region. The top global EV- and ESS-producing companies, CATL from China and LG Chem from South Korea, have partnered with the IBC to achieve this goal.

Creating a suitable domestic environment is necessary to accelerate the marketing of domestically produced EVs. Therefore, IBC also assists with battery charging stations. As the two-wheelers from the smartphone app-based food delivery transportation industry (e.g., Grab, Uber, and Gojek) may be the entry point of EV commercialization in Indonesia, the speed of charging the battery of electric motorbikes becomes an important aspect. To assist this need, battery-swapping, instead of the actual plug-in charging, has been selected as the technology for the public charging stations. Presently, a 10 GWh capacity battery factory is being constructed by the partnership of IBC with Hyundai and LG Chem [63]. By 2025, a 140 GWh capacity battery factory will be in full operation. There are some identified key factors to warrant the success of this target; the price range for four-wheelers suitable for the domestic market is predicted at approximately USD 14,000 per unit and for the two-wheelers it is approximately USD 1200 per unit. Therefore, achieving this price range is vital for the commercial ability of EVs in the country. In addition to the raw material, the battery production technology also contributes to the pricing of the final product. Indonesia currently does not own such technology and still relies on foreign companies. It is estimated that if activities along the production chain can be performed domestically, approximately 20% of the cost can be reduced, and domestic employment can be increased significantly [65]. Environmental wise, the international partners of IBC have global markets that demand green certifications. Responding to the demand, RE or green certified energy must be secured for the whole production chain. Ensuring clean energy supply throughout the production chain is especially important for one of the largest energy-consuming production chain activities, the HPAL, which requires approximately 300 to 400 MW power supply capacity [63]. Furthermore, the establishment of recycling facilities will also determine whether the batteries can be treated appropriately at their end-of-life.

3.2.3. Insights from the EV Industry

The TCO of an EV is smaller than an ICE [67], due to the lower fuel and maintenance costs. However, a survey conducted by Deloitte [68] shows that currently, only 3% of the motorbikes and 13% of the personal car owners are willing to shift to EVs if the EV selling price is still higher than that of an ICE vehicle. In the case where EVs are at the same price as the ICE vehicle, a significant 61% of the market is willing to shift to EV [69]. Furthermore, a significant 23% of the surveyed people plan to buy an EV as their next vehicle. However, this number is still significantly low compared to the 74% of people who still plan to buy an ICE vehicle as their next vehicle. Those who are planning to buy an EV expect to charge EVs most often at home (59%), followed by at the public charging station (29%), and at work (11%) [68]. This kind of customer survey result may influence financial loan institutions such as banks regarding their willingness to lend capital for EV-related businesses in the country. Policywise, the industry is supported by the government regulations that push the industry forward and the established driving permit system from the police department [69]. Technologywise, the industry is developing the designs, spare parts, and other necessary components to produce EVs with a high percentage of domestically produced components to receive incentives from the government and the industry is designing the products in ways that match the needs and purchasing power of the Indonesian market.

Charging stations established in other Asian countries such as Taiwan, China, and India have shown success in serving the needs of EV users in their countries. In Taiwan, a smartphone app-operated battery swap charging stations are widespread. Gogoro Inc., one of the charging station brands in Taiwan, has over 2000 charging stations and it is claimed that the electric scooters can ride up to 170 km for every battery swap [70]. The battery-sharing business model is popular in China, especially in EV-exclusive areas [71,72]. In India, a charging station with a fixed battery is being implemented, for example, by the Ather company, which claims fast charging at strategic points being built across the country [73]. Considering the examples from those highly populated countries, Wika, an Indonesian company producing EV motorbikes, develops a detachable battery so that users can charge their batteries at home, in the office, or in any room with electric sockets. An actual vehicle does not have to be brought close to the charging socket [69].



Symbol	Metal	Mining Reserve (million ton)	World Rank
	Nickel	21	1st
	Copper	51	5th
	Cobalt	Unknown	Unknown
Unknown	Aluminum	1200	6th
	Manganese	43	6th

Figure 6. EV battery material reserves location in Indonesia (compiled by authors from [36,63,74]).

An EV motorbike has fewer parts than an ICE motorbike. Furthermore, most of the parts are transferrable. The only new parts that need to be developed by EV motorbike producers would be the battery, controller, and motor [69]. Measured by the economic value, the Wika's first EV motorbike line *Gesits G1* has achieved 46.7% of its components being made domestically. Componentwise, the company has 85% of the items required for manufacturing supplied by 24 domestic producers [69]. If the domestically produced battery becomes available, it will contribute to a significant 16% increase in the final product's domestic component requirement. Increasing the percentage of domestically made components is essential as it will determine whether the government will purchase them [37] to be used as the officials' vehicle totaling approximately 39,000 units [36] and whether manufacturers will receive other EV regulation supports. Table 3 shows the current state of components' domestic availability in order to manufacture batteries, motors, and controllers for an electric motorbike. While some components are still imported, the materials needed to manufacture these parts are domestically available. For example, the wire cable for the controller is mainly made of copper and aluminum. These metals are available domestically [36] (Figure 6). Like the challenge for battery cell production, the country must develop its technology to produce a high-quality wire cable compatible with the new demand in the emerging EV industry in the country.

Table 3. Domestic product availability of components for battery, motor, and controller [69,75].

	Battery Parts	Brushless DC Motor (BLDC) Parts		Controller Parts
Imported (as of 2021)	Battery Management System (BMS)	Stator core	Insulation tube B	Mainboard PCB controller
	Battery cell	Vinalon rope Heat shrink black	Insulation tube C Rotor core Magnet rotor 35	Wire cable + socket connector
Domestically available	Top cover Socket connector	Enameled wire Copper tube	Rear bracket assy Thermal sensor assy	Plastic cover Heatsink Aluminum
	Cover body extrusion	Varnish A	Rear bracket	Component assembly and integration
	Plastic bottom cover	Solder bar	Front bracket material	Software & programming

Table 3. *Cont.*

Battery Parts	Brushless DC Motor (BLDC) Parts		Controller Parts
Component assembly	Flux solder	O. ring bracket	
	Motor frame	Magnet sensor assy	
	Bolts stopper stator	PCB assy	
	Cable assy	PCB holder	
	Cable seal	Sensor cover	
	Cable plate	O. ring sensor cover	
	Bold cable plate	Bold sensor cover	
	Shaft material	Oil seal	
	Rear endplate	Pulley	
	Front end plate		

3.2.4. Insights from the End-Users

The well-to-wheel (WTW) concept, or the overall chain from production to consumption, can be broken down into: (1) the well-to-tank (WTT) process, which considers the raw materials for the vehicle production; and (2) the tank-to-wheel (TTW) process, which considers the necessary resources to operate a vehicle over a given distance [76]. While manufacturers are mainly concerned with the WTT processes, most end-users are more interested in the costs that must be borne within the TTW boundary. In other words, end-users are more interested in whether the TCO of an EV can be cheaper than an ICE vehicle. Figure 7a,b presents the TCO comparison of the two-wheeler EV and ICE vehicle, and four-wheeler EV and ICE vehicle, respectively. Prices are converted from IDR to USD using October 2021 rates.

The assumed travel distance boundary for the two-wheeler vehicles is 32,000 km, which equal to approximately 3 to 6 years of use or the average duration of motorbike use of the Indonesian people before changing to a different model. The two-wheeler vehicle comparison shows that although the purchasing price for EVs is higher (approximately 2000 USD/unit) [77] than that for ICEs (approximately 1120 USD/unit) [78], almost all the remaining costs required (administration fees, operational cost, taxes, and maintenance costs) are lower for EVs. The government provides tax abatement and discounts for EVs and discounted electricity fees during the overnight charging hours. Moreover, the regular spare part replacement for an EV motorbike is considered minimal. Only the brake lining and the belt (costing USD 11.31) [79] must be changed. The frequency of changing the brake lining depends on how the brake is used, and the belt should be changed every 3000 km traveled. Because EV has only been available on the Indonesian market for a few years, the reselling price is only an estimation [80]. Beyond the assumed travel distance boundary, reinvestment of the EV motorbike battery may become necessary. This reinvestment will require an additional USD 353.13 [81]. A local EV motorbike brand offers a three-year warranty for the battery at the time of its release. Moreover, in the case of multiple vehicle ownership, additional EVs are not burdened with a progressive tax, which is an increased annual tax that depends on the number of vehicles owned. Progressive tax abatement is applicable for both the 2-wheelers and 4-wheelers.

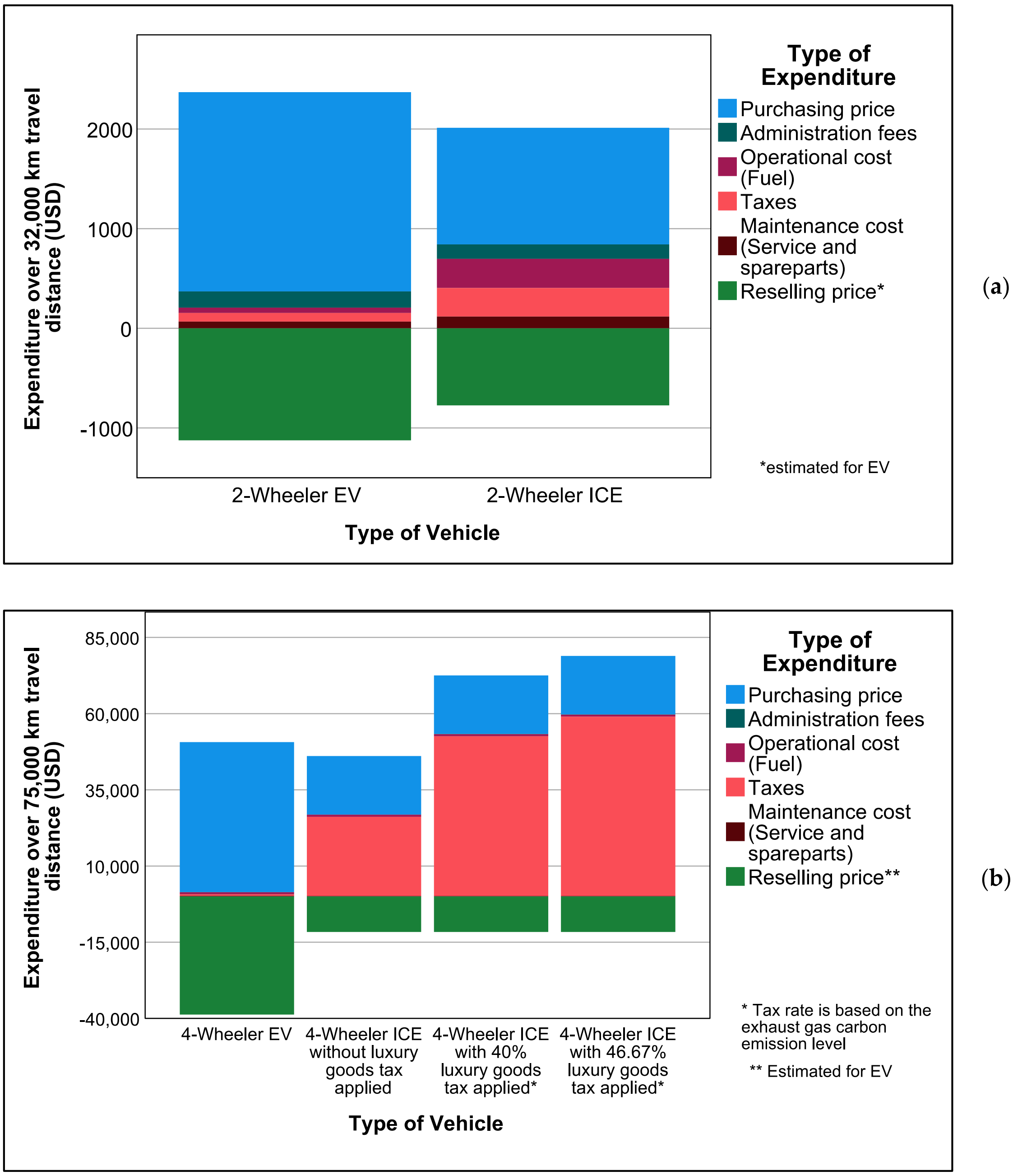


Figure 7. Comparison of the total cost of ownership: (**a**) two-wheeler EV and two-wheeler ICE vehicle, and (**b**) four-wheeler EV and four-wheeler ICE vehicle. Compiled by authors from [77–80,82–91].

The assumed travel distance boundary for the four-wheeler vehicles is 75,000 km, equal to approximately five years of use, which is the average duration of the Indonesian people before changing to another model [91]. The assumed type of the 4-wheeler EV is an entry-level passenger car with less than ten passengers capacity. The assumed type of the 4-wheeler ICE vehicle is a passenger car with less than ten passenger capacity and less than 3000 cc engine cylinder capacity. The comparison in Figure 7b shows that tax abatement (made up of tax for luxury goods abatement, name transfer tax abatement, and reduced annual tax (from 2% to 0.2% for the Jakarta case), significantly reduced the EV TCO. The reselling price of a five-year-old 4-wheeler EV is just an estimation because EV car penetration into the Indonesian market is presently still less than five years. Both the EV and ICE vehicle producers offer up to five years of free maintenance cost [84,89,90]. Without this offer, the EV maintenance cost is estimated to be approximately USD 212 for the overall five years [89]. The ICE maintenance cost varies between USD 46 and USD 147 depending on the km distance traveled [84]. Regular maintenance for an EV is only required for every 15,000 km distance traveled but for ICE, it is required for every 10,000 km distance traveled [88]. Relative to the 4-wheeler ICE, the TCO of a 4-wheeler EV has very recently become more attractive because of the introduction of the Government Regulation Number 74, Year 2021 [83]. The regulation applies the luxury goods tax on 4-wheelers based on their exhaust gas emissions and became effective on 16 October 2021. This new regulation applies the tax on ICE vehicles and hybrid vehicles based on their engine cylinder capacity and fuel efficiency or the CO_2 emissions per km traveled. The tax rate scenarios in Figure 7b for the 4-wheel ICE assumed a 150 g/km CO_2 emission level (15%) and above 250 g/km emission level (40%) [83].

3.3. SWOT Analysis

The strength of the Indonesian EV and battery industry lies in the abundant and diverse mining resources to manufacture batteries (Figure 6), high productive age population that can serve both as market and human resources, and experience in manufacturing ICE vehicles. However, while the country is blessed with resources, the necessary technological knowledge for battery production is presently unavailable. Moreover, the situation becomes more challenging because of the low WTP and market awareness of a low-carbon lifestyle. Such weaknesses can be addressed by opportunities to collaborate with internationally established battery industries through investment schemes and partnerships with other countries. On the other hand, the low percentage of RE in the national energy mix poses a concern about EV sustainability, especially as the electricity demand is expected to increase if EV is widely used in the country. It is then the right time for the government to enable the growth of RE by introducing ambitious policies and regulations. There are some threats that could pose barriers to the initiatives. These include the uncertain outcome of the ongoing lawsuit against the nickel ore export ban at the WTO and competing technologies such as hydrogen-fuel-cell-based vehicles and more affordable nonnickel batteries. While the government has provided the necessary policy instruments to support mechanisms for different fuels (biodiesel, FF, electricity), hydrogen-based transportation's potential should also be considered. Furthermore, focusing only on nickel will pose a threat as nickel is considerably more expensive than other materials such as iron. The SWOT analysis is summarized in Figure 8.

4. Conclusions

Major EV producers and consumer countries worldwide are focusing on technology development for EV energy storage. Most of these countries are the developed countries with high GDP per capita. Indonesia's initiative to reduce the transportation sector's national carbon emissions by joining the shift toward the EV world is backed up with a vast amount of domestic mining reserves necessary for battery production. Furthermore, the country has considerable market potential both domestically and globally. Battery, the most popular technology for energy storage for EVs with a high readiness level, is being scrutinized for ways to reduce its production cost. As the United States' largest EV producer Tesla announced their intention to revisit the LFP technology to reduce cost and remove dependency on nickel, actions towards looking for alternative materials and protecting mining reserves emerged globally. Once the largest world nickel supplier [10], Indonesia introduced a nickel ore export ban [21] to build its domestic EV and battery industry. The present study reviewed government regulations and insights from the key stakeholders: the government, the battery industry, and the EV industry. This study concludes that six factors may support this initiative. These are: (1) pricing, (2) technology, (3) policy, (4) capital investment, (5) infrastructure, socialization, and marketing, and (6) compliance with sustainable practices and certifications (Figure 9).

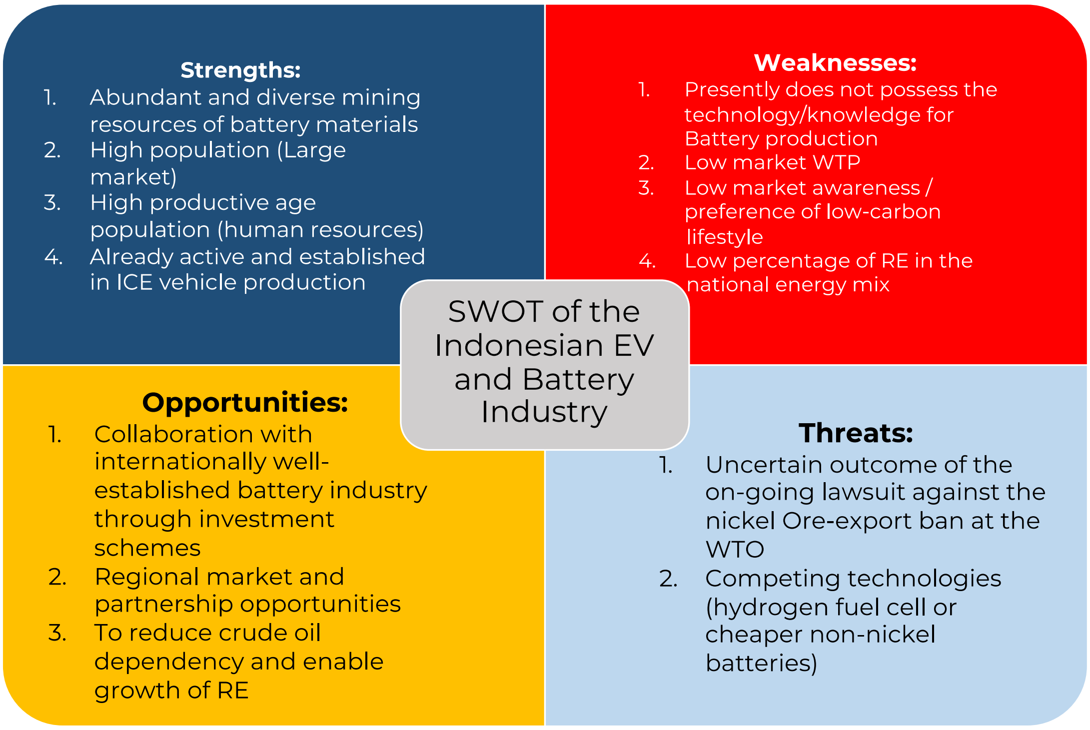


Figure 8. SWOT analysis of the Indonesian EV and battery industry.

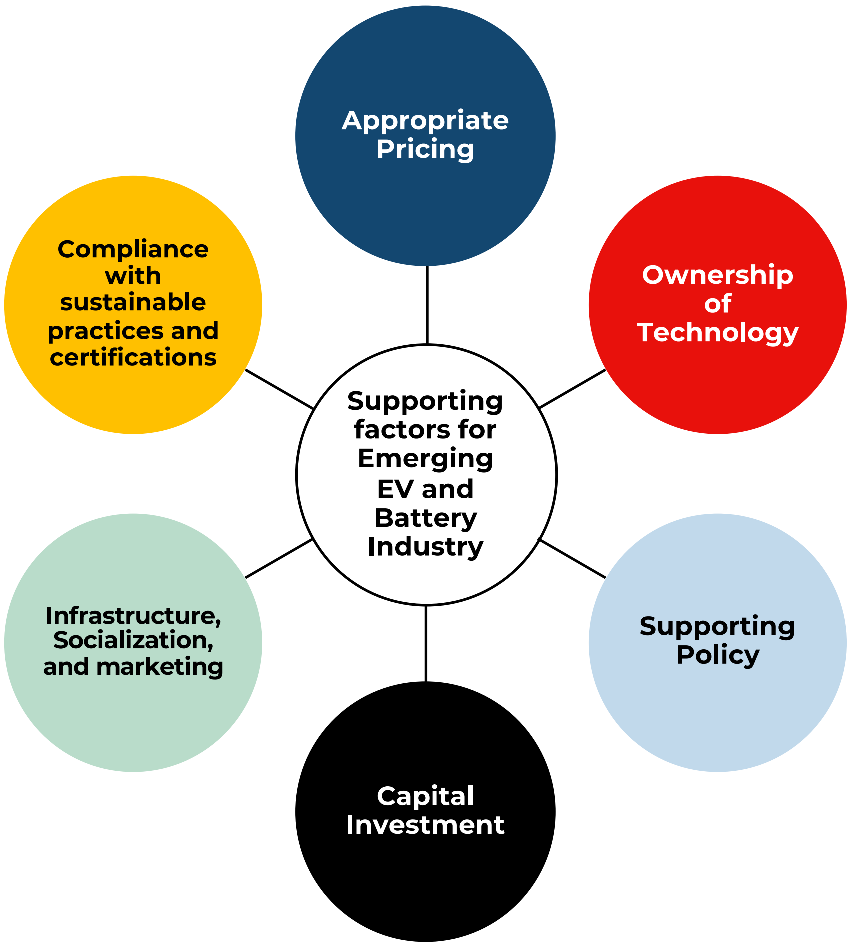


Figure 9. Supporting factors for an emerging EV and battery industry.

The purchasing power of the Indonesian market for EVs is significantly lower than that of the major EV-consuming countries. This low purchasing power is understandable considering that Indonesian GDP per capita is only approximately 1/10th that of many European countries, the United States, and Japan. Because 60% of an EV price is contributed from the cost of a battery, cost reduction should be achieved by producing it domestically. It is predicted that approximately 20% can be saved by conducting all production activities domestically [63]; another set of costs can be saved by eliminating the need for importing parts and materials from abroad. From a larger perspective, if the national dependency on oil for the fuel of ICE vehicles can be reduced, national expenditure can also be reduced by avoiding the FF import expenditure. Other cost-reducing opportunities come from the environmental perspective, such as receiving carbon credits from the reduction of carbon emissions and opportunities to recover materials from the recycling industry. However, whether or not these cost-saving strategies will be enough to push the production cost down to the affordable level for the Indonesian market purchasing power remains unknown. Key stakeholders who contributed their insights to this study agreed that the price range appropriate for the Indonesian market is approximately 14,000 to 20,000 USD per unit for a personal four-wheeler EV [36,63]. This price range is approximately 1/3rd of the current entry-level EV car presently available in Indonesia (Hyundai Kona Electric EV is sold at approximately USD 50,000) [92]. While the nickel-intensive batteries may be suitable for the international market, perhaps developing the technology to utilize more affordable materials such as iron could be an alternative for the domestic market. When reducing the EV price is difficult, the alternative to improve EV competitiveness is by boosting the price of the ICE vehicles. The government has very recently imposed the luxury goods tax for 4-wheeler ICE vehicles based on their passenger capacity, engine capacity, fuel efficiency, or CO_2 emissions per km travel distance from the exhaust gas. The TCO assessment exercised in this study (Figure 7b) has shown that introducing this tax could make an entry-level 4-wheeler EV price become competitive compared to its ICE vehicle counterparts.

Ownership of technology is one key challenge in realizing the battery industry in Indonesia. Presently, the battery-producing technology is still imported from the leading battery-producing countries [63]. There are two ways to own a technology: first, by licensing the technology from the foreign technology owners. Second, conducting research and development domestically with close collaboration between the industry and the university and research institutes. The first path is more likely to be faster and effective but costly, while the second path may be time-intensive due to the newness of the industry in the country. Either way, technology development must remain sensitive to market needs and changing policies to ensure acceptance of the product for commercial use. This study recommends that while the Indonesian battery industry is still entirely new, it needs to diversify its research and development activities to focus not only on using nickel but also on other raw materials. This diversification is important because: (1) the ban may be temporary due to the international trade restrictions and regulation uncertainties; (2) Indonesia has an abundance and diversity of other raw materials for battery production; and (3) as a way to seek further cost-reducing opportunities.

The supporting policies, although new, have been developed quite comprehensively. The roadmap aims to channel the existing employment in the ICE vehicle industry to the new EV industry. Furthermore, the upstream and downstream of the supply chains of the EV and battery industry are covered by combinations of regulations. Raw materials have been reserved for the industry through the ore export ban, government procurement of domestically made products is warranted, and tax relaxation for the consumers is offered. The only uncertainty lies in the permanence of the upstream policy which is one of the main concerns in this study.

A handful of studies have discussed issues around the Indonesian nickel ore ban. Lim et al. [93] found that the latest nickel ore ban did not significantly impact price shocks in the market compared to the ban issued in 2014. Similarly, Situmorang [94] found that the ban on nickel ore exports hurt PT. Vale Indonesia (the largest nickel mining and processing company in Indonesia) during 2015–2017, but the same effect was not found between 2018 and June 2020. The review study conducted by Widiatedja [14] on bans across the world indicated that the accepted reasons for export bans are usually with the interest of environmental protection and the promotion of downstream industries. The study argued that the ban would not be justified based on general exception provisions under Article XX of 1994 of the GATT rules in WTO because "*nickel is not essential in Indonesia based on its domestic demand, ongoing plans, economic contribution, and the current mining law*." A couple of months later, this study showed that the downstream industry is currently being fostered across the country. There are 21 registered companies of EV manufacturers in Indonesia, 3 of which are developing EV buses, and the rest mainly develop electric motorbikes and scooters [36]. There are five raw material smelters and five battery-producing companies that are under construction or in operation (Figure 5). However, Widiatedja's other argument that there is a tendency toward inconsistency in Indonesia's national regulation over the years [12], [14] is valid. The ongoing lawsuit in the WTO is not yet settled. Therefore, Indonesia needs to regain trust, especially from the investors, by showing policy consistency, security, and ease in its implementation.

A significant amount of investment is needed to realize the battery industry in Indonesia. To fulfill the aimed 140 MWh capacity goal targeted to fill the supply shortage in 2030, IBC estimated USD 15.3 million of capital expenditure would be required [63]. Investment is expected to come from the shareholders of IBC (four government-owned companies) and the international partners (LG Chem and CATL). The establishment of IBC highlighted the actions following up the nickel ore export ban to realize the EV industry in Indonesia. As the battery cost contributes over half of an EV price, the success of IBC in lowering battery production cost will significantly influence the final price of EV products in Indonesia.

Infrastructurewise, although the Deloitte survey [68] indicated that people plan to charge their EV at home, the EV industry investors' greatest concern is the low number of public charging stations visible presently [75]. The establishment of more charging stations in strategic locations may improve the confidence of potential EV consumers and may eventually lead banks to lend capital, especially for startup companies. Furthermore, the assumption that an EV has a short driving range and is only suitable for daily office commute can be responded to by providing swap-based charging stations in strategic locations such as the tollways for long-distance road traveling. The EV to charging station ratio can be used as a measurement of the infrastructure readiness of EVs. In 2019, the ratio in Norway was 24:1, in the United States 20:1, and in China 6.5:1 [95]. These countries are considered to have high EV adoption growth. EV's socialization and marketing may require collaboration between EV producers and local governments to provide opportunities for potential buyers. Some examples of EV socialization strategies from other countries that can be experimented with are: (1) establishing EV-sharing mechanisms so people could test-drive the EV on a short-term, low-cost basis (Japan) [96]; (2) allowing EV drivers to use the priority lanes (Norway) [97]; and (3) creating EV-only zones (China) [98].

Finally, an increase in EV use will also increase the electricity demand. To ensure that this practice optimally contributes to the national CO_2 emission reduction, increasing the RE parts in the energy mix is essential. An IEA report projected that the well-to-wheel emissions of the future EV fleet will be significantly lower than those of ICE in 2030 [99]. However, the IESR conducted a more comprehensive emission balance calculation that includes the EV lifecycle, including battery production. The study reported that the grid emission factor should be lower than 734 gCO_2/kWh to achieve a net emissions reduction from EVs [100]. Furthermore, sustainable practices should be ensured along its production chain for the Indonesian EVs and battery products to be accepted in the global market with the growing interest in environmental sustainability [63]. Ensuring sustainable practices will also prevent Indonesia from falling to the same unfortunate fate that DRC faced with their LCOs due violating human rights and other unsustainable practices [4].

Newness of the topic mainly causes the limitations of this study. Many of Indonesia's EV and battery industry activities only started after the nickel ore ban became effective in 2020. While peer-reviewed scientific studies of the topic are still minimal, the present study compiled information from the media and official sources, such as the national regulations and direct communication with the key stakeholders of Indonesia's EV and battery industry.

The implications of this study for other countries are as follows:

1. Other emerging Asian countries with the similar ambitions to develop their EV industries (e.g., Thailand) or shift their ICE markets to EV may also find the six supporting factors (Figure 9) useful. The six factors (price, technology, policy, investment, infrastructure, and sustainable practices) are interrelated. For example, a price appropriate to the domestic and regional purchasing power may be achieved through product diversification, exercising various tax or policy instruments to boost EV price competitiveness in the market, and finally, supporting infrastructure and ensuring sustainable practices that may gain consumers' and investors' confidence to support the EV and battery industry.
2. The SWOT analysis results of this study highlighted the international collaboration opportunities in both the manufacturing sector and the market sector of the EV and battery industry.

Avenues for further studies open as a result of this review study. Among these are the following:

1. To find strategies to reduce the costs of the EV battery production through diversification of material selections, manufacturing technology, and process efficiency improvement techniques.
2. Exploration of ways to commercialize EVs in the emerging countries.
3. Analysis of the effects of the various tax policies on the EV market behavior.
4. Examination of the reselling price of used EVs and other topics related to reusing, refurbishing, and recycling EVs in the emerging countries.

Finally, to ensure the EV industry's contribution to reducing the extreme air pollution in major cities in Indonesia and the surrounding countries, development in the RE sector should also be pushed in parallel.

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References

1. UNEP. Transport | UNEP—UN Environment Programme. 2021. Available online: https://www.unep.org/explore-topics/energy/what-we-do/transport (accessed on 21 October 2021).
2. Bieker, G. *A Global Comparison of the Life-Cycle Greenhouse Gas Emissions of Combustion Engine and Electric Passenger Cars*; The International Council on Clean Transportation: Washington, DC, USA, 2021.

3. World Economic Forum. *A Vision for A Sustainable Battery Value Chain in 2030 Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation*; WEF: Geneva, Switzerland, 2019.
4. Faber, B.; Krause, B.; La, D.; Faber, B.; Krause, B. *Artisanal Mining, Livelihoods, and Child Labor in the Cobalt Supply Chain of the Democratic Republic of Congo*; Center for Effective Global Action: Berkeley, CA, USA, 2017.
5. Zhao, X.; Dunlap, R.A.; Obrovac, M.N. Alloy negative electrodes for Li-ion batteries. *J. Electrochem. Soc.* **2014**, *161*, A1976–A1980. [CrossRef]
6. Nitta, N.; Wu, F.; Lee, J.T.; Yushin, G. Li-ion battery materials: Present and future. *Mater. Today* **2015**, *18*, 252–264. [CrossRef]
7. Wu, E. Cathode and Precursor Materials: Can Success in the Chinese LFP Battery Market be Mimicked in the European and North American EV Markets? 2021. Available online: https://roskill.com/news/ (accessed on 5 August 2021).
8. Greencarcongress. *CATL to Build New $ 280M, 80 Tpy LFP Cathode Materials Plant in China*; BioAge Group: Ricnmond, CA, USA, 2021; Volume 2021.
9. Fraser, J.; Anderson, J.; Lazuen, J.; Lu, Y.; Heathman, O.; Brewster, N.; Bedder, J.; Masson, O. *Study on Future Demand and Supply Security of Nickel for Electric Vehicle Batteries*; Publication Office of the European Union: Luxembourg, 2021.
10. Statista. Nickel Production Top Countries 2020 | Statista. In *Nickel Production Top Countries 2020*; Statista: New York, NY, USA, 2020. Available online: https://www.statista.com/statistics/264642/nickel-mine-production-by-country/ (accessed on 4 August 2021).
11. Bloomberg, N.E.F. Battery Metals Outlook. 2021. Available online: https://spotlight.bloomberg.com/story/battery-metals-outlook/page/1 (accessed on 5 August 2021).
12. Li, A. Analysis on the current situation and future outlook of coal market in Indonesia. *E3S Web Conf.* **2020**, *214*, 1–5. [CrossRef]
13. ESDM. Peraturan Menteri Energi Dan Sumber Daya Mineral Republik Indonesia Nomor 11 Tahun 2020. 2020. Available online: https://peraturan.bpk.go.id/Home/Details/142182/permen-esdm-no-11-tahun-2020 (accessed on 17 August 2021).
14. Widiatedja, I.G.N.P. Indonesia's export ban on nickel ore: Does it violate the World Trade Organization (WTO) rules? *J. World Trade* **2021**, *55*, 667–696.
15. Nikkei Asia. Nickel-Rich Indonesia Draws Global Suppliers of EV Battery Materials—Nikkei Asia. 2021. Available online: https://asia.nikkei.com/Business/Markets/Commodities/Nickel-rich-Indonesia-draws-global-suppliers-of-EV-battery-materials (accessed on 27 June 2021).
16. Hyundai Motor Group and LG Energy Solution Signed MoU with Indonesian Government to Establish EV Battery Cell Plant. 2021. Available online: https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-motor-group-and-lg-energy-solution-sign-mou-with-indonesian-government-to-establish-ev-battery-cell-plant-0000016697 (accessed on 5 August 2021).
17. Automotive Industry Portal MarkLines ASEAN: Thailand and Indonesia Building EV and Battery Production Facilities—MarkLines Automotive Industry Portal. 2021. Available online: https://www.marklines.com/en/report/rep2162_202106 (accessed on 9 September 2021).
18. Asad, H. *Ford, VW and Tesla are Investing in LFP Battery Technology for EV*; Environment + Energy LEADER: Fort Collins, CO, USA, 2021. Available online: https://www.environmentalleader.com/2021/08/ford-vw-tesla-lean-in-to-lfp-battery-technology-for-evs/ (accessed on 17 August 2021).
19. Lambert, F. Elon Musk Says Tesla is Shifting More Electric Cars to LFP Batteries over Nickel Supply Concerns—Electrek. 2021. Available online: https://electrek.co/2021/02/26/elon-musk-tesla-shifting-more-electric-cars-lfp-batteries-nickel-supply-concerns/ (accessed on 17 August 2021).
20. Alvarez, S. Tesla's Shift to LFP Cells for Megapack Batteries Heralds an Energy Storage Revolution. 2021. Available online: https://www.teslarati.com/tesla-lfp-megapack-batteries-disruption/ (accessed on 17 August 2021).
21. Government of Indonesia. *Undang-Undang Nomor 3 Tahun 2020 Tentang Perubahan Atas Undang-Undang Nomor 4 Tahun 2009 Tentang Pertambangan Mineral dan Batubara [JDIH BPK RI]*; Government of Indonesia: Jakarta Pusat, Indonesia, 2009.
22. Home, A. COLUMN-Nickel's Perfect Bull Storm as Indonesia Bans Exports Again: Andy Home. In *Reuters*; Reuters: London, UK, 2019. Available online: https://finance.yahoo.com/news/column-nickels-perfect-bull-storm-122148475.html (accessed on 18 August 2021).
23. Idris, M. Kronologi Larangan Ekspor Bijih Nikel yang Berujung Gugatan Uni Eropa. 2021. Available online: https://money.kompas.com/read/2021/01/18/170109026/kronologi-larangan-ekspor-bijih-nikel-yang-berujung-gugatan-uni-eropa?page=all (accessed on 18 August 2021).
24. Centre for Energy and Mining Law Studies. Why does Indonesia's Nickel Export Ban Upset the EU? | PUSHEP. In *Pushep*; Centre for Energy and Mining Law Studies: Jakarta, Indonesia, 2021. Available online: https://pushep.or.id/why-does-indonesias-nickel-export-ban-upset-the-eu/ (accessed on 18 August 2021).
25. Purwaningsih, A. Konsultasi di WTO: Eropa dan Indonesia Gagal Capai Titik Temu Soal Larangan Ekspor Bijih Nikel | DUNIA: Informasi Terkini Dari Berbagai Penjuru Dunia | DW | 13.02.2021. In *Deutsche Welle Indonesia*; Deutsche Welle: Indonesia, 2021. Available online: https://www.dw.com/id/di-balik-kekisruhan-larangan-ekspor-bijih-nikel/a-56521023 (accessed on 17 August 2021).
26. APBI-ICMA Kebijakan Larangan Ekspor Nikel, Siapa yang Lebih Diuntungkan? | APBI-ICMA. In *APBI-ICMA*; Indonesian Coal Mining Association: Jakarta, Indonesia, 2019. Available online: http://www.apbi-icma.org/news/1778/ (accessed on 18 August 2021).

27. Sandi, F. Siap Tempur Lawan Eropa Soal Nikel, Mendag: Mereka Ketakutan! In *CNBC Indonesia*; CNBC Indonesia: Indonesia, 2021. Available online: https://www.cnbcindonesia.com/news/20210127175840-4-219215/siap-tempur-lawan-eropa-soal-nikel-mendag-mereka-ketakutan (accessed on 18 August 2021).
28. Artha Uly, Y. Semakin Panas, RI Siap Hadapi Gugatan Uni Eropa Soal Ekspor Nikel di WTO, Kompas, Indonesia. 2021. Available online: https://money.kompas.com/read/2021/02/26/201624726/semakin-panas-ri-siap-hadapi-gugatan-uni-eropa-soal-ekspor-nikel-di-wto?page=all (accessed on 18 August 2021).
29. Harsono, N. *'No Compromise on Nickel Ban': Ministry Puts Foot down on Nickel Price Floor—Business—The Jakarta Post*; The Jakarta Post: Indonesia, 2020. Available online: https://www.thejakartapost.com/news/2020/07/27/no-compromise-on-nickel-ban-ministry-puts-foot-down-on-nickel-price-floor.html (accessed on 18 August 2021).
30. Reuters Indonesia President Defends Nickel Export Curbs after EU Complaint at WTO. In *Yahoo Finance*; Yahoo: Indonesia, 2019. Available online: https://finance.yahoo.com/news/indonesia-president-defends-nickel-export-065256064.html (accessed on 18 August 2021).
31. Sappor, J. COVID19—Turns Indonesian Ore Export Ban into Curse for Nickel Market | S&P Global Market Intelligence. In *S&P Global*; S&P Global Market Intelligence: USA, 2020. Available online: https://www.spglobal.com/marketintelligence/en/news-insights/research/covid19-turns-indonesian-ore-export-ban-into-curse-for-nickel-market (accessed on 18 August 2021).
32. Karunia, A.M. *Pabrik Smelter Nikel di Konawe Dibakar Buruh, Menperin Dorong Penyelesaian Dengan Dialog*; Kompas: Jakarta, Indonesia, 2020. Available online: https://money.kompas.com/read/2020/12/16/055536126/pabrik-smelter-nikel-di-konawe-dibakar-buruh-menperin-dorong-penyelesaian (accessed on 17 August 2021).
33. Fauziah, F. *Untung-Rugi Kebijakan Melarang Ekspor Bijih Nikel*; Alinea.id: Indonesia, 2019. Available online: https://www.alinea.id/bisnis/untung-rugi-kebijakan-melarang-ekspor-bijih-nikel-b1XmD9ntt (accessed on 18 August 2021).
34. METI. *Nov 11, 2020—Japan's 2050 Carbon Neutral Goal | METI Ministry of Economy, Trade and Industry*; Ministry of Economy, Trade, and Industry: Tokyo, Japan, 2020.
35. World Bank Population. Total—Indonesia | Data. In *Population, Total—Indonesia*; World Bank: Washington, DC, USA, 2020. Available online: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=ID (accessed on 24 August 2021).
36. Bawazier, T. Industri baterai & kendaraan listrik indonesia. In *Quo Vadis Industri Baterai dan Kendaraan Listrik Indonesia*; Forum Energizing Indonesia: Jakarta, Indonesia, 2021.
37. President of Republic of Indonesia. *Peraturan Presiden No. 55 Tahun 2019 Tentang Percepatan Program Kendaraan Bermotor Listrik Berbasis Baterai (Battery Electric Vehicle) Untuk Transportasi Jalan*; President of Republic of Indonesia: Jakarta Pusat, Indonesia, 2019.
38. Ministry of Industry. *Peraturan Menteri Perindustrian Nomor 27 Tahun 2020 Tentang Spesifikasi, Peta Jalan Pengembangan, dan Ketentuan Penghitungan Tingkat Komponen Dalam Negeri Kendaraan Bermotor Dalam Negeri Kendaraan Bermotor Listrik Berbasis Baterai Battery Electric Vehicle*; Ministry of Industry: Jakarta Pusat, Indonesia, 2020.
39. Deutsche Welle Indonesia. Eropa dan RI Gagal Capai Titik Temu Soal Larangan Ekspor Bijih Nikel. 2021. Available online: https://news.detik.com/dw/d-5372935/eropa-dan-ri-gagal-capai-titik-temu-soal-larangan-ekspor-bijih-nikel (accessed on 18 August 2021).
40. Government of Indonesia. *Peraturan Pemerintah Republik Indonesia Nomor 24 Tahun 2010 Tentang Penggunaan Kawasan Hutan*; Government of Indonesia: Jakarta Pusat, Indonesia, 2010.
41. Government of Indonesia. *Peraturan Pemerintah Republik Indonesia Nomor 1 Tahun 2014 Tentang Perubahan Kedua Atas Peraturan Pemerintah Nomor 23 Tahun 2010 Tentang Pelaksanaan Kegiatan Usaha Pertambangan Mineral Dan Batubara*; Government of Indonesia: Jakarta Pusat, Indonesia, 2014.
42. Ministry of Energy and Mineral Resources. *Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 1 Tahun 2014 Tentang Peningkatan Nilai Tambah Mineral Melalui Kegiatan Pengolahan Dan Pemurnian Mineral Di Dalam Negeri*; Ministry of Energy and Mineral Resources: Jakarta Pusat, Indonesia, 2014.
43. Government of Indonesia. *Peraturan Pemerintah Nomor 1 Tahun 2017 Tentang Perubahan Keempat atas Peraturan Pemerintah Nomor 23 Tahun 2010 Tentang Pelaksanaan Kegiatan Usaha Pertambangan Mineral dan Batubara*; Government of Indonesia: Jakarta Pusat, Indonesia, 2017.
44. Ministry of Energy and Mineral Resources. *Peraturan Menteri Energi dan Sumber Daya Mineral No. 25 Tahun 2018 Tentang Pengusahaan Pertambangan Mineral Dan Batubara*; Ministry of Energy and Mineral Resources: Jakarta Pusat, Indonesia, 2018.
45. Government of Indonesia. *Peraturan Pemerintah Republik Indonesia Nomor 73 Tahun 2019 Tentang Barang Kena Pajak yang Tergolong Mewah Berupa Kendaraan Bermotor yang Dikenai Pajak Penjualan atas Barang Mewah*; Government of Indonesia: Jakarta Pusat, Indonesia, 2019.
46. Ministry of Transportation. *Peraturan Menteri Perhubungan Nomor 45 Tahun 2020 Tentang Kendaraan Tertentu Dengan Menggunakan Penggerak Motor Listrik*; Ministry of Transportation: Jakarta Pusat, Indonesia, 2020.
47. Government of Indonesia. *Undang-Undang Republic Indonesia Nomor 4 Tahun 2009 Tentang Tentang Pertambangan Mineral dan Batubara*; Government of Indonesia: Jakarta Pusat, Indonesia, 2009.
48. Ministry of Energy and Mineral Resources. *Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 13 Tahun 2020 Tentang Penyediaan Infrastruktur Pengisian Listrik Untuk Kendaraan Bermotor Listrik Berbasis Baterai*; Ministry of Energy and Mineral Resources: Jakarta Pusat, Indonesia, 2020.
49. Ministry of Domestic Affairs. *Peraturan Menteri Dalam Negeri No. 8 Tahun 2020 Tentang Penghitungan Dasar Pengenaan Pajak Kendaraan Bermotor Dan Bea Balik Nama Kendaraan Bermotor*; Ministry of Domestic Affairs: Jakarta Pusat, Indonesia, 2020.

50. Artha Uly, Y. *Ada Larangan Ekspor Bijih Nikel, Konsumsi Listrik Sulawesi Bisa Naik 3 Kali Lipat*; Kompas: Jakarta, Indonesia, 2021.
51. Cori, D. Menyoal Kebijakan Hilirasi Nikel. 2021. Available online: https://investor.id/opinion/menyoal-kebijakan-hilirasi-nikel (accessed on 17 August 2021).
52. Sulaeman. Rasio Kepemilikan Mobil di Indonesia 99 Unit Per 1.000 Orang. 2021. Available online: https://www.liputan6.com/bisnis/read/4578268/rasio-kepemilikan-mobil-di-indonesia-99-unit-per-1000-orang-potensi-industri-otomotif (accessed on 18 September 2021).
53. World Bank. *GDP Per Capita (Current US$) | Data*; World Bank: Washington, DC, USA, 2020. Available online: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD (accessed on 24 August 2021).
54. World Bank. *GDP Per Capita (Current US$)—European Union | Data*; World Bank: Washington, DC, USA, 2020. Available online: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=EU (accessed on 24 August 2021).
55. Japan GDP Per Capita. GDP Per Capita (Current US$)—Japan | Data. 2019. Available online: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=JP (accessed on 24 August 2021).
56. Maskur, F. DP Kredit 0 Persen, Ini Daftar Mobil Listrik Baterai Lulus Uji Tipe; Bisnis.com. 2020. Available online: https://otomotif.bisnis.com/read/20201001/275/1299533/dp-kredit-0-persen-ini-daftar-mobil-listrik-baterai-lulus-uji-tipe (accessed on 18 September 2021).
57. CNN Indonesia. OJK Permudah Kredit Untuk Pelaku Industri Kendaraan Listrik. 2020. Available online: https://www.cnnindonesia.com/ekonomi/20200904135821-78-542804/ojk-permudah-kredit-untuk-pelaku-industri-kendaraan-listrik (accessed on 18 September 2021).
58. Government of Indonesia. *Peraturan Pemerintah No. 45 Tahun 2019 Tentang Penghitungan Penghasilan Kena Pajak dan Pelunasan Pajak Penghasilan Dalam Tahun Berjalan*; Government of Indonesia: Jakarta Pusat, Indonesia, 2019.
59. Mo, J.Y.; Jeon, W. The impact of electric vehicle demand and battery recycling on price dynamics of lithium-ion battery cathode materials: A Vector Error Correction Model (VECM) analysis. *Sustainability* **2018**, *10*, 2870. [CrossRef]
60. BNEF. Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh | BloombergNEF. 2020. Available online: https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/ (accessed on 24 August 2021).
61. Economist. Lithium Battery Costs Have Fallen by 98% in Three Decades | The Economist. In *Lithium Battery Costs Have Fallen by 98% in Three Decades*; Economist: London, UK, 2021. Available online: https://www.economist.com/graphic-detail/2021/03/31/lithium-battery-costs-have-fallen-by-98-in-three-decades (accessed on 24 August 2021).
62. Tsiropoulos, I.; Tarvydas, D.; Lebedeva, N. *Li-ion Batteries for Mobility and Stationary Storage Applications*; Publications Office of the European Union: Luxembourg, 2018.
63. Nugroho, T. Rencana Pengembangan Ekosistem EV Battery Indonesia. In *Quo Vadis Industri Baterai dan Kendaraan Listrik Indonesia*; Forum Energizing Indonesia: Jakarta, Indonesia, 2021.
64. Central Government of Indonesia. PP No. 79 Tahun 2014 Tentang Kebijakan Energi Nasional [JDIH BPK RI]. In *National Energy Regulation*; Central Government of Indonesia: Indonesia, 2014. Available online: https://peraturan.bpk.go.id/Home/Details/5523/pp-no-79-tahun-2014 (accessed on 9 September 2021).
65. Wentker, M.; Greenwood, M.; Leker, J. A bottom-up approach to Lithium-ion battery cost modeling with a focus on cathode active materials. *Energies* **2019**, *12*, 504. [CrossRef]
66. IEA. *Southeast Asia Energy Outlook 2019*; IEA: Paris, France, 2019.
67. Peplow, L.; Eardley, C. *Electric Cars: Calculating the Total Cost of Ownership for Consumers*; Element Energy Limited: Cambridge, UK, 2021.
68. Deloitte. *2019 Global Automotive Consumer Study | Deloitte | Automotive, Connectivity*; Deloitte: London, UK, 2019.
69. Samyarto. Quo Vadis—Industri Baterai & Kendaraan Listrik Di Indonesia. In *Quo Vadis Industri Baterai dan Kendaraan Listrik Indonesia*; Forum Energizing Indonesia: Jakarta, Indonesia, 2021.
70. Gogoro. Gogoro Network®Battery Swapping Platform—Gogoro. 2021. Available online: https://www.gogoro.com/gogoro-network/ (accessed on 31 August 2021).
71. CNESA. BAIC BJEV Announces 'Optimus Prime Plan' Combining Battery Swapping, Energy Storage, and Solar Models. In *China Energy Storage Alliance*; CNESA: Beijing, China, 2017.
72. Hyatt, K. China approves national EV battery swap standards, report says. In *Road Show by CNET*; CNET: San Francisco, CA, USA, 2021.
73. Ather. Ather Energy—Building Fast and Intelligent Electric Scooters in India. 2021. Available online: https://www.atherenergy.com/grid (accessed on 31 August 2021).
74. Ministry of Energy and Mineral Resources Coal and Minerals. *Coal and Mineral Reserves in Indonesia*; Ministry of Energy and Mineral Resources Coal and Minerals: Jakarta Pusat, Indonesia, 2021.
75. Questera, N.; QUEST Motors-PT Ide Inovatif Bangsa, Jakarta, Indonesia. Personal communication, 2021.
76. Croce, A.I.; Musolino, G.; Rindone, C.; Vitetta, A. Energy consumption of electric vehicles: Models' estimation using big data (FCD). *Transp. Res. Procedia* **2020**, *47*, 211–218. [CrossRef]
77. Kompas. Harga Motor Listrik Gesits Naik Per Juni. In *Otomotif*; Kompas: Jakarta, Indonesia, 2021. Available online: https://otomotif.kompas.com/read/2021/06/14/131200615/harga-motor-listrik-gesits-naik-per-juni-2021 (accessed on 14 September 2021).

78. Astra-Honda. Sepeda Motor Honda Terbaru | PT Astra Honda Motor. In *Price List*; Astra-Honda: Indonesia, 2021. Available online: https://www.astra-honda.com/product/price-list (accessed on 14 September 2021).
79. Kumparan, O.T.O. Biaya Servis Honda BeAT Selama 2 Tahun Pemakaian | Kumparan.Com. In *Otomotif*; KumparanOTO: Indonesia, 2021. Available online: https://kumparan.com/kumparanoto/biaya-servis-honda-beat-selama-2-tahun-pemakaian-1uzRHWlM2Wa (accessed on 14 September 2021).
80. Muzaki, A. Harga Motor Listrik Gesits, Review, Spesifikasi, dan Simulasi Kredit Juni 2021; Otosia.com, Indonesia. 2021. Available online: https://www.otosia.com/berita/harga-motor-listrik-gesits-kln.html (accessed on 26 October 2021).
81. Kosasih, D.T. *Garansi 3 Tahun, Berapa Harga Baterai Motor Listrik Gesits?—Otomotif Liputan6.Com*; Liputan6: Indonesia, 2019. Available online: https://www.liputan6.com/otomotif/read/4053391/garansi-3-tahun-berapa-harga-baterai-motor-listrik-gesits (accessed on 26 October 2021).
82. Umah, A. Murah! Ini Perbandingan Ongkos Charging Mobil Listrik vs BBM; CNBCl Indonesia. 2021. Available online: https://www.cnbcindonesia.com/news/20210104153420-4-213393/murah-ini-perbandingan-ongkos-charging-mobil-listrik-vs-bbm (accessed on 26 October 2021).
83. Central Government. *PP No. 74 Tahun 2021 Tentang Perubahan atas Peraturan Pemerintah Nomor 73 Tahun 2019 Tentang Barang Kena Pajak Yang Tergolong Mewah Berupa Kendaraan Bermotor yang Dikenai Pajak Penjualan atas Barang Mewah [JDIH BPK RI]*; Central Government: Indonesia, 2021. Available online: https://peraturan.bpk.go.id/Home/Details/171112/pp-no-74-tahun-2021 (accessed on 26 October 2021).
84. Herdianto, R. Biaya Servis Nissan Livina Baru, dari 10.000 km sampai 100.000 Km; Grido.com, Indonesia. 2019. Available online: https://www.gridoto.com/read/221670123/biaya-servis-nissan-livina-baru-dari-10000-km-sampai-100000-km?page=all (accessed on 27 October 2021).
85. Kencana, M.R.B. *Sri Mulyani Terbitkan Aturan Baru Pajak PPnBM Mobil dan Motor, Cek Lengkapnya—Bisnis Liputan6.Com*; Liputan6: Indonesia, 2021. Available online: https://www.liputan6.com/bisnis/read/4689711/sri-mulyani-terbitkan-aturan-baru-pajak-ppnbm-mobil-dan-motor-cek-lengkapnya (accessed on 27 October 2021).
86. Satria, G. *Servis Motor Listrik Gesits, Apa Saja yang Mesti Diganti?* Kompas: Jakarta, Indonesia, 2020.
87. Nugrahadi, A. *Ini Biaya Resmi Urus Balik Nama Kendaraan di Jakarta*; Kompas: Jakarta, Indonesia, 2021. Available online: https://otomotif.kompas.com/read/2021/03/29/151200415/ini-biaya-resmi-urus-balik-nama-kendaraan-di-jakarta (accessed on 26 October 2021).
88. Nayazri, G.M. *Ini Biaya Sevice Rutin Mercedes-Benz—GridOto.Com*; Otomania: Indonesia, 2015. Available online: https://otomania.gridoto.com/read/241170162/ini-biaya-sevice-rutin-mercedes-benz (accessed on 26 October 2021).
89. Rahadiansyah, R. Murah Banget, Cuma Segini Biaya Perawatan Mobil Listrik; detik.com, Indonesia. 2020. Available online: https://oto.detik.com/mobil/d-5252995/murah-banget-cuma-segini-biaya-perawatan-mobil-listrik (accessed on 26 October 2021).
90. Wisnugroho, J.; PT. Hardtmann Mekatroniske Indonesia, Jakarta, Indonesia. Personal communication, 2021.
91. Hidayat, F. Setiap Lima Tahun, Konsumen di Indonesia Ganti Mobil Baru. In *Berita Satu*; Berita Satu: Indonesia, 2015. Available online: https://www.beritasatu.com/otomotif/299441/setiap-lima-tahun-konsumen-di-indonesia-ganti-mobil-baru (accessed on 26 October 2021).
92. Hyundai Indonesia. Pricelist | Hyundai Mobil Indonesia. In *Price List*; Hyundai Indonesia: Indonesia, 2021. Available online: http://hyundaimobil.co.id/pricelist (accessed on 9 September 2021).
93. Lim, B.; Kim, H.S.; Park, J. Implicit interpretation of indonesian export bans on LME nickel prices: Evidence from the announcement effect. *Risks* **2021**, *9*, 93. [CrossRef]
94. Situmorang, H. The effect of the ban on nickel exports on the economic profitability of PT vale Indonesia, Tbk from 2015—June. *Fundam. Manag. J.* **2021**, *6*, 73–82.
95. Marciano, I. *Strengthening the Development of Electric Vehicle Ecosystem in Indonesia, IESR Compare with the United States, Norway, and China—IESR*; IESR: Jakarta, Indonesia, 2021.
96. Times. Times Car Sharing. 2021. Available online: https://share.timescar.jp/ (accessed on 15 September 2021).
97. Marciano, I. *Developing the Ecosystem of Electric Vehicles in Indonesia—IESR*; IESR: Jakarta, Indonesia, 2021.
98. World Resources Institute. Beijing Low-Emission Zone | WRI Ross Center for Sustainable Cities. In *Projects*; World Resources Institute: Washington, DC, USA, 2017. Available online: https://wrirosscities.org/our-work/project-city/beijing-low-emission-zone (accessed on 15 September 2021).
99. IEA. Global EV Outlook 2020—Analysis—IEA. In *Global EV Outlook 2020*; IEA: Paris, France, 2020. Available online: https://www.iea.org/reports/global-ev-outlook-2020 (accessed on 15 September 2021).
100. Adiatma, J.C.; Marciano, I. *The Role of Electric Vehicles in Decarbonizing Indonesia's Road Transport Sector—IESR*; IESR: Jakarta, Indonesia, 2020.